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Instrumentation and Controls Division

AN EVALUATION OF ETHERNET VIA THE PROPOSED STANDARD WIRING PLAN

John D. Stanley

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OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
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1. INTRODUCTION

The Instrumentation and Controls (I&C) Division has conducted a series of tests investigating the new integrated wiring plan using unshielded twisted-pair wire and transmitting local area network (LAN) data over this wire using various industry-standard protocols. This report covers the testing done with the twisted-wire variant of the Ethernet protocol, 10BASE-T, and evaluates vendor equipment and cable. Testing done with the IBM token-ring protocol is presented in a separate report.[1]

2. BACKGROUND

2.1 LOCAL AREA NETWORKS

LANs tying computers of various sizes and capabilities together have emerged as a vital and inevitable part of today's engineering environment. The proliferation of personal computers in the workplace has accelerated an already existing need for effective networking and resource sharing.

The ideal LAN would be completely transparent, accepting any data stream in any format and at any data rate, and passing it on unimpaired to its destination based on routing instructions contained in the data itself. Further, the ideal network would have a high degree of flexibility, allowing it to be easily reconfigured as user needs change and as the technology matures. It would also be reliable and not require constant adjustment. And lastly, it would be easily managed and not ruinously expensive to implement.

The ideal LAN just described does not exist in today's marketplace, and because of the nature of various design trade-offs required, it may be unobtainable. The obstacles to achieving the ideal network revolve around three issues: protocol, data rate, and topology. Historically, these three have not tended to be mutually exclusive.

2.2 PROTOCOL

A data protocol sets forth the rules for manipulating and interpreting the bits of a data stream; however, standard commercially available protocols are usually designed around a particular maximum data rate and network topology. For example, Ethernet's protocol is a compatible version of the IEEE 802.3 standard; it resides in the physical and data link layers of the OSI model and is implemented as a communications protocol operating at a maximum data rate of 10 Mbytes/s. Furthermore, the hardware used to implement the Ethernet protocol uses signaling and transmitting procedures dependent on an overall bus topology.

In contrast, the token-ring protocol as originally introduced operated at an upper data rate of 4 Mbytes/s and used technology uniquely dependent on its ring topology. IBM has now announced a 16-Mbyte/s token ring.

2.3 DATA RATES

Data rates have increased dramatically over the years, all the way from the old Type 33 Teletype's 110 baud and RS-232's 9600 baud, through token ring's 4 Mbytes/s and Ethernet's 10 Mbytes/s, and beyond to the recent fiber distributed data interface (FDDI) rate of 100 Mbytes/s. Inevitably, as data rates have increased, so have user expectations; adding momentum to the push for higher data rates has been the rapidly growing number of 32-bit machines now in use.

2.4 LAN TOPOLOGY

Local area networks are typically arranged into one of four major configurations: bus, ring, star, or branching tree, with all hybrid arrangements predominantly using one of these four topologies.

The bus topology (see Fig. 2.1) uses a central pathway among the network users and feeds the various areas it serves with relatively short, direct links. Advantages of the bus topology include distributed electronics, less preplanning required during design and installation, and lower initial cost. Disadvantages include the difficulty of troubleshooting and the fact that one node can take the entire system down. Therefore, when a bus topology is used, the system should be segmented, both for "damage control" and system integrity.

The ring topology (see Fig. 2.2) has its central path arranged in a circle, with network users fed from nodes on the ring. One advantage of the ring topology is that each user has equal access to the system; that is, the system is deterministic if, for example, each 20 users has a guaranteed 1/20th of the total bandwidth available. Another advantage is that if one node goes down, the entire system does not go down.

The star topology (see Fig. 2.3) links each user node with several others, creating a high degree of redundancy and a variety of paths between nodes. The strongest advantage of this arrangement is its flexibility, with the corresponding disadvantage being the cost of providing multiple signal paths.

The branching tree topology (see Fig. 2.4) allows most of the controlling electronics to be placed in a central location, with additions to the system made easily. This particular topology can be grafted on to any of the other three, allowing great flexibility in configuring a network.

It is this final branching tree at the end-user level that enables a data network to be partially preinstalled for new construction much as telephone outlets would be, running branches from individual offices back to a central communications closet or room.

2.5 ETHERNET

The term "Ethernet" refers to a software communications protocol developed jointly by Digital Equipment Corporation (DEC), Intel, and Xerox that closely approximates the Institute of Electrical and Electronics Engineers (IEEE) 802.3 standard. As with all the 802 standards, this protocol resides in the first two layers of the OSI model, the physical and data link layers. Over the years, Ethernet has taken on the additional colloquial meaning that includes the hardware and firmware used to implement this communications protocol. DEC, in its own literature, defines Ethernet as a high-speed LAN that embraces the latter of these two meanings.

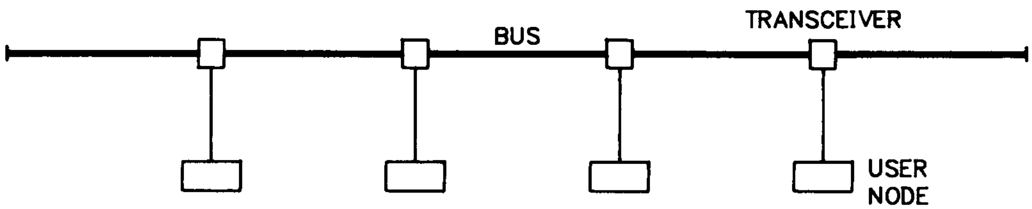


Fig. 2.1. Typical bus topology. Features broadcast mode and dynamic bandwidth allocation.

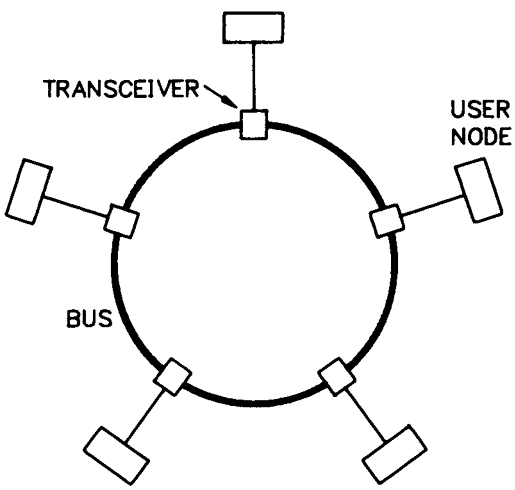


Fig. 2.2. Typical ring topology. Features broadcast mode and static bandwidth allocation.

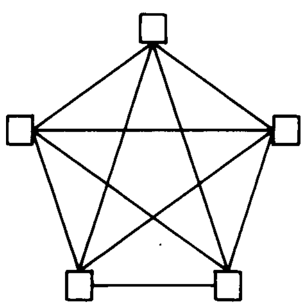


Fig. 2.3. Typical star topology. Features multiple signal paths.

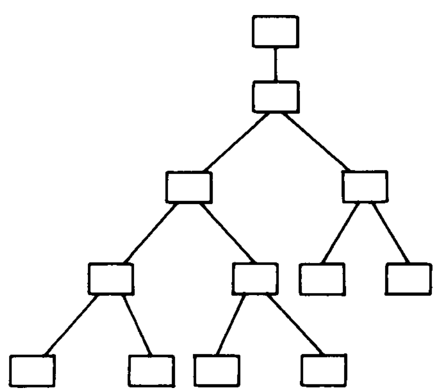


Fig. 2.4. Typical branching tree topology.

The Ethernet protocol uses a "carrier sense, multiple access with collision detection" (CSMA/CD) technique—that is, there is no central control; rather, the stations themselves control access to the transmission media. Each node listens before transmitting, and if no collision detection signal is present on the bus, it goes ahead and transmits. If two user nodes attempt to transmit packets at the same time, a collision is detected and a signal is transmitted that stops all node transmissions for an arbitrary time interval. Based on the configuration of the "back-off" algorithm, transmissions begin again upon the expiration of each node's random interval.

In its earliest version, the Ethernet system (see Fig. 2.5) used a large-diameter coaxial cable as the main bus, tapped it with a vampire-tap arrangement for access by a transceiver, and cabled the transceiver to a Digital Equipment local network interface (DELNI) unit. The DELNI was connected via multiconductor cables, thick-wire, to as many as eight individual users desiring network services. Propagation delays and resistive losses impose various constraints on cable lengths and, by extension, on overall system size. If a collision occurs, all transceivers must be able to respond quickly to the collision detection signal, stop transmitting, and begin their random timing sequence. Although DELNI can be tiered, DEC does not support using these units more than two deep. In similar fashion, a constraint exists on how closely together transceivers can be positioned on the main coaxial cable. Because this thick-wire implementation of Ethernet has been available for several years and has proved popular in the marketplace, it consequently has a large installed user base.

There are some inherent disadvantages to using the thick-wire hardware in a crowded work area, however. Not only is the cable bulky with a bending radius that makes installation difficult and unsightly, but there can be a rapid escalation in the number of DELNIs required to configure a system. With thick-wire Ethernet, the signal was not baseband rf beyond the transceiver at the main coax (i.e., the bus), hence the use of multiconductor thick-wire transceiver cables downstream from that point.

In response to these disadvantages, a thin-wire hardware implementation of the Ethernet protocol was developed (see Fig. 2.6), with the DELNI replaced by a Digital Equipment multiport repeater (DEMPR). The DEMPR, which is connected to a transceiver by a standard thick-wire transceiver cable, converts the incoming transceiver signal back to baseband rf. Although the DEMPR has only eight small-diameter coaxial user ports, each of these eight can be teed (i.e., looped) to 29 users. This capability, with the small-diameter coaxial cable used, makes the DEMPR a very powerful device in configuring an Ethernet LAN. As would be expected, various constraints must be honored with this design approach; for instance, the lengths of end-user cable runs are inextricable linked with the number of nodes served. However, this trade-off is not unworkable. Because a single DEMPR can serve a large number of users, the form factor of the equipment for the thin-wire approach does not get out of hand in a high-density user environment.

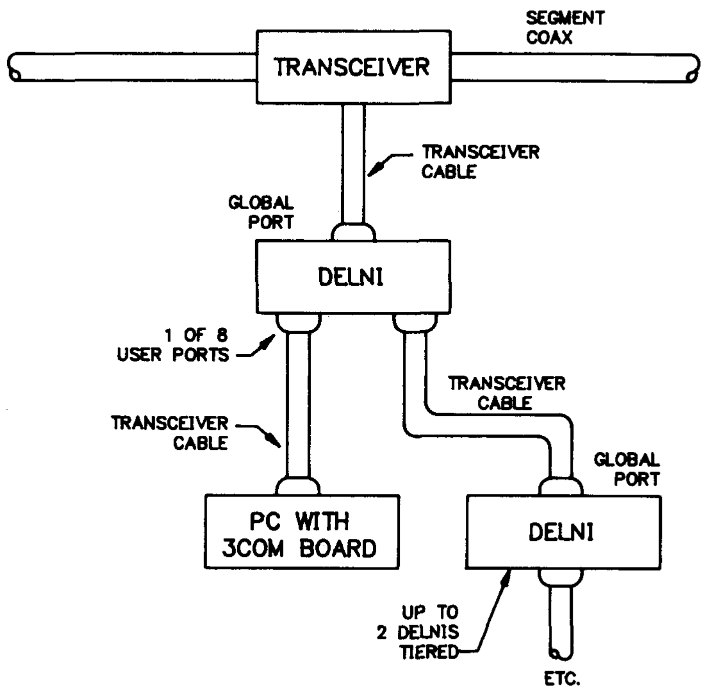


Fig. 2.5. DEC thick-wire Ethernet.

