ARCNET's ALREADY FLEXIBLE PHYSICAL LAYER ENHANCED WITH SEVERAL EIA-485 VARIANTS

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ABSTRACT

ARCNET is regarded as one of the most flexible industrial networking technologies to wire due to the many cabling options available to the user. ARCNET can be configured as a star network using hubs or a bus without hubs. Cabling can be coaxial, twisted-pair or fiber optics. With the proper selection of hubs, repeaters and links, cabling and topology can be mixed to a distance of four miles. Now with new ARCNET controller chips, simplified interfacing to the popular EIA-485 multipoint networking standard is possible providing the user with more options. This paper describes the tradeoffs in implementing DC coupled, AC coupled and optically coupled EIA-485 ARCNET networks.

INTRODUCTION

ARCNET (attached resource computer network) was originally developed by Datapoint Corporation as the network which linked its minicomputers together acting as one large computer.[1] Devices were connected using coaxial cable and active hubs in a distributed star topology. A total of 255 nodes were supported spanning four miles. The data rate was 2.5 Mbps and access to the network was managed by a token passing scheme. Standard Microsystems Corporation (SMC) has now provided technical leadership for ARCNET and has produced a family of controller chips that not only support the traditional coaxial cable transceivers but popular EIA-485 transceivers as well.

TRADITIONAL ARCNET

ARCNET is defined in ANSI/ATA 878.1.[2] The ATA (ARCNET Trade Association) is a recognized ANSI standards development body that develops its standards through the canvass method. This standard defines ARCNET as operating only at 2.5 Mbps and using a dipulse signal for a logic "1." Neither EIA-485 nor fiber optics are defined in the standard and need to be appended to the standard in order to ensure interoperability at the physical layer. The standard calls out several transceivers which are referred to as traditional hybrid transceivers.

Coaxial Star

In Datapoint's original specification, ARCNET was cabled using 93 ohm RG-62/u coaxial cable in either a star or distributed star topology utilizing active or passive hubs to facilitate cabling. Network interface modules (NIMs) connect to either another NIM or a port on a hub. Hub-to-hub connections are used to create the distributed star implementation. In each instance a single
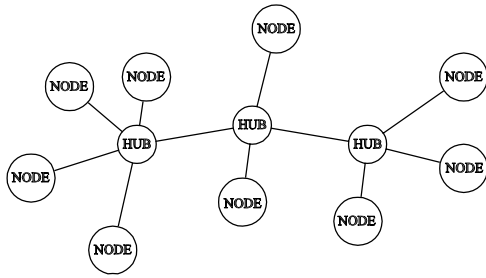
A distributed star topology is possible using hubs.

ARCNET transceiver connects to one other ARCNET transceiver. Active hubs utilize the same ARCNET transceivers as used in the NIMs. No external termination is required since each low-impedance ARCNET transceiver effectively provides the proper termination to the RG-62/u cable. In summary, star and distributed star topologies utilize low-impedance transceivers which are wired in a point-to-point manner. Coaxial star segments can be as long as 2000 feet in length and a complete network can span 4 miles by cascading active hubs.

Coaxial Bus

The coaxial bus transceiver was developed in order to implement a lower cost hubless network. Up to eight NIMs can be connected in one bus segment using BNC Tee connectors at each node and BNC terminators (93 ohms) at each end. The cable used was RG-62/u. Segment length was limited to 1,000 feet but active hubs or links could be used to extend the distance.

Twisted-Pair Bus

By modifying the circuitry of the coaxial bus implementation while retaining the basic coaxial bus transceiver, a twisted-pair bus design was introduced. This design again supports eight nodes on a single bus segment but at a reduction in segment length to only 400 feet. Connections are usually made with RJ-11 connectors. Cable could be either shielded (STP) or unshielded twisted-pair (UTP). RJ-11 style terminators are required at the ends of the bus segment.

