IMPLEMENTATION ISSUES FOR AN IEEE 802.4
TOKEN BUS LAN CARRIERBAND PHYSICAL LAYER

Tom Balph
Motorola Semiconductor Products
Phoenix, AZ

Abstract

The IEEE 802.4 Standard for a token-passing bus LAN provides for a single media access protocol for use with multiple physical layers. The single-channel phase-coherent FSK or "carrierband" standard is the best choice for a cost-effective, easily configured, high speed physical layer suitable for industrial applications.

This paper first briefly provides background on the IEEE 802.4 physical layers, and then expands into an overview of the carrierband physical layer. The overview describes the carrierband modulation and introduces the key elements of the associated cable plant including cables, taps, and signal budget. The remainder of the paper deals with implementation issues including associated hardware, connectors, cables, taps, installation and maintenance, and redundancy.

Background

The IEEE 802.4 specification was developed using a very intelligent approach to the configuration of the Medium Access Control (MAC) Sublayer and its various Physical Layers (refer to Figure 1). A standardized interface called the "Exposed DTE-DCE Interface" is defined within the specification that allows a single MAC function (and thus a common silicon implementation) to be used with the several different Physical Layers. These layers include: 1) 1 Mb/s, 5 Mb/s, and 10 Mb/s broadband; 2) 5 Mb/s and 10 Mb/s phase-coherent FSK; 3) 1 Mb/s phase-continuous FSK; and 4) 5 Mb/s, 10 Mb/s, and 20 Mb/s fiber optic variations. (Note that MAP only includes the 10 Mb/s broadband and 5 Mb/s phase-coherent FSK standards at the time of this writing). The standardized DTE-DCE interface allows the user to employ the physical layer of his or her choice.

The phase-coherent FSK or "carrierband" physical layer has found favor as the lowest cost/easiest-to-implement means for plant floor device connectivity. Although lacking the long distance capability and much higher effective throughput potential of broadband (the multi-channel nature of broadband allows multiple LANs to reside on a single cable) and also not meeting the maximum noise rejection capability of fiber optic, carrierband offers a very robust signalling scheme, ease of installation and service, good data rate, and high reliability. The phase-coherent standard is best suited to localized environments of typically up to 500 meters of cable and 20 to 40 stations, although longer distances and more stations can be used.

Although MAP has been a driving force for IEEE 802.4 Token Bus, many companies in factory automation and/or process control are using IEEE 802.4 with carrierband starting at the factory "cell" control level where real-time response is a key issue and full MAP compatibility is not required. These semi-proprietary, base level networks can be IEEE 802.4 compatible without being totally MAP compatible, that is, the communications services running on the network may not meet the MAP standard. This concept has the advantage of minimizing risk and cost, while maintaining an easy migration path to MAP because MAP compatibility becomes a matter of software issues as opposed to hardware changes.

Since the definition of the IEEE 802.4 specification in general and the carrierband version of the physical layer specifically, considerable progress has been made in components suited to carrierband networks and in understanding, as well as solving, implementation issues. The rest of this paper discusses these components/issues, beginning with a capsule network overview.
Carrierband (Single-Channel) Phase-Coherent FSK
Physical Layer Overview

As its name implies, the token bus carrierband modulation signal is the only information on the cable, and frequency shift keying (FSK) is a modulation technique where the digital information is impressed on a carrier by shifting the frequency of the transmitted signal between two frequencies. For phase-coherent FSK, the signalling frequencies are one or two times the data rate with transitions between the two frequencies made at zero crossings of the waveform.

Figure 2 illustrates the phase-coherent signalling and associated data symbols. Note that data symbols include SILENCE (no signal) and NON-DATA pairs (used to delimit data frame boundaries) as well as the expected ONES and ZEROS. The data symbols are defined in terms of half and full cycles of the signalling frequencies. For the more common 5 Mb/s data rate, the lower signal frequency is 5 MHz and the upper signal frequency is 10 MHz. This signalling technique has advantages of easy encoding/decoding and a 50% duty cycle for ac coupling.