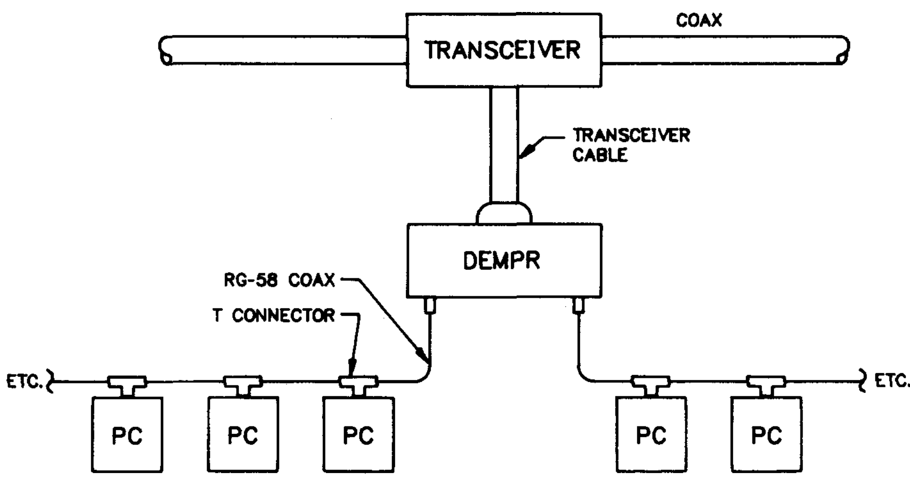


Fig. 2.6. DEC thin-wire Ethernet.

As an interesting footnote, it is worth noting that DEC has not made these two approaches, thick-wire and thin-wire, mutually exclusive. For example, a DEMPR can have its global port cabled to one of the eight user ports of a DELNI rather than having to go only to a transceiver on the main coax (see Fig. 2.7). This melding of the new with the old (i.e., lateral compatibility) has accelerated the acceptance of thin-wire in the marketplace.

2.6 SUMMARY

The only similarity that exists between the various LAN topologies is at the final tributary level, where a truncated branching tree configuration can be grafted onto the overall approach (see Fig. 2.8). It is this final similarity, regardless of the overall network topology employed, that allows a LAN to be partially preinstalled for new construction much as telephone jacks would be, running branches from individual nodes back to a centrally located communications closet or room.

Lending power to this approach of prewiring data networks during the construction of new buildings is the recent emergence of both unshielded and shielded twisted-pair wire as possible media for high-speed data transmission. It is the development of low-capacitance twisted-pair wire combined with the final branching tree characteristic, therefore, that has prompted various vendors to adapt the popular Ethernet protocol to the twisted-pair medium. This combination of equipment, media, and topology thereby sets the stage for the investigations contained in this report.

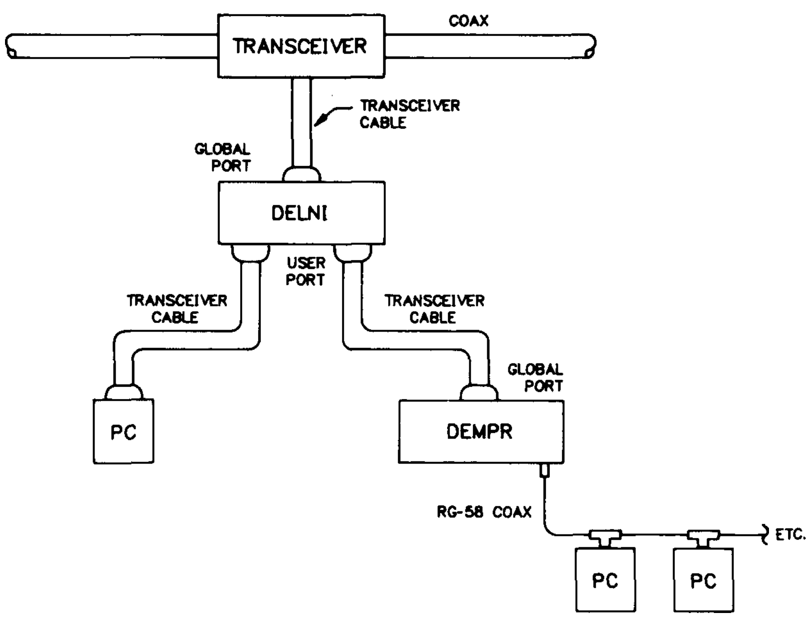
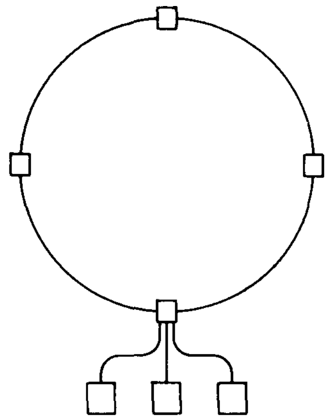
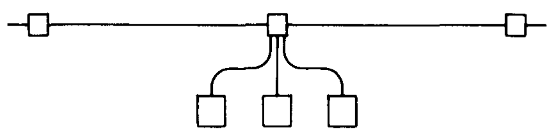


Fig. 2.7. DEC combined thick-wire and thin-wire Ethernet.



TOKEN RING WITH BRANCHING TREE



BUS WITH BRANCHING TREE

Fig. 2.8. Typical hybrid topologies.

3. NEW DEVELOPMENTS

3.1 PREMISES DISTRIBUTION SYSTEM

As LAN became more common and moved out of the engineering-intensive laboratory environment into the general business community, there began to evolve a need to systematize its installation. The Bell Operating Companies (BOCs) traditionally used twisted-pair wire for their analog telephone installations, and as they found themselves increasingly involved with data transmission, they asked just how adaptable twisted-pair could be for data.

Further, the BOCs had a healthy spare capacity for two reasons: not only did the extra pairs greatly simplify adding new service without having to pull new cables, but the BOCs tariff structure was typically based in part on the size of their installed cable plant. As LANs began creating new growth opportunities for BOCs, the operating companies became convinced that an all-digital approach was the next logical development for telephone central offices. And so digital voice plus digital data became codified as Integrated Services Digital Network (ISDN), which is now slowly beginning to be implemented across the country.

AT&T Technologies (i.e., formerly Western Electric) was tasked with supporting this approach, and partially in response, developed what became known as the Premises Distribution System (PDS) line of hardware. In addition to punch-down terminal blocks and fittings developed specifically for twisted-pair wire, there are data plugs of various sizes, data jacks in a wall receptacle configuration, punch-down tools, patch cables, and so forth, to implement the voice-and-data-over-twisted-wire concept.

Components of the PDS system were used for this series of tests; the punch-down terminal blocks were mechanically keyed to assist in fanning and laying down conductors properly, and patch cables were also keyed to prevent conductors from transposing. The system is designed to accept wire from No. 22AWG to No. 26AWG; these tests used No. 24AWG. Terminating a pair of conductors does not require individually stripping the insulation from the wire; instead, the punch-down terminal strip that is located over the wire uses knife-edged insulation-displacement contacts for an electrically and mechanically secure connection.

3.2 ETHERNET-OVER-TWISTED-PAIR SYSTEM

Although a 10BASE-T task force operating under the aegis of the IEEE 802.3 working group is still generating the formal specifications for this transmission technique, several vendors already have Ethernet-over-twisted-pair equipment on the market. All of the major "players" are represented on the task force, including Hewlett-Packard, SynOptics, DEC, Intel, Bell Labs, AT&T, Ungermann-Bass, 3COM, Belden, and Wang.

One of the main objectives of the task force was to have a technology that would support cable runs of 100 m, and the DEC-3COM design was capable of only 50 to 70 m according to their own literature. Therefore, the task force did not look favorably on the DEC-3COM proposal, and it was withdrawn from consideration. Unfortunately, DEC had already begun marketing a product line using the rejected "orphan" design. DEC and 3COM are promising to participate in further task force work, however.

The approach that is being endorsed by the task force is the one proposed by SynOptics and supported by Hewlett-Packard, AT&T, Micom-Interlan, Wang, Western Digital, and Ungermann-Bass. This agreement at least suggests the possibility that SynOptics equipment, for example, can be compatible with the equipment of other vendors.

Each PC used for these tests was equipped with an Ethernet board that enabled the PC to be tied into an Ethernet LAN. The 3COM Ethernet board that was used has both a thick-wire and a thin-wire I/O connector. The thick-wire DB-15F connector accepts the standard Ethernet transceiver cable, also known in the literature as an access unit interface (AUI) cable. Of the various Ethernet-over-twisted-pair arrangements examined for this report, only DEC used the thin-wire coax connector on the 3COM board. The 3COM board was supplied from the factory with the thin-wire coax connector enabled (i.e., with the board's transceiver chip used). To use the thick-wire DB-15F connector, the board's transceiver chip was disabled by moving a jumper on the board.

To convert the standard Ethernet signal generated by the 3COM board to a form that supports the twisted-pair media, each vendor examined for this report uses a separate outboard unit located near the PC for signal conditioning and filtering, with output equalization designed for a cable length of 100 m. These outboard conversion units are typically equipped with a DB-15M connector on the standard Ethernet end for connection to the 3COM board in the PC (except for the DEC unit, which uses thin-wire), and an RJ-45 eight-conductor data jack on the twisted-pair end for connection by a patch cord to either a wall-mounted data receptacle or to punch-down terminals in a communications closet. The conversion units are powered from the 3COM board that they are serving (see Fig. 3.1).

The central unit, or concentrator, is mounted in the communications closet near the punch-down terminal blocks; it typically can either stand alone for a self-contained Ethernet-over-twisted-wire system, or it can be connected through a repeater or bridge to another Ethernet segment. The concentrator provides all the basic Ethernet functions, including collision detection, heartbeat, reclocking, and preamble generation.

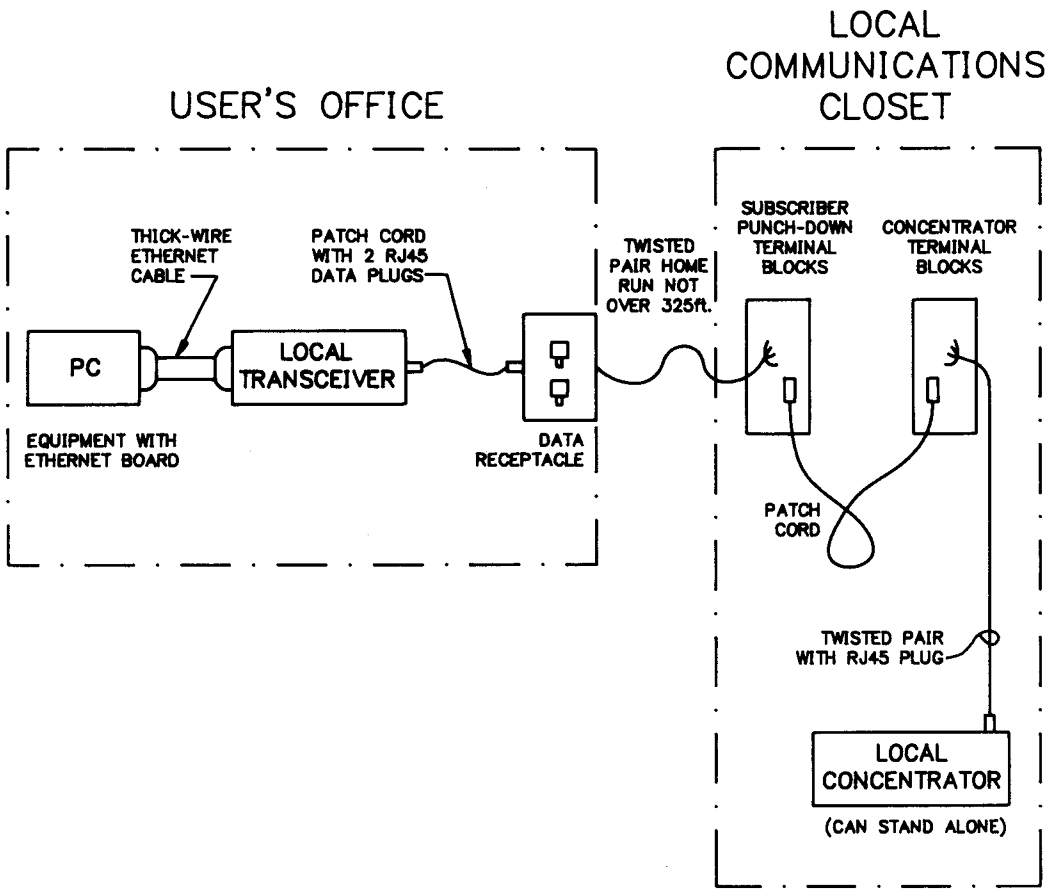


Fig. 3.1. Typical Ethernet over twisted pair.