Twisted-Pair Star

By simply adding coaxial to twisted-pair BALUNs (balance/unbalance) to a coaxial star transceiver, a twisted-pair star connection is possible requiring active hubs (with identical BALUNs) for network expansion. Some products have built-in BALUNs on their NIMs and active hubs to eliminate the bulkiness of the installation.

Fiber Optics

Although not formally standardized, single mode and multimode interfaces exist that greatly extend the distance a single cable can span before intervention is required by either a hub or link. With popular 62.5/125 multimode fiber (850 nm), a segment can span 6000 feet while single mode fiber (1300 nm) can span six miles! By cascading active hubs, very large networks can be achieved requiring that the ARCNET controller chips be set to extended time-outs in order to accommodate the increased cable delay.

Dipulse Signaling

The 878.1 specification defines a logic "1" signal as a single dipulse with equal positive and negative excursions. The dipulse can be considered a single sine wave with a period of 200 ns. Its width is not 400 ns as expected for a 2.5 Mbps data rate. The cable is idle during the second half of a logic "1" transmission and is idle for the complete 400 ns of a logic "0." This dipulse is created by the generation of two consecutive but non-overlapping pulses P1 and P2 each of 100 ns in duration. These pulses, which are absent for a logic "0," originate from the ARCNET controller chip and drive the hybrid transceiver. There is no separate "data out" signal. The data out is simply the P1, P2 sequence. There is, however, a "RXIN" line from the transceiver which transitions in a positive direction upon receipt of received data.
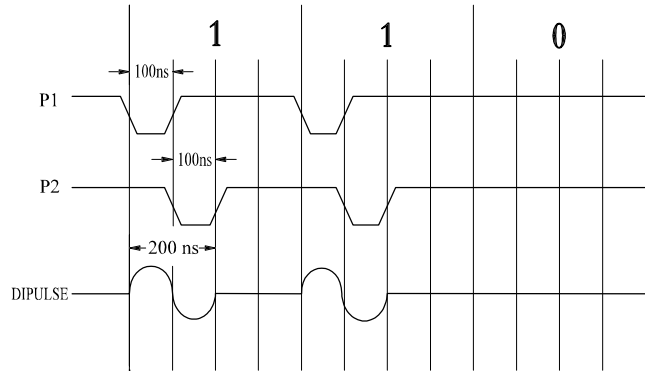
Traditional ARCNET utilizes a dipulse to indicate a logic "1" which is generated by pulses P1 and P2.

NEWER ARCNET CONTROLLERS

Traditional ARCNET was implemented on several controller chips beginning with a two chip design (9026/9032) which was sourced by four different vendors. Since that introduction, several other designs followed each adhering to the ARCNET data link specification:

SMC 90C65; 90C165; 90C66
NCR 9098; 90126; 90198

The latest generation of ARCNET controller chips come from SMC and they include the following:

SMC 20019; 20020; 20022

These chips feature several software enhancements in addition to the support of EIA-485.[3] Newer chips have wide data rate selections as low as 19 Kbps and as high as 10 Mbps. Since the traditional ARCNET hybrid transceiver would only operate at 2.5 Mbps, a different transceiver had to be used and the logical choice was the inexpensive EIA-485 transceiver.

Backplane Mode

A new operating mode and pin connection were created on the newer controller chips to simplify the interfacing to EIA-485 transceivers. First, a new pin was defined called TXEN. This pin is used to enable the EIA-485 transmitter (remove it from a 3-state condition) in preparation for transmitting data. This pin connects directly to the EIA-485 transmitter. Second, if the

ARCNET controller is programmed to enter "backplane" mode, several of the pins change definition. P1 is elongated to half the bit time becoming P1P2. Instead of 100 ns it becomes 200 ns wide. P2 becomes a clock or if the sense of TXEN needs to be inverted to accommodate a particular EIA-485 transmitter, P2 can be grounded. With EIA-485, P2 is not used, P1 becomes "data out" and TXEN is used to gain bus access. Also in backplane mode, the sense of "RXIN" is inverted in order to have a direct connection with an EIA-485 receiver. This was all done to reduce the hardware cost of implementing EIA-485.