The defined data symbols are also called MAC symbols. The MAC Sublayer (typically implemented with the Motorola MC68824 Token Bus Controller) sends these symbols to the physical layer which modulates the carrier in response. In the alternate direction, the physical layer also receives the modulated signal from the cable and reports the associated MAC symbols to the controller.

The medium or cable plant (sometimes referred to as Layer 0) includes the trunk cable, taps, and drop cables. Figure 3 shows how the elements combine to form a cable system. The medium was defined by the IEEE 802.4 to provide a robust signal environment while facilitating ease of installation and maintenance.

The trunk and drop cables are typically RG-11 coax with a characteristic impedance of 75Ω. The topology is normally a long unbranched trunk with drop cables (not to exceed 50 meters in length) routed to station sites. Drop cables are connected to the trunk via non-directional, isolating, impedance matching taps. The taps are passive devices that transfer to the drop cable a fixed small fraction of the signal energy travelling on the trunk cable. Also, a signal originating from a station on the drop cable is attenuated by the tap and propagates out in either direction on the trunk cable. The taps are specified at a standard 20 ± 0.5 dB drop loss (in either direction) between the trunk and drop cables. There is also an insertion loss through the tap (typically 0.2 - 0.5 dB) which is due primarily to the power division (the tap itself is essentially a transformer or low loss device). In addition to single port taps, dual and quad port configurations are available to minimize insertion losses.

The passive, isolating taps allows the use of long drop cables without letting an open or shorted drop cable bring down the entire network by corrupting the trunk cable. The cable connection is also low-cost in comparison to an Ethernet-type tap because no active
Figure 3. An IEEE 802.4 carrierband cable plant is composed of a trunk cable, taps, and drop cables. Single, dual, and quad port taps are commonly used.

circuitry or power supplies are required. The disadvantage to the use of these taps is that a large portion of the signal power budget is lost in the taps.

The total signal budget determines the allowable number of stations and total trunk cable length. Signal strength is measured in units of dBmV which is a comparison to a 1 mVrms signal into a 75Ω impedance (0.0 dBmV), that is:
\[ \text{dBmV} = 20 \log_{10} \left( \frac{\text{rms voltage of signal}}{1 \text{ mVrms}} \right) \]

The transmit signal level of a station must be between +63 and +66 dBmV, and the minimum receiver sensitivity is +10 dBmV. Therefore, the total loss in the cable plant should not exceed 53 dB (the worst case difference between minimum transmit and receive signal levels).

The 53 dB signal budget is allotted to drop losses (20dB/tap), insertion losses (about 0.2 - 0.5 dB/tap), and cable attenuation loss. Figure 4 provides a convenient table (enhanced cable for carrierband) that can be used to estimate cable length versus number of taps in a 5 Mb/s system. To further illustrate, consider a 20 dual-port tap system (0.3 dB insertion loss/tap) where the lumped tap losses are:

- Drop loss in first tap: 20.0 dB
- Insertion loss of 18 taps: 5.4 dB
- Drop loss of last tap: +20.0 dB
- Total lumped losses: 45.4 dB

This leaves a 53 - 45.4 = 7.6 dB budget for cable.

With the enhanced RG-11/U (Belden 1224A) cable having a loss of about 1.23 dB/100 meter (@ 10 MHz for a 5 Mb/s system), the total cable length including drop cables would be 618 meters. Thus, this network could handle 40 stations at a distance of about 600 meters.

If more stations are desired, the quad-port taps allow a larger number of stations with minimum additional tap loss. If the insertion loss per tap were still 0.3 dB, the same network could increase to 80 stations with no decrease in cable length.

Figure 4. Carrierband cable length versus the number of taps for 5 Mb/s.
Although signal loss due to attenuation is the primary limiting factor, secondary limitations due to cable propagation group delay (PGD) or cable tilt are possible. The table of Figure 4 also shows the Belden 1224A RG-11/U cable limitations (as determined by standards set by the IEEE 802.4). With this enhanced cable, attenuation is the limiting factor, and if longer distances are desired, better coax cable can extend the attenuation limit.