4. OBJECTIVES

The objectives for this report include the following:

1. To determine what length of twisted-pair wire could be used without experiencing marked signal degradation if a single Ethernet signal were using different vendors' equipment and wire.

2. To determine what length of twisted-pair wire could be used without experiencing marked signal degradation if two separate Ethernet signals shared adjacent pairs in the same cable (i.e., the extent of signal interaction, if any).

3. To determine what length of twisted-pair wire could be used to transmit Ethernet and RS-232C information on adjacent pairs of the same cable (i.e., the extent of signal interaction, if any).

4. To gather some baseline information on the electrical characteristics of some typical twisted-pair wire.

5. METHODOLOGY

5.1 HARDWARE

5.1.1 Equipment

5.1.1.1 Lannet. The Lannet LE-6 series expanders are used in pairs to enable two shielded twisted pairs to be used in lieu of the standard AIU cable between a DEC DELNI and a PC. At the DELNI end of the cable, an LE-6/T (i.e., DTE configured) with its own external power supply plugs into one of the eight user ports of a DELNI; at the PC end of the cable run, an LE-6/C (i.e., DCE configured) effects the transition back to thick-wire and plugs into the 3COM board on the PC (see Fig. 5.1).

As covered by Sect. 6 of this report, the Lannet units are inappropriate for use with the new integrated building wiring plan because they require a fifth continuous conductor between units to function (i.e., they are designed to be used with the shield continuous from one end of the run to the other, as opposed to having shields going to an earth ground at the punch-down terminal blocks and floating at the equipment ends). The vendor product literature on the LE-6 is less than straightforward about this fact.

Lannet also builds a unit that houses a DEC DELNI without its enclosure and contains a common power supply for the eight LE-6/Ts. Testing was not done with this composite unit when the limitations of the Lannet design were realized.

5.1.1.2 DEC. The DEC Ethernet-over-twisted-wire equipment is intended for operation with a DEC thin-wire system (see Fig. 5.2). As a result, the BNC thin-wire connector is used on the 3COM board in the PC, and the link to the external office adapter unit is coax. The modular jack in the office adapter is keyed asymmetrically, as is the corresponding jack in the local office receptacle; therefore, non-DEC data receptacles or patch cords cannot be used.

The office adapter, via the intervening twisted-pair wire and punch-down terminal blocks, is connected to a satellite equipment room adapter that can be rack mounted. The room adapter connects to the terminal blocks using another of DEC's keyed data jacks and connects upstream via a BNC thin-wire connector.

Each of the room adapter BNC connectors requires a dedicated DEMPR port (i.e., for this equipment, the DEMPR port will not support 29 adapter BNC connections teed together). Therefore, a full rack width of room adapter units would serve 32 users but require in turn four DEMPRs for access to the overall system.

The DEC Ethernet-over-twisted-wire system, according to DEC's own product literature, will not support a length exceeding 70 m from the office adapter to the room adapter. Therefore, extensive testing was not done with this equipment.

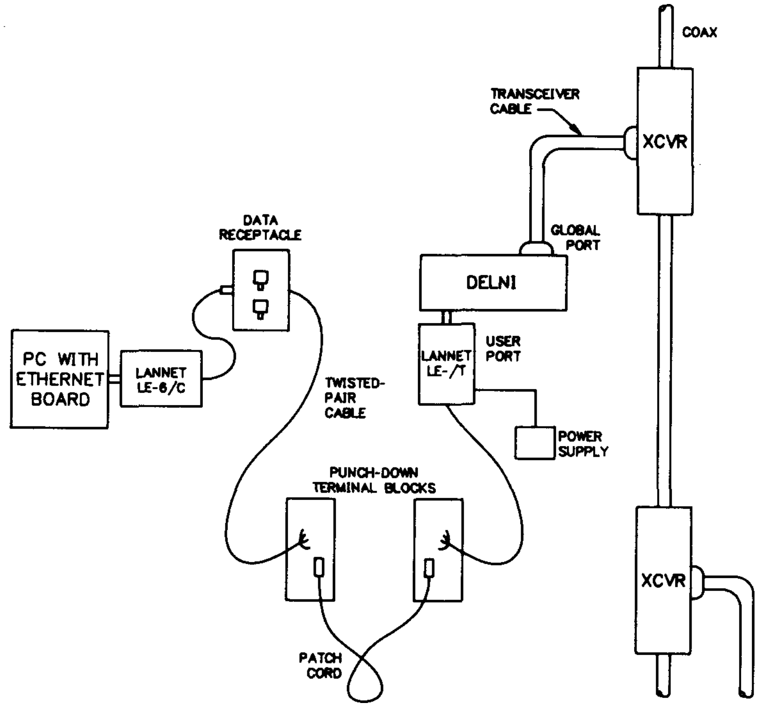


Fig. 5.1. Lannet LE-6 arrangement.

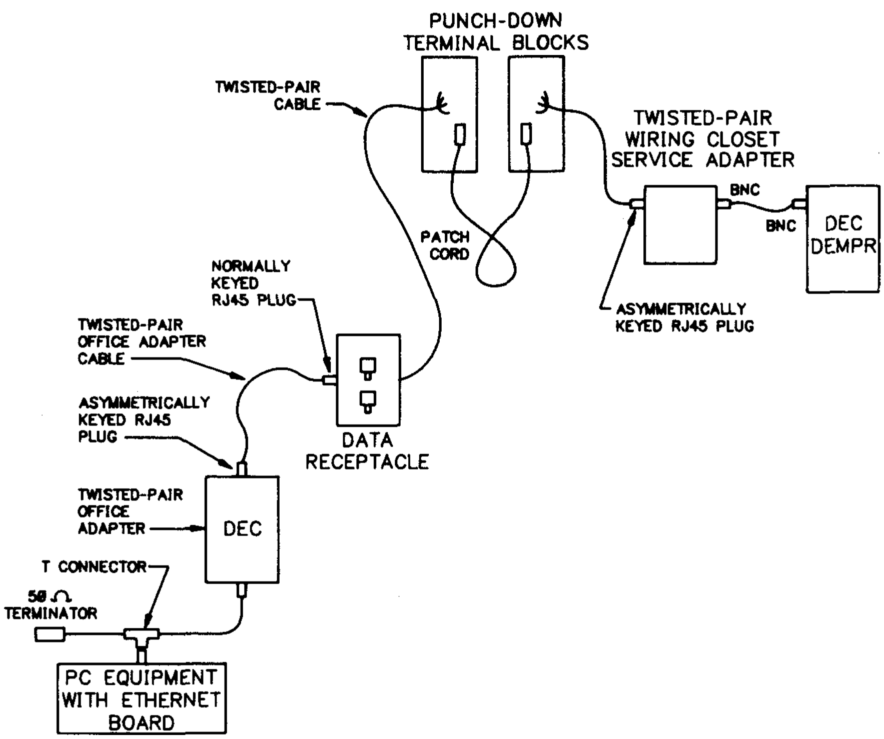


Fig. 5.2. DEC twisted-wire arrangement.

5.1.1.3 <u>SynOptics</u>. The SynOptics Lattisnet system used for these tests consists of a Model 505 unshielded twisted-pair local transceiver used with each PC and a department concentrator (Model 1010). The department concentrator has space for three plug-in modules, each of which can support eight users. The module installed was Model 405 unshielded twisted-pair host (see Fig. 5.3).

SynOptics also markets a functionally identical concentrator with an eight-module capacity called the Premises Concentrator (Model 1000) that communicates over twisted-pair wire, with each local transceiver using two pairs, one for transmitting data and one for receiving data. Each concentrator can be used alone, providing the functionality of a DEMPR or DELNI, or it can be linked by fiber optic cable to a central concentrator as far as 2000 m away.

Tying the Premises Concentrator into an existing Ethernet system requires either a repeater or a bridge. For our series of tests, one of the user ports on the plug-in module was connected through a Model 505 transceiver to a bridge. Thus, the department concentrator could serve 23 users: 3 host modules, each equipped with 8 RJ45 data jacks, with 1 of those 24 jacks used for access to an existing system.

Each SynOptics transceiver is equipped with two LEDs. The link status LED is on when the transceiver is connected to a powered-on PC and there is a connection to a concentrator. The concentrator can be either on or off, and the link status LED on the transceiver will still indicate circuit continuity. The signal quality error (SQE) test LED is on when the transceiver is powered from the host and the SQE test function is enabled. The SQE test is part of the 802.3 standard for Ethernet. It checks to see whether the collision detection mechanism is working by a loop back from the transceiver to the Ethernet interface card. The SQE test can be disabled with a jumper on the PC board inside the transceiver.

Each device connection on the concentrator host module has a link status LED. If the connection is intact between the host module RJ45 jack and the local transceiver, the host LED will be on if the PC powering the transceiver is on. Therefore, the host LED's being out can indicate either a faulty link connection or the local PC not being powered on.

5.1.2 <u>Twisted-Pair Wire</u>

The wire used for these data transmission tests was No. 24AWG solid copper, four twisted-pair, plenum rated, with an overall mylar aluminum shield with drain wire. Of the three vendors evaluated, the AT&T cable had a capacitance of ~25 pF/ft, whereas Teledyne and Accutech cables were in the 16-pF/ft range. As Sect. 6 shows, this difference in capacitance is significant.

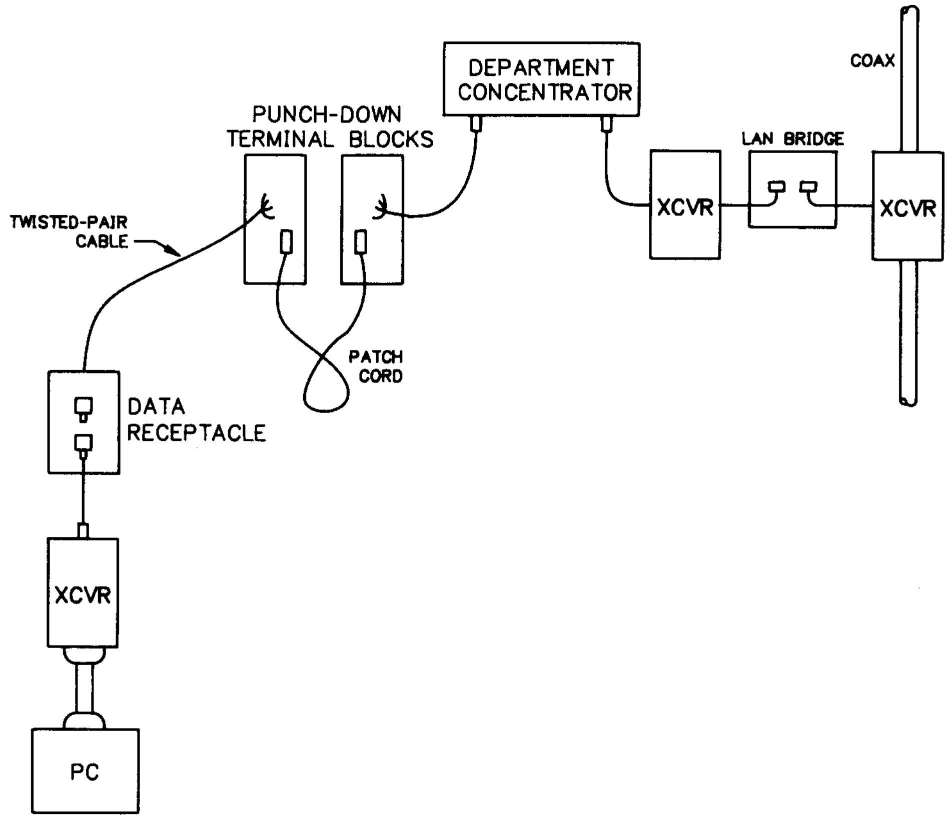


Fig. 5.3. SynOptics twisted-wire arrangement.