Compatibility with Traditional ARCNET

When the new ARCNET controller chips are first powered up, they appear as a traditional ARCNET node operating at 2.5 Mbps and generating conventional P1 and P2 signals (non-backplane mode). To enter backplane mode requires a register change and, therefore, a change to the ARCNET software driver. This sounds innocent enough but care must be exercised so that backplane mode is not entered when using a traditional hybrid transceiver since it will be destroyed by either the elongated P1 or the periodic P2. For embedded designs, this is not usually a problem since the code is in ROM and the OEM knows what transceiver is being used. However, for bus board NIMs especially in a PC, it is very easy to mix boards and drivers and have the incorrect combination. One approach to solving the problem is not to use backplane mode for EIA-485. The elongated P1 and the inverted RXIN can easily be implemented in hardware and added to the EIA-485 circuitry. This implementation is called non-backplane mode EIA-485 and has the advantage that the software driver for coaxial cable can be used for EIA-485. Regardless of which implementation is used, the signaling for EIA-485 is different from dipulse signaling.

EIA-485 Signaling

As mentioned previously, a logic "1" is represented by an elongated P1 of 200 ns in width while a logic "0" is represented by an absence of a pulse. These definitions get a little confusing when using the terms "mark, logic 1, off" and "space, logic 0, on" as referenced in the EIA-485 specification. The best way of thinking of this is that inverted P1 is driving the bus. When P1 goes low, a SPACE condition occurs which is an ARCNET logic "1" while a return to MARK indicates an ARCNET logic "0." This would be strictly true if ARCNET was using NRZ (non-return to zero) encoding as used on serial ports. However, since an ARCNET logic "1" returns to the off state before completion of the bit time, the encoding is properly called RZ (RTZ or return to zero). The significance of this is that the baud rate (1 divided by the width of the symbol) is twice the data rate. Therefore, a 10 Mbps ARCNET data rate requires 20 Mbps transmission capability which is technically beyond the limit for the EIA-485 standard.

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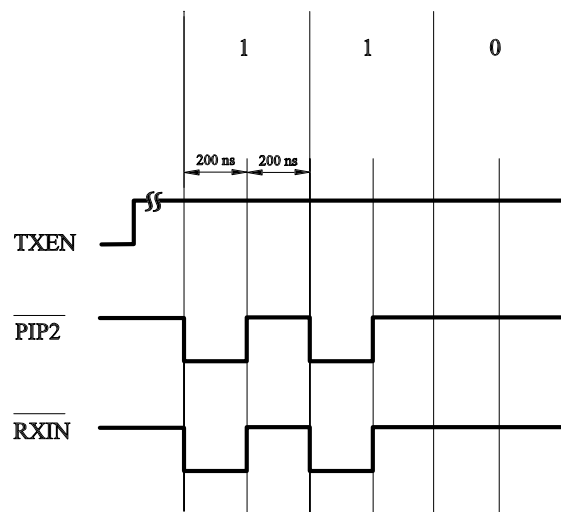
The EIA-485 Standard

The EIA-485 standard, authored in April 1983, is entitled "Standard for Electrical Characteristics of Generators and Receivers for Use in Balanced Digital Multipoint Systems."[4] The standard addresses issues such as the voltage, current and resistive proprieties of receivers and generators but it does not address protocols, signal timing, signal quality and pin assignments. Therefore, strict adherence to the EIA-485 standard does not guarantee that any two ARCNET nodes will communicate to one another. This standard is relatively short (22 pages) and is applicable to systems operating at data rates up to 10 Mbps which, at first glance, appears to suit the needs of ARCNET. Based upon the standard, there are numerous compatible transceivers available that operate over the specified $\pm$ 7 volt common mode range. These transceivers must be able to drive 32 unit loads and a total of 60 ohms of termination resistance which implies a nominal cable impedance of 120 ohms. A single two wire cable is bussed to all nodes but the type of cable is not specified nor is the overall length of the cable. However, the standard does provide guidance on those topics.