With the above overview as a reference point, implementation issues concerning the modems, cables, taps and other factors can be discussed.

**Carrierband Modem Hardware**

Because the IEEE 802.4 carrierband spec developed from a concept and testbed results (as opposed to an existing standard and/or proprietary LAN), there was no existing silicon solution to build modems. This meant that early designs were done with standard logic and analog devices and, as a result, were physically large and not very cost-effective. Dedicated LSI such as the Motorola MC68194 Carrierband Modem is now available both as a simple component and as the basis of a fully integrated, tested module that solves the modem cost/space problem.

Figure 5 shows a simplified block diagram of the carrierband modem function based on the MC68194 and a photocopy of an actual surface mount, tested module that is a complete station connection from the cable connector to the controller interface. It is interesting to note that only a few square inches is now required for the modem function and cost is competitive with other common LAN solutions.

The choice of using silicon to design one's own solution versus using a standard module is the classic make/buy decision. Many factors including volume, form factor, test capability, special needs, and costs will drive this decision. The important issue is that cost-effective modem solutions are readily available.

**Cable Plant Issue**

In the industrial environment, the cable plant (or cable system) is probably the area most vulnerable to failure. The possibilities range from outright cable failures (the forklift crushed the drop cable) to longer term problems such as signal degradation due to corrosion causing poor connections. The prevention for these types of problems is varied and is also driven by cost and how great the need for un-interrupted communications service. As an example, process control applications often employ redundant cable plants and some companies even extend the redundancy through the modem and controllers. In the following paragraphs, factors affecting the cable plant are described.

**Connectors**

The venerable type “F” connector was selected for “low-cost” connections between cables and taps and/or stations. When the IEEE 802.4 was written and until recently, no recognized standards for F connectors existed and as a result, the forms and quality of F connectors varies greatly. Industrial grade F connectors should be used for carrierband.

For the male F connector (usually connected to the cable, stations and taps use female connectors), the most important feature is a captive center conductor pin. In-expensive male F connectors use the cable center conductor as the connector center conductor. This can lead to damage of the female center conductor and poor contact due to oxidation of the cable center conductor. A second feature is that the male connector make good contact with cable shield(s) around the entire circumference of the cable.

For mating parts of the connectors, tin, nickel/tin, nickel/tin-compatible or gold plating should be used. Tin, nickel/tin, and/or nickel/tin-compatible is adequate for most environments. Gold is normally only used on the center conductor when present. The plating types should not be mixed, i.e., gold should contact only gold and nickel/tin type should contact only nickel/tin type.

In response to industrial user needs, the Electronic Industries Association (EIA) has developed the EIA P550 standard for industrial FD connectors. The standard sets important characteristics of the FD connector and provides a reference for users. It should be noted, however, compliance with the full standard makes for a very expensive connector which may not be required. Seeking advice from the connector manufacturer is recommended.

**Cable**

Flexible coaxial cable such as RG-11, RG-6, and RG-59 is most commonly used for carrierband. The larger diameter RG-11 is used for the trunk cable, and the thinner RG-6 and RG-59 are used for drop cables. Some cable companies are now supplying cable specifically suited to IEEE 802.4 LAN applications with multilayer shield (foil/braid/foil/braid) and optimized electrical characteristics. These special cables are
Figure 5. A carrierband modem can be implemented with the MC68194 chip. Totally assembled and tested modules are also available.
designed to operate in the low megahertz frequency range and have low resistance conductors and shields for low attenuation and adequate shielding.

As previously mentioned, attenuation is the main factor limiting cable length. However, two characteristics that occur as part of attenuation are tilt and group delay. Tilt is the difference in signal amplitude that occurs because higher frequency signals get attenuated more than lower frequency signals. Group delay is the difference in time delay that occurs because higher frequency signals travel faster than lower frequencies. Both of these conditions (in excess) can translate to signal jitter (variation in the zero-crossings of the ac signal) which lowers the reliability of the network. As it turns out however, the simple signal loss due to attenuation (calculated at the upper frequency of the phase-coherent modulation) is usually the overall upper limit on cable length.