5.2 SOFTWARE

The software tool used for the evaluation of test configurations was the DECNET-DOS network test utility (NTU) loop circuit command. This command can be executed from an originating node and directed to any other node on the network; the loop circuit command sends a message of up to 512 bytes as many as 512 times, and the destination node retransmits (i.e., loops) the message it has just received. The integrity of the returned message is then examined by the originating node, and if the message is identical, a successful completion is reported. On the other hand, if the message is not identical to the original, the correct message is retransmitted by the originating node. Retransmissions are continued until either the correct message is received back at the starting point or until the PC retransmit factor is reached.

The retransmit factor is one of several executor node characteristics that can be adjusted by a feature of DECNET-DOS known as the Network Control Program (NCP). If the retransmit factor is set for 6, for example, the PC will try to send each individual loop circuit message as many as six times before disconnecting the logical link and reporting a loop back error. A loop back error can be the result of a packet collision, a mangled address, a poor physical connection, or other reasons.

The loop back error display has a final tally that reports the number of loop back errors for the 512 messages that were transmitted. This error count is a good index of the health of the network and was used as a benchmark to compare the results of several combinations of wire and equipment.

5.3 TEST BENCH SETUP

The AT&T PDS punch-down terminal blocks were arranged on the test bench to simulate a communications closet array, with a No. 8AWG copper wire secured across the top of the blocks as a ground bus and run to a nearby cold water pipe to create a ground to earth. Various incremental lengths of each vendor's wire were terminated and tagged on one end at the punch-down blocks; on the other end, they were terminated and tagged at one of several AT&T data receptacles.

Similarly, wire was run from the punch-down blocks to the particular concentrator under test. Then, by changing patch cords at the punch-down blocks and plugging the user node into a different data receptacle while the host hookup remained the same, cable vendors and cable lengths were changed.

A DEC LAN bridge, a DELNI, and a DEMPR were located at the test position to allow access to the I&C Ethernet for various portions of the testing. Also, a Hewlett-Packard 4194A impedance/gain-phase analyzer was rented and used to determine the electrical characteristics of the twisted-pair wire being examined.

6. EVALUATION AND RESULTS

6.1 BASELINE DETERMINATION

Initially, only an IBM-XT and the ICENET VAX 11/780 were available for the project, meaning that the I&C Ethernet would also be a part of the test setup. Therefore, before collecting and evaluating data on Ethernet concentrators and twisted wire, it was deemed essential to understand the baseline conditions of the I&C Ethernet. Accordingly, the arrangement shown in Fig. 6.1 was used to collect the data presented in Table 6.1.

As the results indicate, the lowest average number of loop back errors was achieved by setting the PC retransmit factor to 15. Also, with any Ethernet segment, packet collisions and loop back errors are to be expected; although they will vary with system usage throughout the day, their average number taken before and after any given test run serves as a useful control in assessing the effectiveness of the equipment and wire.

6.2 CABLE CHARACTERIZATION

Cable characteristics were determined using a Hewlett-Packard 4194A impedance/gain-phase analyzer. The first analyzer received from the rental company would not go through its self-diagnostic routine satisfactorily on startup; a replacement machine was ordered that did perform satisfactorily. Because the manual accompanying the analyzer was not comprehensive, a great deal of time was required for familiarization with the machine; ultimately, additional material had to be requested from the factory in Japan.

The analyzer had coaxial (i.e., unbalanced) inputs and came with the necessary test fixture to accept axial component leads. Machine setups and compensation routines could be stored and retrieved from memory, and alphanumeric readouts presented values that were also shown graphically.

6.2.1 Characteristic Impedance

The characteristic impedance of twisted-pair wire cannot be measured directly; rather, the impedance of the wire is examined with the conductors open at the end of the cable (Z-OPEN) and with the conductors shorted (Z-SHORT) for the particular frequency of interest, in this case 1 MHz. The characteristic impedance (Z-CHAR) is the square root of the product of Z-OPEN and Z-SHORT.

Because the HP analyzer had coaxial, unbalanced inputs and because the twisted-pair wire being measured was balanced, a balun (i.e., BALanced-UNbalanced) was connected to the test fixture and the machine offsets. Then it was run to adjust the internal compensation; this way, the balun did not skew the measurements of the wire. These results are presented in Table 6.2.

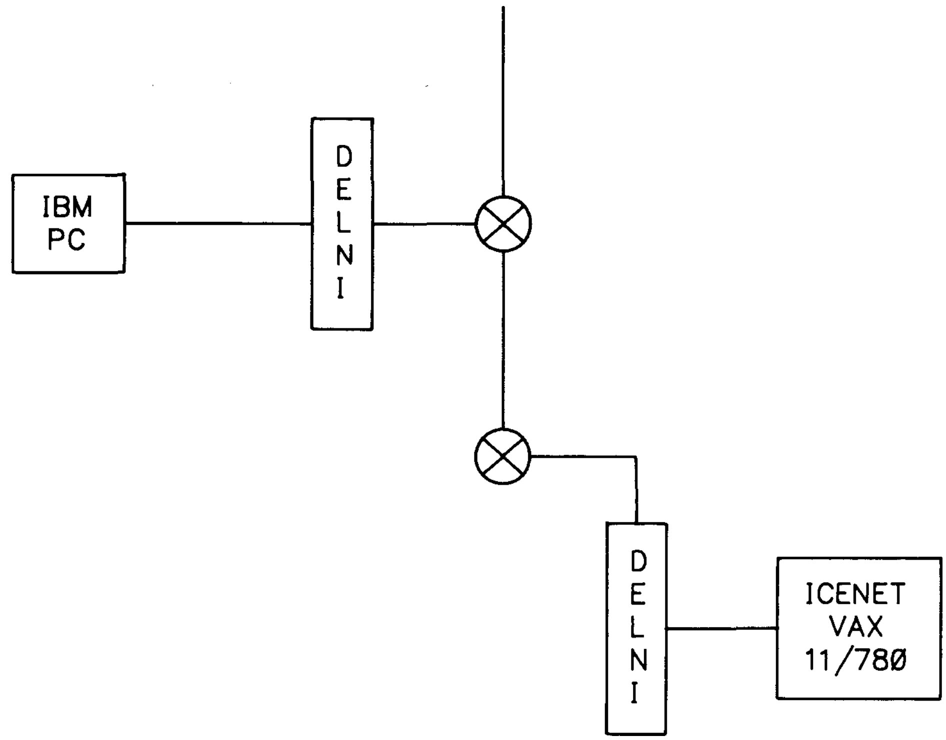


Fig. 6.1. Baseline test arrangement.

6.2.2 Mutual Capacitance

The HP analyzer read capacitance directly, automatically switching units; however, nanofareds were the smallest units presented, but to several decimal places. Therefore, these results are converted to picofareds for presentation in Table 6.3.

Each capacitance figure presented is the average of four separate measurements made between the two conductors of each of the four pairs. Table 6.3 shows that the average capacitance of the AT&T cable at 26.01 pF/ft is more than 50% greater than the average capacitance of the other two cables.

6.2.3 Attenuation

Cable attenuation was examined by using the analyzer's dual output and the input reference channel (see Fig. 6.2). Notice the baluns inserted in the reference loop to balance those used with the twisted-pair wire being evaluated. The test results are presented in Table 6.4 and in Fig. 6.3.

The graph in Fig. 6.3 shows very little variation in attenuation among the three vendors' cable at 1 MHz; however, at 10 MHz, the higher capacitance of the AT&T cable is responsible for significantly higher losses.

Table 6.1. Baseline loop back errors on the ICENET LAN using standard thick-wire Ethernet 20 m long[a]

Retransmit factor	Test	Loop back errors	Average errors
6	1	12	12.2
	2	11	
	3	10	
	4	16	
	5	12	
	6	17	
	7	11	
	8	10	
	9	11	
	10	12	
10	11	10	7.3
	12	6	
	13	8	
	14	5	
15	15	1	4.6
	16	7	
	17	4	
	18	7	
	19	4	
20	20	6	4.8
	21	5	
	22	5	
	23	3	
	24	5	
	25	5	
25	26	8	6.4
	27	2	
	28	4	
	29	6	
	30	12	

[a]Data were taken using DECNET-DOS V1.1 and PC-DOS V3.10; NTU; and loop circuit node 53.1, count 512, and length 512.

Table 6.2. Cable characteristic impedance[a,b]

Ft	Z-OPEN	Z-SHORT	Z-CHAR	Average Z-CHAR
		Accutech cable		
350	233.914	47.271	105.15	
450	56.126	185.680	102.09	
550	91.087	130.179	108.89	106.44
650	152.627	74.481	106.62	
750	83.671	143.203	109.46	
		Teledyne cable		
350	276.886	31.029	92.69	
450	62.489	136.923	92.50	
550	58.430	152.321	94.34	91.77
650	163.105	48.599	89.03	
750	100.888	80.843	90.31	
		AT&T cable		
250	107.111	44.718	69.21	
350	95.211	49.808	68.86	
450	35.781	140.661	70.94	
550	96.551	55.803	73.40	69.53
650	82.750	61.545	71.36	
750	49.004	82.093	63.43	

[a]Measured with Hewlett-Packard 4194A impedance analyzer, compensated/with/black box balun connected to 16047D test fixture, open and shorted offset on, cable examined at 1 MHz.

[b]Characteristic impedance (Z-CHAR) = square root of the [open impedance (Z-OPEN) × shorted impedance (Z-SHORT)].

Table 6.3. Cable mutual capacitance[a,b]

Ft	pF	pF/ft	Average pF/ft
		Accutech cable	
350	5,766	16.47	
450	7,349	16.33	
550	8,581	15.60	16.52
650	11,069	17.03	
750	12,868	17.16	
		Teledyne cable	
350	5,098	14.57	
450	7,378	16.39	
550	8,672	15.76	16.41
650	11,398	17.54	
750	13,356	17.81	
		AT&T cable	
350	8,543	24.40	
450	11,446	25.44	
550	13,365	24.30	26.01
650	17,110	26.32	
750	22,199	29.60	

[a]Measured with Hewlett-Packard 4194A impedance analyzer, compensated with black box balun connected to 16047D test fixture, cable examined at 7 KHz.

[b]Direct readouts in nanofareds have been converted to picofareds; 1.000 nF = 1000 pF.

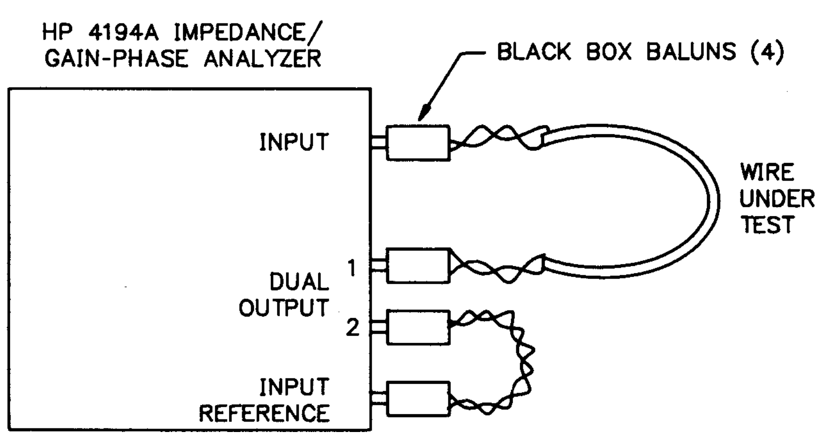


Fig. 6.2. Cable attenuation test arrangement.

Table 6.4. Cable Attenuation at 1 and 10 MHz[a,b]

Ft	Attenuation in dB 1 MHz	10MHz
	Accutech cable	
350	4.94	10.66
450	6.13	14.06
550	6.46	16.28
650	7.60	19.76
750	8.88	22.80
	Teledyne cable	
350	3.39	8.69
450	4.38	10.98
550	5.13	13.84
650	5.63	15.83
750	6.93	18.08
	AT&T cable	
350	4.74	13.28
450	5.45	16.91
550	6.24	20.94
650	8.15	24.80
750	9.08	25.93

[a]Measured with Hewlett-Packard 4194A gain phase analyzer.

[b]One side of the analyzer dual output fed the input reference channel using two black box baluns to structure the reference channel signal to match the two baluns required for the cable under test.