The two wires that attach to all the nodes requires that only one device have access to the network at any one time. The ARCNET data link layer protocol is half-duplex. Nodes can receive all messages, but no two nodes can transmit at the same time. There is no need to designate a master since any node can initiate a message once it receives the token. Therefore, incorporating the EIA-485 physical layer with ARCNET is quite feasible. There has been three styles of implementation: DC coupled, AC coupled and optically coupled EIA-485. There are design issues to implementing EIA-485 that must be addressed. These issues include termination, biasing, grounding and isolation.

TERMINATING THE BUS

The high speeds at which ARCNET operates require that the cable be terminated with a value equal to its characteristic impedance. Since any device on the bus can transmit, it is probable that a node within the middle of the bus will transmit requiring that termination be applied to both ends of the bus segment. National Semiconductor offers a highly in-depth discussion on termination in application note AN-807[5] and offers several alternatives. The most popular approach is DC termination although this results in higher power dissipation.

Resistive terminators typically have values of 100 to 120 ohms although twisted-pair cable impedances can be as low as 78 ohms. A value matching the cable impedance must be applied at some convenient location closest to the ends of the cable segment as possible. One possibility is to provide the resistor on a NIM with a jumper to disable this option if termination is not required. The problem with this approach is that each NIM will be configured differently since only two NIMs should have terminators. Care must be exercised to ensure that only the proper modules have termination invoked in order not to cause excessive bus loading. The other problem is that the value of the onboard termination may be incorrect for the cable used and, therefore, unusable wasting this option.

External termination ensures that the proper resistance value is used at the correct place assuming that the terminator can be attached to the connector on the NIM. If dual bussed RJ-11 connectors are used on each NIM, a RJ-11 style terminator could be plugged into the unused connector on the NIM attached to the end of the segment. All NIMs, other than end NIMs, would have both their connectors used with daisy-chain signal cable. If a four pin open style connector is used with bussed pins, the terminating resistor can similarly be applied to the two vacant pins on the connectors of the NIMs located at the ends of the bus segment.
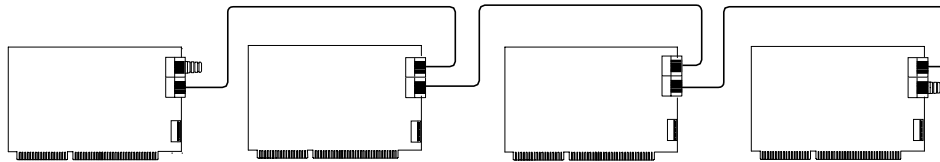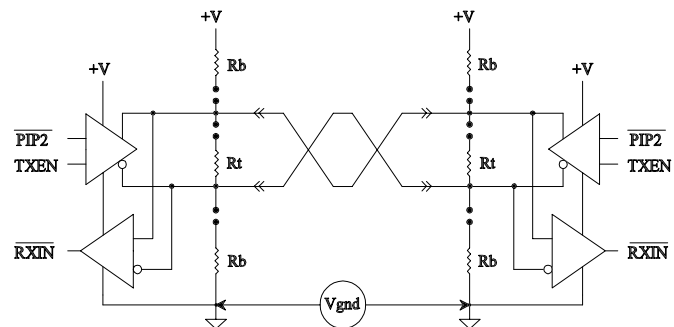

With dual bussed RJ-11 connectors on each NIM, RJ-11 style terminators can be inserted in vacant connectors on each end NIM of a bus segment.