If any of these cable characteristics is too limiting, solutions exist in the form of better cable and/or repeaters. Semi-rigid or rigid cable has lower losses and can go longer distances. If distances or station loading is still too great, a segmented architecture is possible with use of repeaters.

The specialty cables available for LAN also come in versions armored with corrugated aluminum and/or in versions suitable for plenum applications where nonflammable materials are required. The investment in good quality cable goes along with using industrial grade connectors to maintain system integrity.

Taps

Early taps used with carrierband were spin-offs from the CATV industry. Much work has been done since then to modify these taps, and specialized taps suitable to the IEEE 802.4 are available. The non-directional, isolating taps provide 20 ± 0.5 dB attenuation between any tap port and the trunk cable. Through loss or insertion loss should be about 0.2 dB or less per port. Taps are available in single, dual, and quad port varieties.

Some early multi-port taps did not provide isolation between drops which could cause problems. A failure on one drop cable would affect the station on a drop cable attached to the same tap. Newer taps will provide 20 dB or more isolation between ports on a given tap.

These newer specialized taps are also hardened for the industrial world. Ruggedized bodies encapsulated in plastic with grounding connections are available. Gold contacts and surge suppression are options.

Installation and Maintenance

It is beyond the scope of this paper to go into great detail on how to install and maintain a carrierband network, however, some key points can be made. Investment in quality cable, taps, and connectors at the beginning is money well spent considering that most common long term problems are due to gradual degradation of the network. In the short term, providing for planning, quality installation and verification of a new cable plant pays dividends.

If one considers that lost production time is incredibly expensive in terms of manpower, lost product, and capital equipment costs, the initial extra expense to properly install a cable plant is easily justified. Before actual work is started, a good plan should be designed considering the physical size, tap location, number of nodes, and future expansion needs of the cable plant. Qualified people should install the network to minimize electrical problems (loss of signal or noise problems) that can occur as the result of mechanical faults (poor cable splices, bad connections, or stressed cables where characteristic impedance or ground integrity is lost). Finally, on-site testing should be done to verify the electrical performance and integrity of the cable plant.

For the longer term, an ongoing program of test and maintenance can prevent the gradual decline of LAN performance. As mentioned earlier, problems with corrosion and other gradual failures are more common than catastrophic failures.

Greater Reliability Equates to Redundancy

For many applications, a well designed and maintained single cable plant will provide acceptable reliability. Other areas such as continuous process control will require a higher level of LAN availability, and the common solution is some form of redundancy. Figure 6 illustrates how redundancy can vary from the most simple case of a second cable plant to the most complex of complete duplication of the network function including the MAC.

For the case of Figure 6A, the system management services at each station will monitor the integrity of the data flow on a given cable. If that cable shows any form of degradation of services, the electronics can switch to the second cable. Under
normal conditions, both cables carry identical message traffic. When one cable experiences problems, the second cable can provide service. Because the cable plant will normally be the weakest link in the network, this approach is an excellent first step and is the least expensive to implement.

The next case of Figure 6B adds redundancy at the physical modem level. Duplicate modems are provided such that each cable plant is supported by its own modem at each station. The message flow at each station to/from the modems is controlled by an additional logic block that performs a line selection and control function.

The final case of Figure 6C extends the redundancy clear back to the controller. Two complete LANs provide full parallel communication services. These last two cases are obviously the most complex and expensive to implement, however, some applications can justify the cost and design problems associated with these approaches.

Conclusion

The IEEE 802.4 carrierband spec originated from some early testbed experiments and the collective minds and experience of the defining committee. The continuing work done by early implementer/users of carrierband has not only worked out many of the problem areas, but it has also shown the carrierband environment to be a robust, practical industrial LAN. The basic tools and components are now available to install and use carrierband for cost-effective, practical LAN solutions.

References