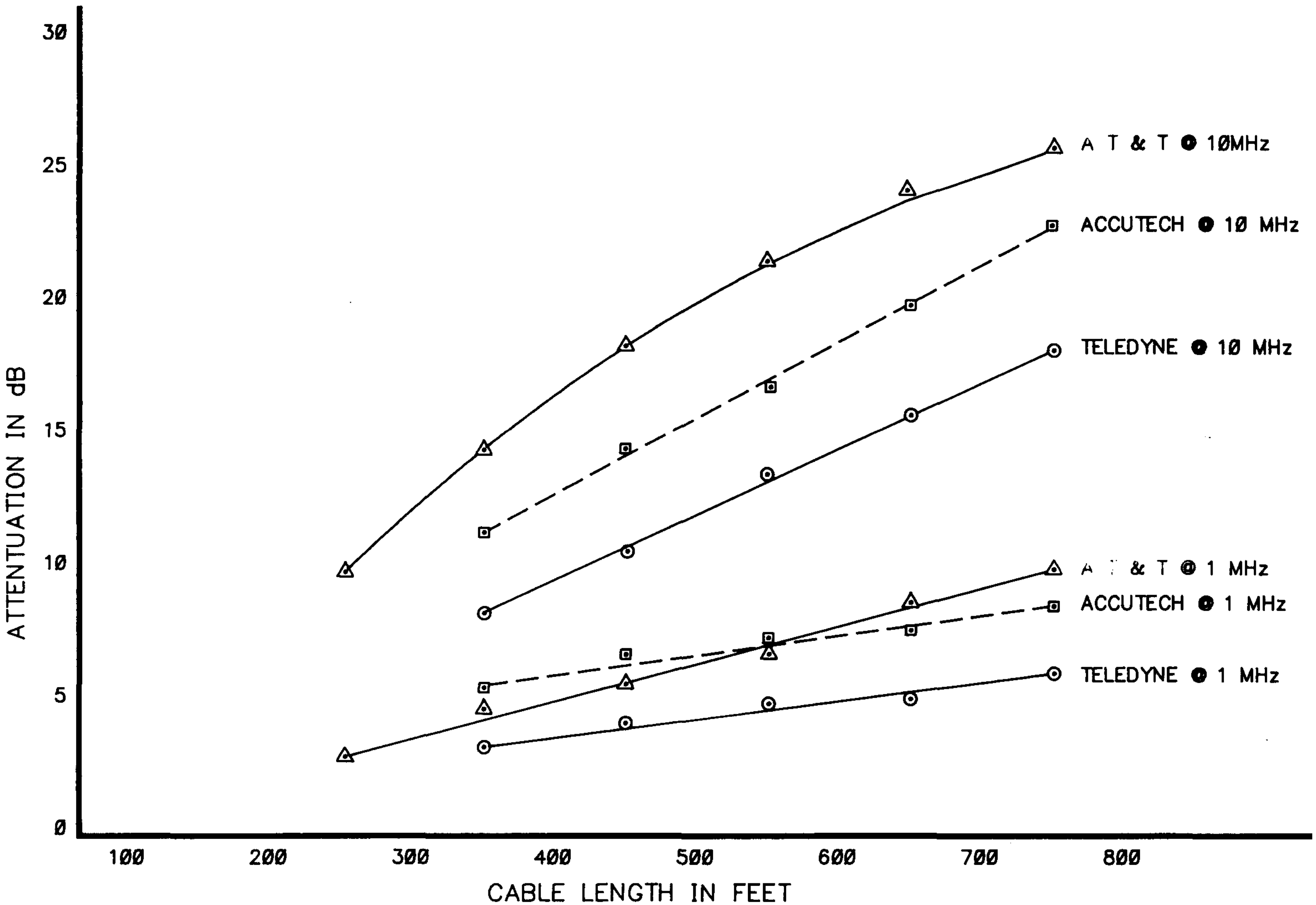


Fig. 6.3. Typical cable attenuation.

6.2.4 dc Resistance

The dc resistances of the three cable types were measured and are presented in Table 6.5. Note how the average dc resistance of each type in turn compares closely with the value IBM specifies in its Type 3 media specification, that is, "a maximum of 28.6 Ω DC resistance/305 m (1000 ft)."

6.3 ETHERNET, COMPUTER TO COMPUTER

The tests of this section were run before receiving two PC clones from the Computing and Telecommunications Division (C&TD); therefore, the I&C Ethernet became part of the test setup. These tests involved two computers exchanging data over twisted wire.

6.3.1 Lannet

The first Ethernet "expander" equipment examined was the Lannet LE-6 series, and the test arrangement used is the one shown in Fig. 5.1. A zero-length cable was used initially between the data receptacle and the punch-down terminal blocks to work out terminal assignments and punch-down techniques. This cable turned out to be quite useful because the AT&T data receptacle is not wired straight through (i.e., pins 1 through 8 on the RJ45 jack are not terminated on punch-down terminals 1 through 8, respectively, at the rear of the receptacles). Some time was spent ringing out conductors to sort out this situation (see Fig. 6.4).

Also notice the use of the SHIELD terminal on the Lannet unit. This terminal was wired straight through to the corresponding SHIELD terminal on the companion unit using the drain wire of the twisted-pair cable. Even though an examination of the Lannet PC board did not indicate a trace emerging from this terminal, operation of the Lannet units depended on the existence of this connection. The Lannet cut sheet for the device shows this terminal connected to a braided cable shield; this arrangement clearly violates the requirements of the C&TD wiring plan.

The Lannet LE-6 expander test results that were achieved using five conductors are shown in Table 6.6 and presented graphically in Fig. 6.5.

6.3.2 DEC

The DEC thin-wire-to-twisted-pair equipment was set up as shown in Fig. 5.2, and data successfully exchanged over 500 ft of Accutech cable with a moderate error rate. However, extensive testing was not done with this equipment for the reasons discussed in Sect. 3.2 of this report.

Table 6.5. Cable dc resistance[a]

		<u>Accutech cable</u>		
(10.99 Ω/350 ft)	×	1000 ft	=	31.4 Ω/1000 ft
(13.02 Ω/450 ft)	×	1000 ft	=	28.9 Ω/1000 ft
(15.62 Ω/550 ft)	×	1000 ft	=	28.4 Ω/1000 ft
(18.70 Ω/650 ft)	×	1000 ft	=	28.8 Ω/1000 ft
(20.70 Ω/750 ft)	×	1000 ft	=	27.6 Ω/1000 ft
		Average value	=	29.0 Ω/1000
		<u>Teledyne cable</u>		
(10.00 Ω/350 ft)	×	1000 ft	=	28.6 Ω/1000 ft
(12.38 Ω/450 ft)	×	1000 ft	=	27.5 Ω/1000 ft
(14.96 Ω/550 ft)	×	1000 ft	=	27.2 Ω/1000 ft
(17.38 Ω/650 ft)	×	1000 ft	=	26.7 Ω/1000 ft
(19.90 Ω/750 ft)	×	1000 ft	=	26.5 Ω/1000 ft
		Average value	=	27.3 Ω/1000 ft
		<u>AT&T cable</u>		
(9.57 Ω/350 ft)	×	1000 ft	=	27.3 Ω/1000 ft
(11.83 Ω/450 ft)	×	1000 ft	=	26.3 Ω/1000 ft
(14.15 Ω/550 ft)	×	1000 ft	=	25.7 Ω/1000 ft
(16.43 Ω/650 ft)	×	1000 ft	=	25.3 Ω/1000 ft
(18.53 Ω/750 ft)	×	1000 ft	=	24.7 Ω/1000 ft
		Average value	=	25.9 Ω/1000 ft

[a]These values were measured with a Hewlett-Packard 3455A digital voltmeter. See Fig. 6.4.

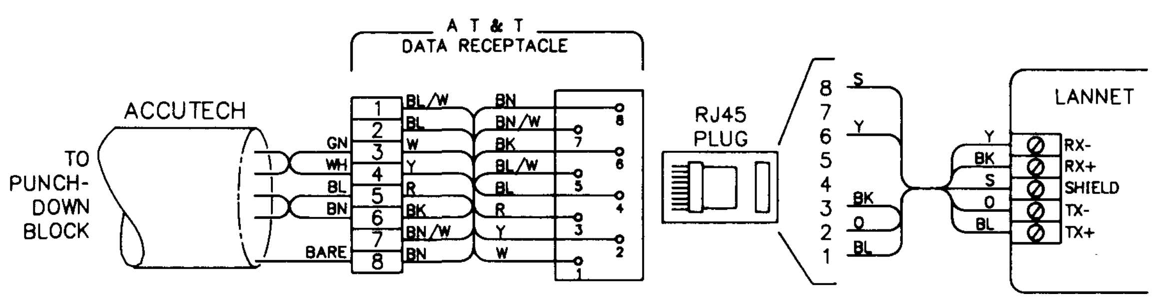


Fig. 6.4. Lannet/receptacle wiring diagram.

Table 6.6. Lannet LE-6 expander test results[a]

Cable type	Length (ft)	Retransmit factor	Test	Loop back errors	Average errors
Accutech	0	15	1	9	11.5
			2	14	
			3	11	
			4	9	
			5	8	
			6	18	
			7	14	
			8	7	
			9	12	
			10	13	
Accutech	350	15	1	14	14.6
			2	10	
			3	19	
			4	15	
			5	9	
			6	11	
			7	11	
			8	27	
			9	17	
			10	13	
Accutech	450	15	1	19	21.5
			2	21	
			3	20	
			4	26	
			5	16	
			6	20	
			7	28	
			8	23	
			9	24	
			10	18	
Accutech	550	15	1	Exited after 10 tries	
			2	Exited after 10 tries	
			3	Exited after 10 tries	
			4	Exited after 10 tries	
			5	Exited after 10 tries	
			6	Exited after 10 tries	
			7	Exited after 10 tries	
			8	Exited after 10 tries	
			9	Exited after 10 tries	
			10	Exited after 10 tries	

Table 6.6. (continued)

Cable type	Length (ft)	Retransmit factor	Test	Loop back errors	Average errors
Accutech	650	15	1	Exited after 10 tries	
			2	Exited after 10 tries	
			3	Exited after 10 tries	
			4	Exited after 10 tries	
			5	Exited after 10 tries	
			6	Exited after 10 tries	
			7	Exited after 10 tries	
			8	Exited after 10 tries	
			9	Exited after 10 tries	
			10	Exited after 10 tries	
Accutech	750	15	1	Exited after 10 tries	
			2	Exited after 10 tries	
			3	Exited after 10 tries	
			4	Exited after 10 tries	
			5	Exited after 10 tries	
			6	Exited after 10 tries	
			7	Exited after 10 tries	
			8	Exited after 10 tries	
			9	Exited after 10 tries	
			10	Exited after 10 tries	
Teledyne	350	15	1	11	14.2
			2	16	
			3	14	
			4	16	
			5	15	
			6	13	
			7	18	
			8	13	
			9	11	
			10	15	
Teledyne	450	15	1	17	16.1
			2	16	
			3	20	
			4	16	
			5	16	
			6	17	
			7	20	
			8	11	
			9	18	
			10	10	

Table 6.6. (continued)

Cable type	Length (ft)	Retransmit factor	Test	Loop back errors	Average errors
Teledyne	550	15	1	Exited after 10 tries	
			2	Exited after 10 tries	
			3	Exited after 10 tries	
			4	Exited after 10 tries	
			5	Exited after 10 tries	
			6	Exited after 10 tries	
			7	Exited after 10 tries	
			8	Exited after 10 tries	
			9	Exited after 10 tries	
			10	Exited after 10 tries	
Teledyne	650	15	1	Exited after 10 tries	
			2	Exited after 10 tries	
			3	Exited after 10 tries	
			4	Exited after 10 tries	
			5	Exited after 10 tries	
			6	Exited after 10 tries	
			7	Exited after 10 tries	
			8	Exited after 10 tries	
			9	Exited after 10 tries	
			10	Exited after 10 tries	
Teledyne	750	15	1	Exited after 10 tries	
			2	Exited after 10 tries	
			3	Exited after 10 tries	
			4	Exited after 10 tries	
			5	Exited after 10 tries	
			6	Exited after 10 tries	
			7	Exited after 10 tries	
			8	Exited after 10 tries	
			9	Exited after 10 tries	
			10	Exited after 10 tries	
AT&T	350	15	1	Exited after 10 tries	
			2	Exited after 10 tries	
			3	Exited after 10 tries	
			4	Exited after 10 tries	
			5	Exited after 10 tries	
			6	Exited after 10 tries	
			7	Exited after 10 tries	
			8	Exited after 10 tries	
			9	Exited after 10 tries	
			10	Exited after 10 tries	

[a]Data were taken using Lannet LE-6 expanders; DECNET-DOS V1.1, PC-DOS V3.10; NTU; and loop circuit node 53.1, count 512, length 512.