INCORPORATING FAIL-SAFE BIAS

EIA-485 is a multipoint standard where individual devices transmit and receive data sharing a common two wire medium. The opportunities for collisions (two transmitters on at the same time) are immense and a method of medium access control (MAC) is required. ARCNET incorporates a token-passing scheme for medium access control which grants each node a limited time interval to conduct its business or pass the token. After the token is passed to another node, the bus becomes idle since it takes about 12.6 µs for the ARCNET controller chip to process the token passing command. During this time, the bus will "float" enabling noise to falsely trigger one of the bus receivers. This can occur because the receiver's output is undefined when the receiver's input voltage is less than 200 mv which could happen when the bus floats. To ensure that the bus assumes a defined state when all transmitters are off, fail-safe bias must be applied.

National Semiconductor's AN-847[6] application note fully discusses the need for fail-safe bias and recommends the proper biasing resistors needed to ensure that the bus differential voltage will not dip below 200 mv when idle. This note recommends a pull-up resistor attached to one signal line and a pull-down resistor attached to the other. In conjunction with an end-of-line terminator, a voltage divider is created which impresses a bias across the line that exceeds 200 mv. Therefore, the receivers are biased in the "mark" (off, logic 1) state. When a transmitter sends data, the line will revert to "space" (on, logic 0).
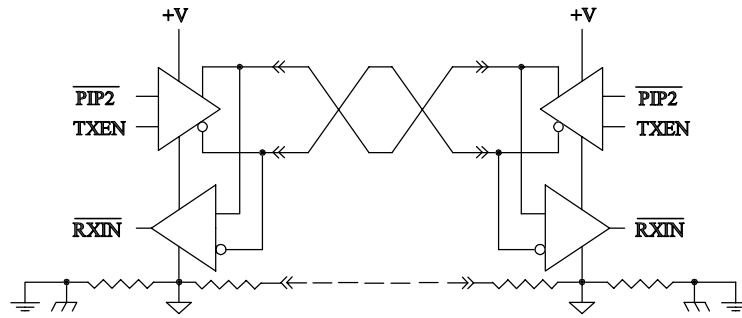
Bias can be applied to any point on the bus segment but it is not necessary to lump the bias at only one point. The bias can be distributed with each NIM providing a

Disconnects are provided for fail-safe bias and termination.

6

portion of the bias. The advantage of this approach is that there is no need to provide an external bias network and power supplies. The problem with this approach is that the amount of bias developed depends upon the number of NIMs on the bus. If too few NIMs are used, insufficient bias may result. Too much bias can result if too many NIMs are used causing excessive loading. If it is desired to supply lumped bias, a source for +5 volt power needs to be found which may be awkward to arrange. The other approach is to provide the complete bias requirement on each NIM while providing disconnecting jumpers on the NIM. In this way, only one NIM needs to be strapped for bias so record keeping must be good to ensure that the location of this NIM is known when a replacement is necessary.

GROUNDING

Is EIA-485 a two wire or a three wire system? It is most definitely a three wire system. The standard clearly states that generators and receivers require a return path between circuit grounds at each end of a connection. This return path could be an actual wire in the cable connecting each of the logic grounds together or earth can provide the return path by having each logic ground returned to earth. Using the latter approach, a single pair twisted cable can be used. If the third wire is to be used, the standard states that the connection between logic ground and the third wire contain some resistance to limit circulating currents when other ground connections are provided

If a third wire connection is used, resistors must be used to limit circulating ground current.

for safety. This resistor could be between logic ground and frame (frame is tied to earth) or it can be between the logic ground and third connection. The standard uses 100 ohms as an example for both situations.

There is much confusion and misunderstanding of the third wire requirement and difficulty in even finding a third wire. If the logic grounds of the transceivers are tied to earth and a third wire is used, there is almost a guarantee of a ground loop current which may or may not induce excessive noise that could disrupt data transmissions. The third wire will also be the path for fault currents which could be significant when the two ground potentials are different due to a significant electrical event. Still the third wire helps to ensure that the common mode requirements ($\pm$ 7 volts) of the transceivers are maintained. Excessive common mode voltage is the most common reason for transceiver failure.

Protection Circuitry

To protect EIA-485 transceivers from excessive common mode voltages, diode protection circuits are used which are referenced to earth or logic ground. Usually protection is provided from each data line to earth and it is necessary to protect against either a positive or negative

occurrence which doubles the protection circuitry. The more robust the protection, the more the capacitance which limits the data rate. It is quite possible that ARCNET will refuse to work at the desired data rate due to the increased capacitance. Some protection is afforded when the protection circuit consists of a bulky transient voltage suppressor in series with a diode. The capacitive divider created by the diode and suppressor in series yields a capacitance which is less than the diode itself thereby lessening the impact of protection on data rate. Of course, protection is possibly required at each node increasing the likelihood that either data rate or distance will be compromised by adding protection circuitry.
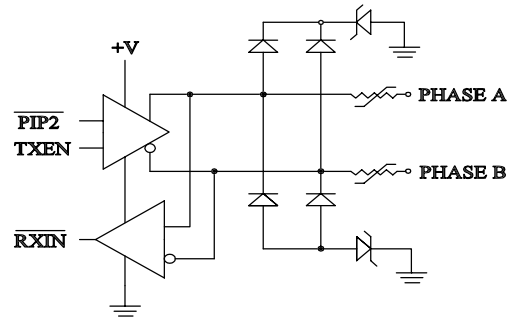

Protection circuitry is usually referenced to earth.

ISOLATION

The EIA-485 standard does not discuss optical isolation or transformer isolation as a solution to the grounding and protection needs of the transceivers; however, both isolation methods have been successfully used with ARCNET.
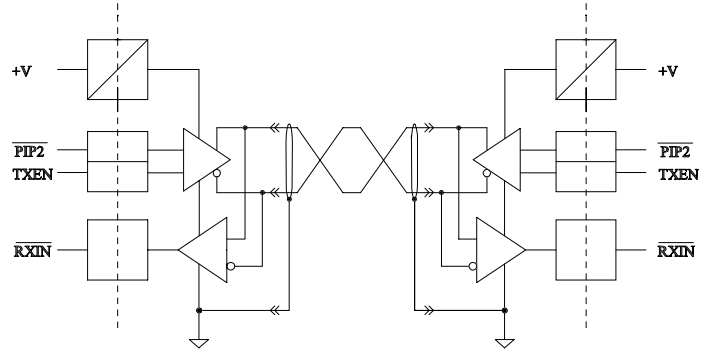
Transformer Isolation

The traditional hybrid transceiver incorporates transformer isolation which has proven to be very robust. Transformer isolated EIA-485 (AC Coupled EIA-485) offers several advantages to DC coupled EIA-485. Since each transceiver is isolated from one another because of a transformer, fail-safe biasing issues are much simplified. Each transceiver can now have fail-safe bias permanently applied on board. Termination issues are no different than DC coupled EIA-485. Terminating resistors can be applied at the ends of the bus segments. However, there are problems. The RZ encoding for DC coupled EIA-485 is not usable since a DC component exists which will eventually saturate the transformer. SMC defined a method for encoding that utilized a center-tapped transformer and a flip-flop.[7] On each successive P1 pulse, the line would be first pulsed high and then pulsed low thereby eliminating the DC component. Two EIA-485 receivers, biased the same, would each be connected to one side of the center-tapped transformer and would check for either phase of the pulse. The outputs of the receiver would be combined and fed to the ARCNET controller chip. This encoding scheme becomes polarity insensitive allowing wires at each node to be flipped without concern. The problems are lack of standardization on the circuit and the transformer and the inability of the design to operate over all data rates. Since a center-tapped transformer is used to detect the two phases, a 50% reduction in receiver voltage is experienced. Still the transformer coupled design provides low-cost isolation and eliminates the need for a third wire to interconnect nodes.