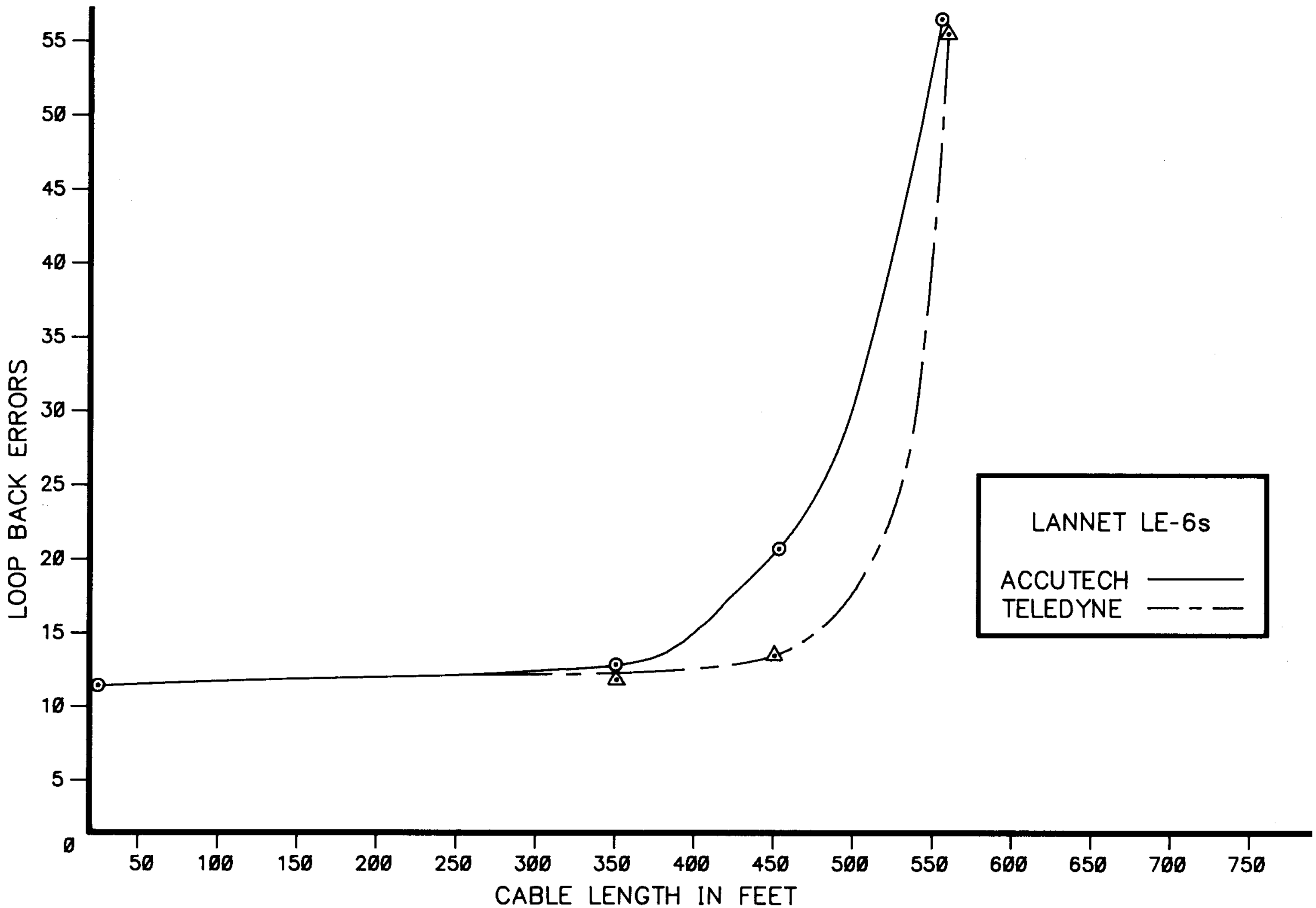


Fig. 6.5. Lannet LE-6 performance.

6.3.3 SynOptics

The SynOptics Lattisnet concentrator and associated transceivers were set up as shown in Fig. 5.3. As the test results in Table 6.7 indicate, the SynOptics equipment worked well at distances up to 450 ft if used with low-capacitance cable. This result is well beyond the original design goal of 100 m. Note that only the single Ethernet signal was present on the cable, and, although the test was not run in a screen room, the test was conducted in a relatively clean EMI environment.

The test results of Table 6.7 indicate that SynOptics equipment performed at 450 ft better than both Accutech and Teledyne cable, but it did not get packets through at all at the 550-ft length with a retransmit factor of either 6 or 15.

The higher capacitance of the AT&T cable has limited to 250 ft the length of AT&T cable that can be used successfully with the SynOptics equipment. Notice that no packets were successfully received at the 350-ft length with the retransmit factor set at 6, and that resetting it to 15 did not improve system performance.

6.4 COMBINATIONS OF ETHERNET AND RS-232C

6.4.1 Ethernet and Ethernet

To better evaluate the performance of two Ethernet systems sharing the same 4-pair cable, several equipment configurations were examined on the test bench. Fig. 6.6 depicts four of the arrangements studied, starting with a simple one and progressing to one that includes a SynOptics Lattisnet concentrator.

With the equipment arrangement shown at the top of Fig. 6.6, an NTU test of 512 loop back messages, each 512 bytes long, took 10:23 min and generated 17 loop back errors.

The second equipment arrangement depicted in Fig. 6.6 shows a second DELNI inserted in the signal path; this time, the identical NTU test ran in 10:26 min and generated 19 loop back errors (i.e., no significant change).

The third arrangement in Fig. 6.6 added a DEC LAN Bridge 100 in the signal path. The throughput capacity of the bridge was high enough that there was no discernable impact on the NTU test results: 10:26 min and 19 loop back errors.

The final equipment arrangement shown in Fig. 6.6 substituted the SynOptics Lattisnet concentrator for the first DELNI of the preceding test. Whereas the Lattisnet transceivers were connected to the concentrator with RJ45/RJ45 patch cords, all other cabling was standard AIU transceiver cable. Once again, there was no impact on the NTU test results. The 10:20-min execution time and 16 loop back errors were essentially identical to the test configurations just examined.

Table 6.7. SynOptics Lattisnet system test results[a]

Cable type	Length (ft)	Retransmit factor	Test	Loop back errors	Average errors
Accutech	0	6	1	0	
			2	0	
			3	0	
			4	0	
			5	0	0
			6	0	
			7	0	
			8	0	
			9	0	
			10	0	
Accutech	350	6	1	0	
			2	0	
			3	0	
			4	0	
			5	0	0
			6	0	
			7	0	
			8	0	
			9	0	
			10	0	
Accutech	450	6	1	0	
			2	1	
			3	0	
			4	0	
			5	0	0.2
			6	0	
			7	1	
			8	0	
			9	0	
			10	0	
Accutech	550	6	1	Exited after 10 tries	
			2	Exited after 10 tries	
			3	Exited after 10 tries	
			4	Exited after 10 tries	
			5	Exited after 10 tries	
			6	Exited after 10 tries	
			7	Exited after 10 tries	
			8	Exited after 10 tries	
			9	Exited after 10 tries	
			10	Exited after 10 tries	

Table 6.7. (continued)

Cable type	Length (ft)	Retransmit factor	Test	Loop back errors	Average errors
Accutech	550	15	1	Exited after 10 tries	
			2	Exited after 10 tries	
			3	Exited after 10 tries	
			4	Exited after 10 tries	
			5	Exited after 10 tries	
			6	Exited after 10 tries	
			7	Exited after 10 tries	
			8	Exited after 10 tries	
			9	Exited after 10 tries	
			10	Exited after 10 tries	
Teledyne	350	6	1	0	
			2	1	
			3	0	
			4	0	
			5	0	0.1
			6	0	
			7	0	
			8	0	
			9	0	
			10	0	
Teledyne	450	6	1	0	
			2	0	
			3	0	
			4	0	
			5	0	0.1
			6	1	
			7	0	
			8	0	
			9	0	
			10	0	
Teledyne	550	6	1	Exited after 10 tries	
			2	Exited after 10 tries	
			3	Exited after 10 tries	
			4	Exited after 10 tries	
			5	Exited after 10 tries	
			6	Exited after 10 tries	
			7	Exited after 10 tries	
			8	Exited after 10 tries	
			9	Exited after 10 tries	
			10	Exited after 10 tries	

Table 6.7. (continued)

Cable type	Length (ft)	Retransmit factor	Test	Loop back errors	Average errors
Teledyne	550	15	1	Exited after 10 tries	
			2	Exited after 10 tries	
			3	Exited after 10 tries	
			4	Exited after 10 tries	
			5	Exited after 10 tries	
			6	Exited after 10 tries	
			7	Exited after 10 tries	
			8	Exited after 10 tries	
			9	Exited after 10 tries	
			10	Exited after 10 tries	
AT&T	250	6	1	0	
			2	0	
			3	0	
			4	0	
			5	0	0.2
			6	0	
			7	1	
			8	1	
			9	0	
			10	0	
AT&T	350	6	1	Exited after 10 tries	
			2	Exited after 10 tries	
			3	Exited after 10 tries	
			4	Exited after 10 tries	
			5	Exited after 10 tries	
			6	Exited after 10 tries	
			7	Exited after 10 tries	
			8	Exited after 10 tries	
			9	Exited after 10 tries	
			10	Exited after 10 tries	

Table 6.7. (continued)

Cable type	Length (ft)	Retransmit factor	Test	Loop back errors	Average errors
AT&T	350	15	1	Exited after 10 tries	
			2	Exited after 10 tries	
			3	Exited after 10 tries	
			4	Exited after 10 tries	
			5	Exited after 10 tries	
			6	Exited after 10 tries	
			7	Exited after 10 tries	
			8	Exited after 10 tries	
			9	Exited after 10 tries	
			10	Exited after 10 tries	

[a]Data were taken using SynOptics Model 1010 concentrator equipped with a Model 405 twisted-pair host module; SynOptics Model 505 unshielded twisted-pair transceiver (2 each); 7 ft of unshielded twisted-pair patch cords equipped with RJ45 data plugs; and NCR PC8s equipped with DECNET-DOS V1.1; NTU; loop circuit node 53.300, count 512, length 512.