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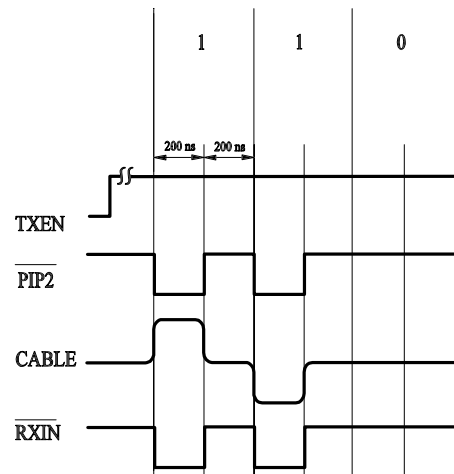
Optical Isolation

The problem with operating over the full range of data rates does not exist with optical isolation. Optically isolated transceivers can be treated like DC coupled transceivers. The termination and fail-safe bias issues are the same so what is isolated? What is isolated is P1P2, TXEN and RXIN. Therefore, three opto-isolators are required. The two used for data should be high speed while the transceiver enable isolator can be slower. A DC-DC converter needs to be provided and its breakdown voltage will probably be the limiting factor in terms of isolation. The optically isolated transceiver is the most expensive of the transceivers and it does not guarantee that the EIA-485 transceivers, which are connected directly to the cable, will survive abuse from severe electrical transients. Chances are, however, that the damage will stop at the isolators and not involve the PC or controller using the NIM. Optically-isolated EIA-485 forces a third wire connection since the transceivers must have a return path. However, this time there is no ground loop since logic ground of the transceivers is not connected to earth. Where do we get the third wire? Many times the shield is used and not everyone is in agreement on the wisdom of this approach. Since such a small current is going to flow, it seems a reasonable approach.

*Sometimes the shield is used as the third wire.*

CONNECTORS

With coaxial and fiber optic cabling, specifying connectors is easy since there is common practice in the industry. However, with twisted-pair cabling there are many options. Since the EIA-485 standard does not address connectors, the ATA needs to do so. From practice there seems to be three popular approaches. The traditional approach is to use a four pin, six position RJ-11 or eight position RJ-45. The ANSI/ATA 878.1 standard specifies these connectors for use with traditional twisted-pair bus wiring; however, only two pins are defined for signals and there is no provision for a third wire reference. One or two of the spare pins needs to be defined as the third wire reference with an appropriate resistor to logic ground. An investigation needs to be made in order to determine if a shielded RJ-11 connector is available to address the issue of EMC compatibility since shielded twisted-pair cable has become more popular.

Another approach to connectorization is to use removable open style screw connectors. Currently, four position connectors are used with redundant signal connections. Again there is no provision for a three wire reference connection implying that an earth connection is made. If this style connector is to be used, it should be expanded to a five position connector so that a third wire reference can be provided.

Another popular connector is the DB9 connector which is used with the PROFIBUS standard.[8] With nine pins, it is easy to accommodate signals, logic ground, shield connection and power pins. DB9 housings are also available with metal shrouds for better EMC performance and one housing has built-in termination provisions. This is certainly a connector to be investigated.

Modular Connector Pin Assignments	
6-Contacts	
Pin	Usage
1	Not Available
2	Not Used
3	Line- (Phase B)
4	Line+ (Phase A)
5	Not Used
6	Not Available
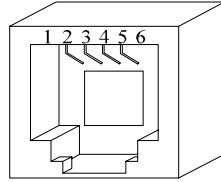
Modular jacks offer convenient locking connections.

Screw Terminal Connector Pin Assignments	
Pin	Usage
1	Line+ (Phase A)
2	Line- (Phase B)
3	Line+ (Phase A)
4	Line- (Phase B)
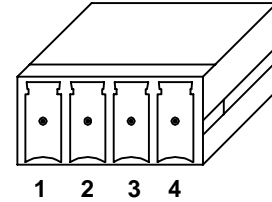
Bussed connections on open style connectors allow for daisy chaining.

NODE COUNT AND CABLE DISTANCE

SMC developed recommendations for the number of nodes that can be connected to a single segment and over what distance could be achieved.[9] Interestingly the number of nodes do not total 32 as the EIA-485 indicates. These tests were done at 2.5 Mbps and at 5.0 Mbps. As of yet, no silicon exists for 10 Mbps ARCNET, therefore, no tests have been conducted. Companies have elected to provide there own limitations on node count and segment distance based upon experience. What needs to be done is a complete characterization of the ARCNET network by first specifying the connectors to be used and the cable type. This would have to be done for all data rates which could be a challenge. Only in this way will we develop consensus on ARCNET's limitation with EIA-485. The following table incorporates SMC's recommendations.[10]

Permissible Cable Lengths and Nodes Per Segment						2.5 Mbps
Transceiver Description	Cable	Connectors	Cable Length Min	Max	Max Nodes Bus Segment	Notes
coaxial star	RG-62/u	BNC	0	2000ft/610m	N/A	5.5 dB/1000ft max
coaxial star	RG-59/u	BNC	0	1500ft/457m	N/A	7.0 dB/1000ft max
coaxial bus	RG-62/u	BNC	6ft/2m[1]	1000ft/305m	8	5.5 dB/1000ft max
fiber optic (850 nm)	50/125	SMA or ST	0	3000ft/915m	N/A	4.3 dB/km max
fiber optic (850 nm)	62.5/125	SMA or ST	0	6000ft/1825m	N/A	4.3 dB/km max
fiber optic (850 nm)	100/140	SMA or ST	0	9000ft/2740m	N/A	4.0 dB/km max
fiber optic (1300 nm)	single mode	ST	0	46000ft/14000m	N/A	0.5 dB/km max
fiber optic (1300 nm)	50/125	ST	0	32800ft/10000m	N/A	1.5 dB/km max
fiber optic (1300 nm)	62.5/125	ST	0	35000ft/10670m	N/A	1.5 dB/km max
twisted-pair star	IBM type 3	RJ-11	0	330ft/100m	N/A	uses internal BALUNs
twisted-pair bus	IBM type 3	RJ-11	6ft/2m[1]	400ft/122m	8	
DC coupled EIA-485	IBM type 3	RJ-11 or screw	0	900ft/274m	17	DC coupled
AC coupled EIA-485	IBM type 3	RJ-11 or screw	0	700ft/213m	13	transformer isolated
Opto coupled EIA-485	IBM type 3	RJ-11 or screw	0	900ft/274m	17	optically isolated

[1] *This represents the minimum distance between any two nodes or between a node and a hub.*

HUBS AND REPEATERS

EIA-485 segments can be extended using active hubs or repeaters; however, care needs to be exercised in the selection of repeaters. Since only two wires are used, the direction of signal flow through the repeater must change dynamically. Usually a direction control line is provided to the repeater to control flow or the repeater automatically senses traffic and adjusts accordingly.[11] Do not assume any low-cost EIA-485 repeater will work at ARCNET's high speeds. It is recommended that repeaters be constructed with the same timing electronics found in any ARCNET active hub. In this way, signals are regenerated without accumulated jitter and squelching of signals is accomplished with an understanding of the ARCNET data link layer protocol. The necessary hub unlatch time is known from the protocol, but it varies as a function of data rate. Therefore, the hub or repeater must be set for the proper data rate. Another value to using hubs is that all ARCNET cabling options can be mixed in the hub if the proper transceiver is used on each hub port thereby providing physical layer connectivity between options.

SUMMARY

The ANSI/ATA 878.1 standard bus has not had a revision since 1991. The practice of using EIA-485 transceivers should be recognized and appended to the standard through the ANSI standards development process. This process requires industry comments and users need to share their experience with implementing the EIA-485 standard. The recommendations from users will become a proposed amendment to the 878.1 standard. Once approved by the canvass process, ARCNET will gain additional cabling options ensuring its position as one of the most flexible networking technologies for cabling.

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