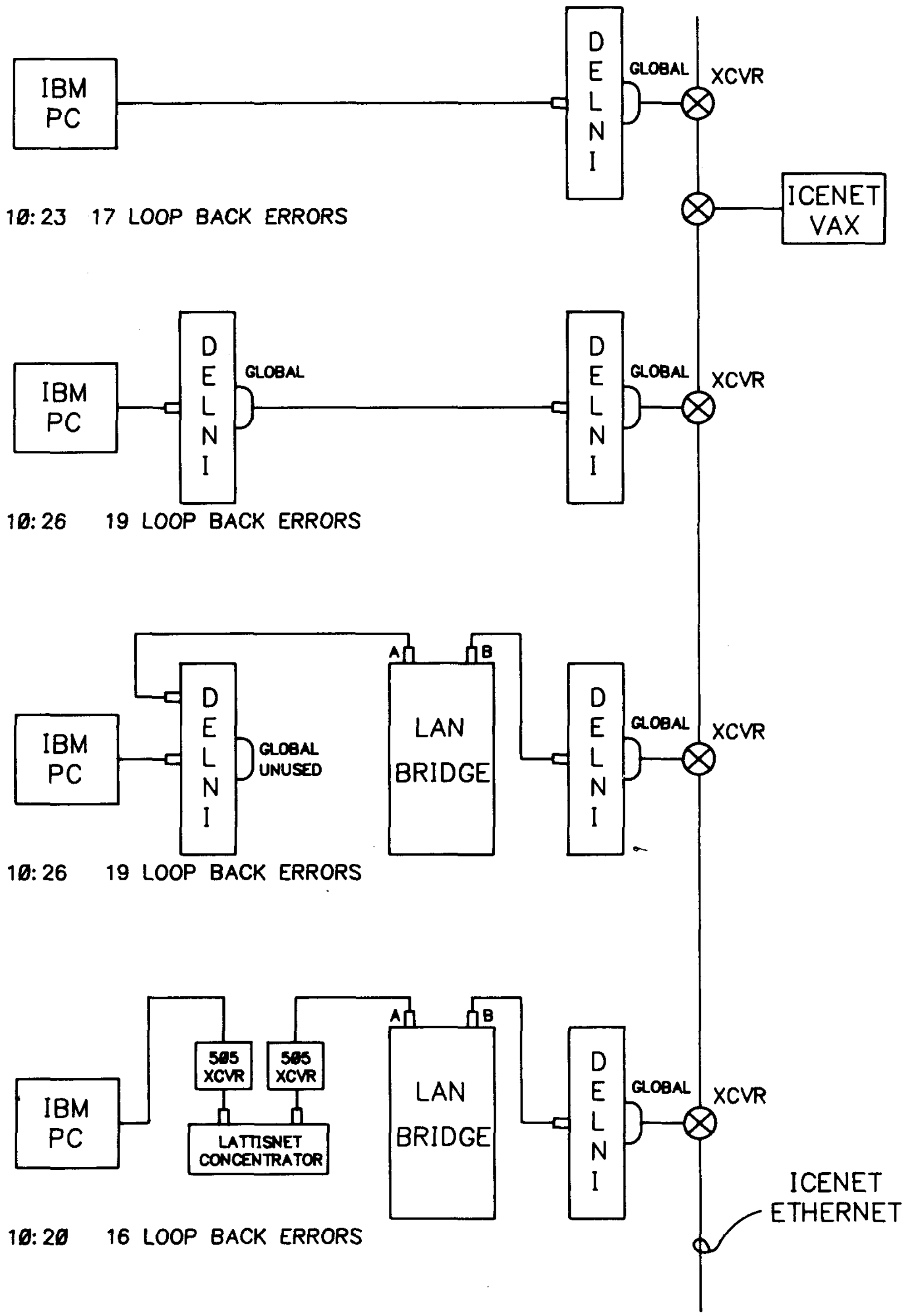


Fig. 6.6. Equipment test configurations.

This result led to the test configuration shown in Fig. 6.7 with a data receptacle, twisted-pair wire, and AT&T punch-down blocks inserted in the signal path, creating the first of the two Ethernet systems to be examined. The same NTU test ran in 10:35 min, generating 22 loop back errors; this longer execution time and greater number of errors seems to indicate that the 350 ft of twisted-pair wire was the contributing factor, and that the greater number of retransmissions associated with these errors was responsible for increasing the run time.

Figure 6.8 depicts the second of the two Ethernet systems that shared the same twisted-pair cable. The NCR PC clones on loan from C&TD were 286-based units. This fact explains their much faster execution time for the NTU loop back test. An elapsed time of 2:21 min and only 1 loop back error were typical for these machines alone running over as much as 450 ft of twisted-pair wire.

The tests of Figs. 6.6, 6.7, and 6.8, therefore, not only established some performance figures for subsequent Ethernet/Ethernet testing, but also demonstrated that the SynOptics Lattisnet equipment does not seem to play a role in degrading system performance or execution time. Figure 6.9 shows the combined test configuration used for the Ethernet/Ethernet test runs; this arrangement is a combination of the ones shown in Figs. 6.7 and 6.8.

For the tests run with Fig. 6.9, the objective was to have both Ethernet systems running simultaneously. Because the NCR test cycle was five times faster than the IBM-XT/VAX cycle, the NCRs were continually recycled for the duration of each IBM run. The results of the first NCR test cycle were recorded with subsequent runs discarded. In addition, each series of 10 tests for a given cable vendor and cable length was both preceded and followed by two control runs. The first of these was with the NCR machines disconnected at the SynOptics concentrator and the IBM machine cycled. The second control run was with the IBM machine disconnected at the concentrator and the NCR machines cycled.

These test results, which are presented in Table 6.8, indicate that with two Ethernet systems using the same twisted-pair cable, some degradation of the IBM/VAX link and a marked degradation of the NCR/NCR link occur. The IBM-XT was much slower than the NCR, and the ICENET VAX was sharing its resources over several user nodes; therefore, the actual data rate, or dynamic bandwidth required, was rather low between these two machines. Therefore, a good margin existed for the degradation of this communications link before the number of background loop back errors began increasing. On the other hand, the NCR machines were on a dedicated Ethernet, performing no other tasks, and operating at a substantially higher clock rate. As the test results in Table 6.8 indicate, the NCR machines thereby become more vulnerable to link degradation.

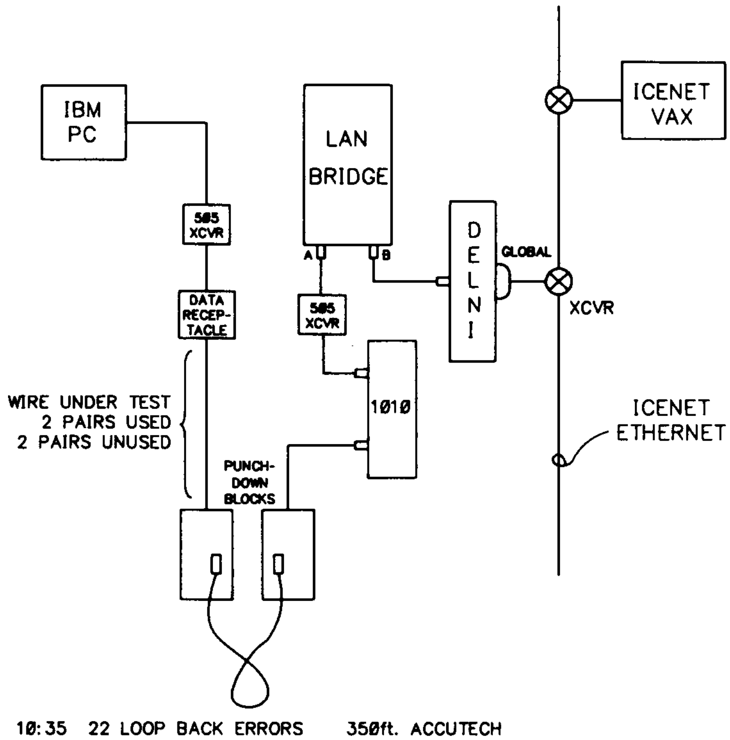


Fig. 6.7. IBM-PC/VAX test configuration.

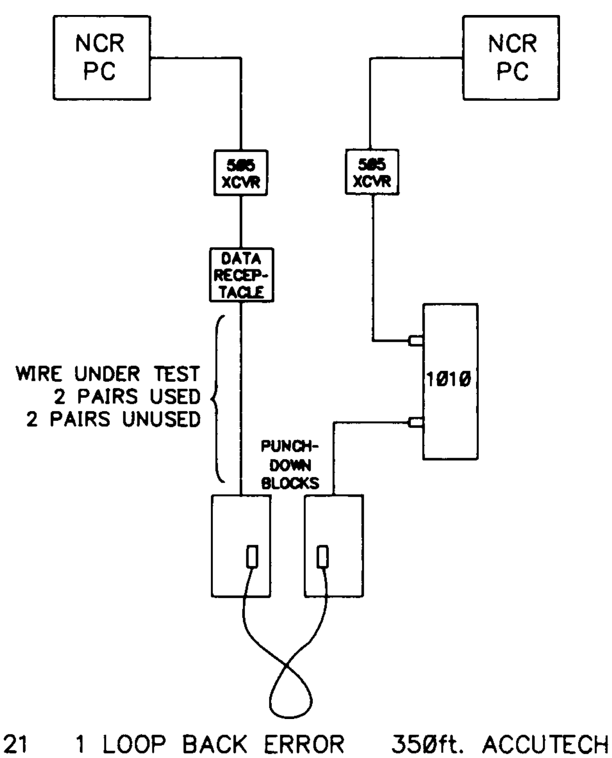


Fig. 6.8. NCR/NCR test configuration.

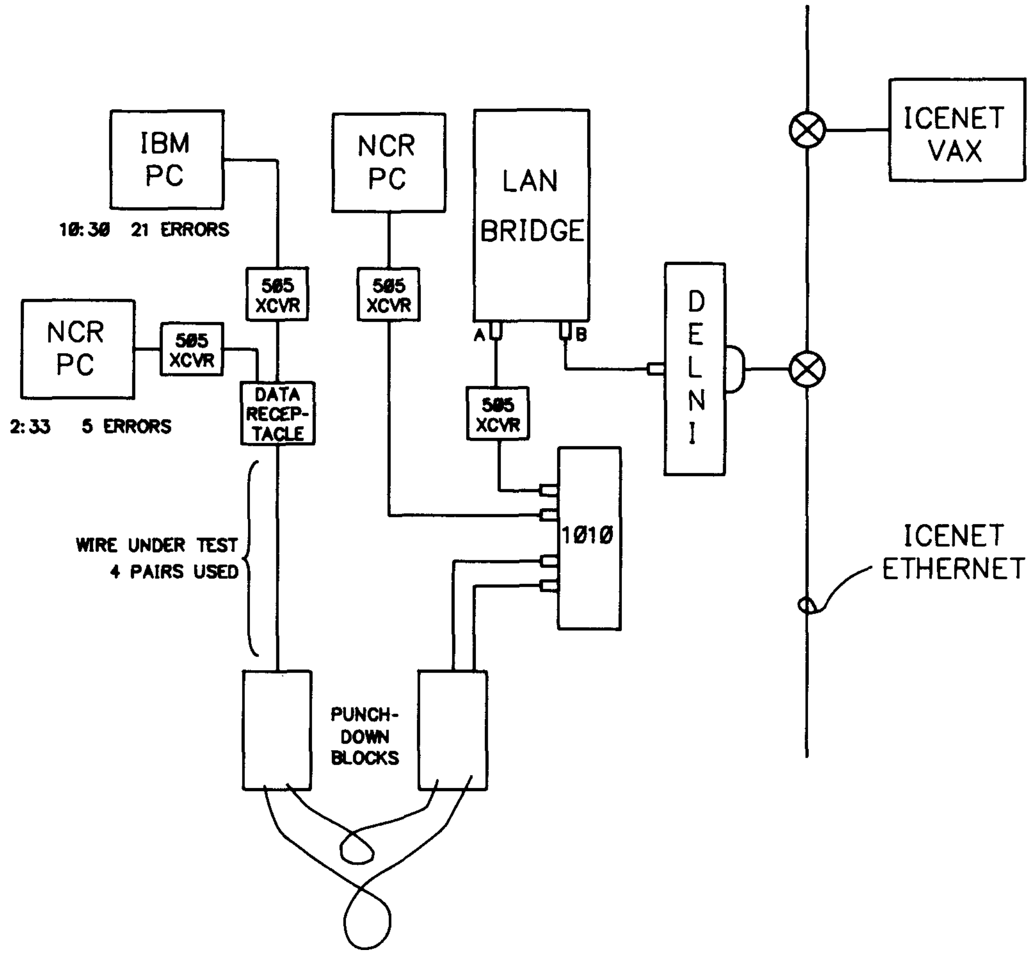


Fig. 6.9. Ethernet/Ethernet configuration.

Table 6.8. Ethernet/Ethernet test results

Test	NCR/NCR	IBM-XT/VAX
	350-ft Accutech cable	
Control[a]		11
Control[a]	1	
1	8	10
2	10	16
3	4	18
4	3	13
5	8	17
6	5	21
7	9	18
8	7	19
9	9	20
10	8	17
Control[a]	0	
Control[a]		19
	450-ft Accutech cable	
Control[a]		19
Control[a]	0	
1	10	16
2	10	16
3	10	19
4	Exited midway	19
5	6	17
6	8	17
7	6	22
8	5	17
9	10	18
10	7	22
Control[a]	0	
Control[a]		17
	350-ft Teledyne cable	
Control[a]		8
Control[a]	0	
1	7	21
2	6	19
3	5	16
4	9	18

Table 6.8. (continued)

Test	NCR/NCR	IBM-XT/VAX
5	5	21
6	2	18
7	5	17
8	7	18
9	11	16
10	9	18
Control[a]	0	
Control[a]		12
	450-ft Teledyne cable	
Control[a]		23
Control[a]	0	
1	7	20
2	5	24
3	10	19
4	7	29
5	7	13
6	5	17
7	11	21
8	6	22
9	5	13
10	7	16
Control[a]		21
Control[a]	0	
	300-ft Accutech cable	
Control[a]		19
Control[a]	1	
1	5	14
2	7	17
3	5	15
4	2	24
5	4	13
6	4	23
7	3	24
8	6	19
9	4	16
10	6	19

Table 6.8. (continued)

Test	NCR/NCR	IBM-XT/VAX
Control[a]		22
Control[a]	0	
	300-ft Teledyne cable	
Control[a]		21
Control[a]	0	
1	1	20
2	7	15
3	4	26
4	7	22
5	10	13
6	8	11
7	2	13
8	3	18
9	3	22
10	3	14
Control[a]		25
Control[a]	0	

[a]Control runs done with one pair of machines disconnected at the SynOptics Lattisnet concentrator.

Based on the numbers in Table 6.8, a marked difference does not seem to exist between the results obtained with the Accutech and the Teledyne cable. The AT&T cable performed so poorly in earlier tests that it was not used again.

6.4.2 Ethernet and RS-232C

Tests with Ethernet and RS-232C sharing the same twisted-pair cable were conducted using the test arrangement depicted in Fig. 6.10. The RS-232C signals generated by the Fireberd 2000 were fed through the remaining two pairs of the twisted-pair cable, and the test results presented in Table 6.9 were examined for evidence of signal interaction or cross talk. For both the Accutech and Teledyne cables used in this test, no degradation of the integrity of either signal occurred.

For the Ethernet signal, the number of loop back errors did not increase, and the bit error rate cycle printout of the Fireberd read "ABER 0.00E-06 1E7", indicating that the average bit error rate over the 10 previous bit error rate tests was zero and that it was measured over 10 million bits.

Also note that although no interaction occurred between the two types of signals, a cable of four twisted pairs does not have enough conductors for both Ethernet and the array of signal and control leads typically required to implement RS-232C. Although three signal leads (transmit, receive, and signal ground) and a data terminal ready would be the bare minimum required, these four leads would not be enough in many situations. For example, if a modem were needed, additional control leads would be required. Because the Ethernet signal uses two of the four pairs available in the cable being tested, additional provisions would have to be made for RS-232C to be successfully implemented.

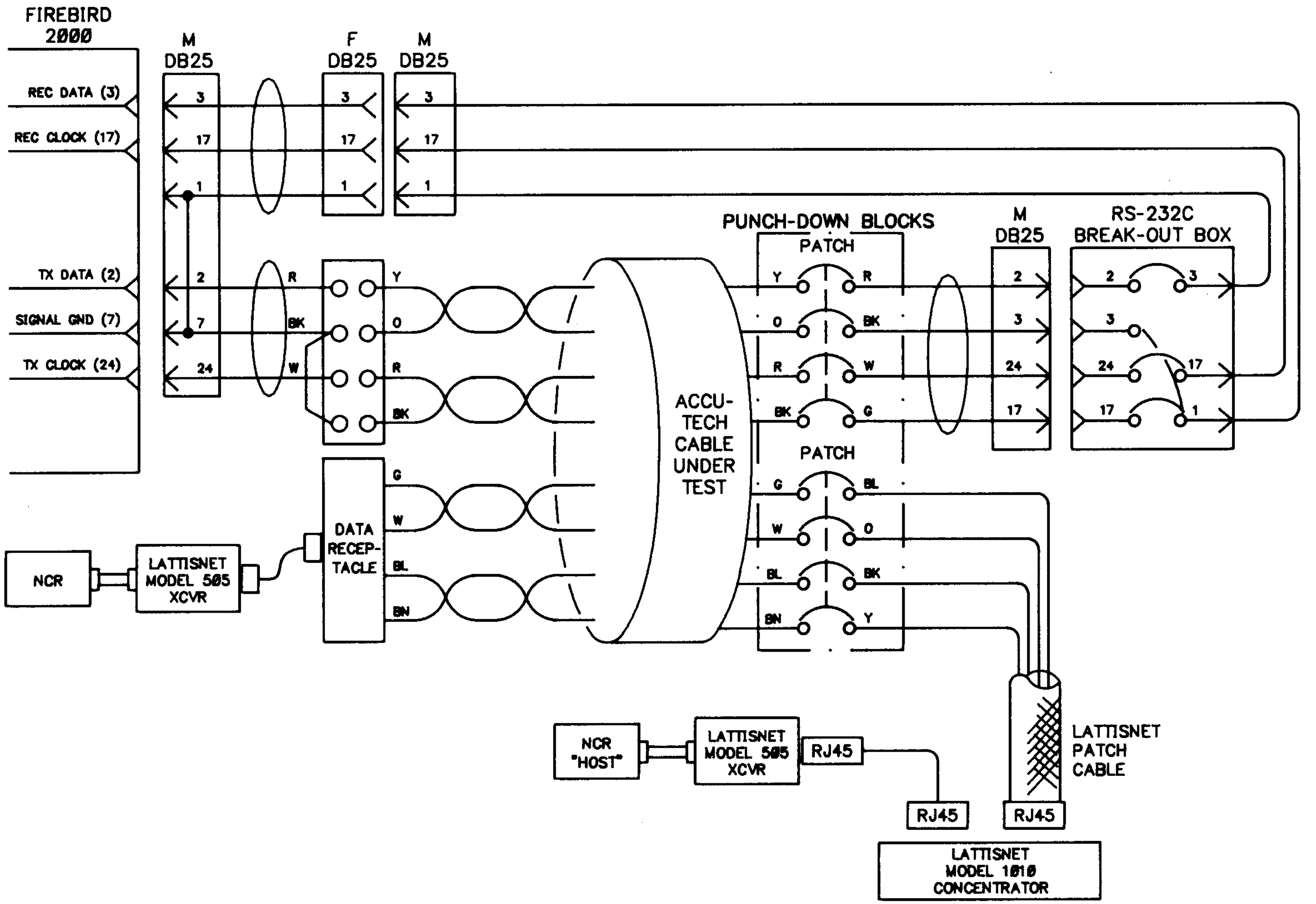


Fig. 6.10. Ethernet/RS-232C test configuration.

Table 6.9. Ethernet/RS-232C test results[a]

Cable type	Length (ft)	Retransmit factor	Test	Loop back errors	Average errors
Accutech	350	6	1	0	
			2	0	
			3	0	
			4	0	
			5	0	0.0
			6	0	
			7	0	
			8	0	
			9	0	
			10		
Accutech	450	6	1	0	
			2	0	
			3	0	
			4	0	
			5	0	0.2
			6	0	
			7	1	
			8	0	
			9	1	
			10	0	
Teledyne	350	6	1	0	
			2	0	
			3	0	
			4	0	
			5	0	0.0
			6	0	
			7	0	
			8	0	
			9	0	
			10	0	
Teledyne	450	6	1	0	
			2	0	
			3	0	
			4	0	
			5	0	0.0
			6	0	
			7	0	
			8	0	
			9	0	
			10	0	

Table 6.9. (continued)

Cable type	Length (ft)	Retransmit factor	Test	Loop back errors	Average errors
AT&T	450	6	1	0	
			2	0	
			3	0	
			4	0	
			5	0	0.0
			6	0	
			7	0	
			8	0	
			9	0	
			10	0	

[a]Data were taken using SynOptics Communications Lattisnet equipment: Model 1010 concentrator equipped with a Model 405 twisted-pair host module, Model 505 unshielded twisted-pair transceiver with the signal quality error function enabled (2 each), and 7 ft of unshielded twisted-pair patch cords equipped with RJ45 data plugs; NCR PC8s equipped with DECNET-DOS V1.1; NTU; loop circuit node 53.300, count 512, and length 512; and the Fireberd data error analyzer (GENERATOR CLOCK TX (RX), 9600 kHz).

7. CONCLUSIONS AND RECOMMENDATIONS

Ethernet-over-twisted-pair, like any new technique, has both its strengths and its limitations; understanding the limitations thoroughly can become the key to using this medium's strengths well. These tests have shown that:

1. Careful cable selection is required for the successful implementation of any LAN, but especially for a LAN using twisted-pair wire. Wire with a capacitance of ~16 pF/ft performed well, but the much higher 26 pF/ft cable was totally unsuitable for this application.

   This finding points out the rather curious argument advanced by some vendors for the twisted-pair approach: that because the telephone company, in many cases, has already pulled additional pairs that are now unused, minimal cable cost is involved in going to a data-over-twisted-pair system. Although these pairs may be useful for extremely short runs, twisted-pair installed by the telephone company for analog telephone use has a capacitance that is too high to support long home runs and Ethernet data rates. Some vendors cope with this problem creatively by quickly adding that they encourage a careful inspection of the existing cable plant to evaluate its suitability.

   Another source of concern is the inductive coupling of telephone ringing voltages onto the pairs reserved for data transmission. Because the individual twisted pairs are not shielded, a problem could arise if spare pairs in an existing telephone cable were arbitrarily assigned to data use.

   Therefore, we recommend using only new, dedicated, low-capacitance, data-grade cable for Ethernet-over-twisted-pair installations with the associated punch-down terminal blocks in the communications closet well segregated from those reserved for voice.

2. All of the hardware combinations examined for this report required additional outboard electronics packages at the user location for signal conditioning. The migration of these external units to printed circuit boards that will plug into the local PC is inevitable—and in fact has already begun; however, regardless of the physical location of these units, they represent an additional level of electronics that must be maintained.

3. Of the three hardware vendors examined for this report, all three had different pin-outs at the data receptacle, and one used a nonstandard keying for the RJ45 data plug, requiring special translation patch cords. Because the SynOptics methodology is the one endorsed by the 10BASE-T task force, the SynOptics pin-assignments will probably become the standard, as the latest working papers indicate. However, pin-outs are still fluid, thus

affecting the flexibility of the prewired approach. Specifically, if a change in the vendor's equipment at the communications closet requires rewiring every data receptacle on that floor, this fact needs to be taken into consideration.

4. Two Ethernet signals cannot successfully share the same twisted-pair cable. Tests indicate that significant interaction exists between the two signals; the resulting loading effect on the network of the additional retransmissions indicates that this approach is not viable.

5. A SynOptics Ethernet segment, like any other separate Ethernet segment, requires either a repeater or a bridge to communicate with other segments. SynOptics is in the process of developing its own repeater.

6. The Ethernet-over-twisted-wire system with punch-down terminal blocks will be difficult to administer well unless cross-connect lists are well maintained. This fact leads, by implication, to the conclusion that the system is much better suited to a stable office environment than it is to a more volatile, rapidly changing developmental laboratory setting.

7. The Lannet equipment, designed for use with individually shielded twisted pairs, is inappropriate for use with the new integrated wiring plan.

8. Similarly, the DEC equipment evaluated does not honor the 10BASE-T approach and is therefore also inappropriate for consideration.

9. Continued flexing of the solid conductors at the punch-down terminal blocks and at the data receptacles as the cables were reterminated resulted in several broken conductors over several months. Therefore, adequate slack is needed at both ends of the cable runs for this progressive loss of cable length.

10. Performance of the SynOptics equipment with good cable deteriorated in a clean environment at 450 ft home runs, but was still good at 350 ft. I&C therefore recommends limiting home runs to 325 ft (100 m), thus creating a reasonable safety margin.

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