IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re *Inter Partes* Review of:)
U.S. Patent No. 7,489,786)
Issued: February 10, 2009)
Application No.: 10/316,961)
Filing Date: December 11, 2002)

For: **Audio Device Integration System**

FILED VIA E2E

DECLARATION OF INGRID HSIEH-YEE, PH.D, UNDER 37 C.F.R. § 1.68

I, Ingrid Hsieh-Yee, Ph.D., do hereby declare as follows:

1. I have been retained as an independent expert witness on behalf of JAGUAR LLC ("Jaguar") for *Inter Partes* Review ("IPR") of U.S. Patent No. 7,489,786.

2. I am being compensated for my work in this matter at my accustomed hourly rate. I am also being reimbursed for reasonable and customary expenses associated with my work and testimony in this investigation. My compensation is not contingent on the results of my study, the substance of my opinions, or the outcome of this matter.

3. In the preparation of this declaration, I have reviewed the exhibits referenced below, each of these is a type of material that experts in my field would reasonably rely upon when forming their opinions:

(1) Mufid, A.M. (2000). Future Automotive Multimedia Subsystem Interconnect Technologies ("Mufid"), in *Automotive Electronics : Delivering Technology's Promise, SAE Conference Proceedings*, no. 360 (2000), pp. 167-182, obtained from Library of Congress on May 11, 2018, **Exhibit-1**;

(2) Bibliographic record for *Automotive Electronics* available at the online catalog of Library of Congress at https://lccn.loc.gov/2001269738, accessed May 8, 2018, **Exhibit-2**;

(3) MARC record for *Automotive Electronics* available at the online catalog of Library of Congress at https://catalog.loc.gov/vwebv/staffView?searchId=9511&recPointer=0&recCount=25&searchType=0&bibId=12452747, accessed May 8, 2018, **Exhibit-3;**

(4) Mufid, A.M. (2000). Future Automotive Multimedia Subsystem Interconnect Technologies ("Mufid"), in *Automotive Electronics : Delivering Technology's Promise, SAE Conference Proceedings*, no. 360 (2000), pp. 167-182, obtained from the library of the Massachusetts Institute of Technology through WTS (Wisconsin TechSearch) on May 22, 2018, **Exhibit-4**;

(5) Bibliographic record for *Automotive Electronics* available at the online catalog of the Massachusetts Institute of Technology Libraries at http://library.mit.edu/item/000959917, accessed May 22, 2018, **Exhibit-5**;

(6) MARC record for *Automotive Electronics* available at the online catalog of the Massachusetts Institute of Technology Libraries at http://library.mit.edu/F/37UUX4LQB1MHNPQFHSLA7TP5S212

MH7YAKU66UGES4DCSECHG6-01482?func=full-set-set&set_number=018233&set_entry=000001&format=001, accessed on May 22, 2018, **Exhibit-6**;

(7) Mufid, A.M. (2000). Future Automotive Multimedia Subsystem Interconnect Technologies ("Mufid"), in *Automotive Electronics : Delivering Technology's Promise, SAE Conference Proceedings*, no. 360 (2000), pp. 167-182, obtained from the library of the Pennsylvania State University through WTS on May 22, 2018, **Exhibit-7**;

(8) Bibliographic record for *Automotive Electronics* available at the online catalog of the Pennsylvania State University Libraries at https://cat.libraries.psu.edu/ from a title search on May 22, 2018, **Exhibit-8**;

(9) MARC record for *Automotive Electronics* available at the online catalog of the Pennsylvania State University Libraries at https://cat.libraries.psu.edu/ from a title search and a display of detailed information in MARC on May 22, 2018, **Exhibit-9**.

4. In forming the opinions expressed within this declaration, I have considered:

(1) The documents listed above;

(2) The reference materials cited herein; and

(3) My own academic background and professional experiences, as described below.

5. My complete qualifications and professional experience are described in my curriculum vitae, a copy of which is provided as **Appendix A**. The following is a brief summary of my relevant qualifications and professional experience.

6. I am currently a Professor in the Department of Library and Information Science at the Catholic University of America. I have experience working in an academic library, a medical library, and a legislative library and have been a professor for more than 25 years. I hold a Ph.D. in Library and Information Studies from the University of Wisconsin-Madison and a Masters in Library and Information Studies from the University of Wisconsin-Madison.

7. I am an expert on library cataloging and classification and have published two books on this subject, *Organizing Audiovisual and Electronic Resources for Access*: *A Cataloging Guide* (2000, 2006). I teach a variety of courses, including Cataloging and Classification, Advanced Cataloging and

Classification, Organization of Internet Resources, Organization of Information, Digital Content Creation and Management, Internet Searches and Web Design, Information Literacy Instruction, and Advanced Information Retrieval and Analysis Strategies. My research interests cover cataloging and classification, information organization, metadata, information retrieval, information architecture, digital collections, scholarly communication, user interaction with information systems, and others.

8. I am fully familiar with a library cataloging encoding standard known as the "Machine-Readable Cataloging" standard, also known as "MARC," which became the national standard for sharing bibliographic data in the United States by 1971 and the international standard by 1973. MARC is the primary communications protocol for the transfer and storage of bibliographic metadata in libraries. Experts in my field would reasonably rely upon MARC records when forming their opinions.

9. A MARC record comprises of several fields, each of which contains specific data about the work. Each field is identified by a standardized, unique, three-digit code corresponding to the type of data that follows. **Appendix B** is a true and correct copy of Parts 7 to 10 of "Understanding MARC Bibliographic" (http://www.loc.gov/marc/umb/)

from the Library of Congress that explains commonly used MARC fields. For example, the personal author of the work is recorded in Field 100, the title is recorded in Field 245, publisher information is recorded in Field 260, the physical volume and characteristics of a publication are recorded in Field 300, and topical subjects are recorded in the 650 fields.

10. The Online Computer Library Center (OCLC) is the largest bibliographic network of the world, with more than 380 million records and more than 16,964 member institutions (many of which are libraries of some type) from 122 countries. According to the "Third Article, Amended Articles of Incorporation of OCLC Online Computer Library Center, Inc.," OCLC was created "to establish, maintain and operate a computerized library network and to promote the evolution of library use, of libraries themselves, and of librarianship, and to provide processes and products for the benefit of library users and libraries, including such objectives as increasing availability of library resources to individual library patrons and reducing the rate of rise of library per-unit costs, all for the fundamental public purpose of furthering ease of access to and use of the ever-expanding body of worldwide scientific, literary and educational knowledge and information." The Third Article, Amended Articles of Incorporation of OCLC Online Computer Library Center, Inc. was last revised on November

30, 2016 and is available at https://www.oclc.org/content/dam/oclc/membership/articles-of-incorporation.pdf (presented as **Appendix C**).

11. OCLC members can contribute original cataloging records in MARC to the system or derive cataloging records from existing records, an activity referred to as "copy cataloging." When an OCLC participating institution acquires a work, it can create an original MARC record for this work in OCLC's Connexion system (a system for catalogers to create and share MARC records), and the system will automatically generate a code for the date of record creation in the *yymmdd* format, and the creating library's OCLC symbol is recorded in subfield ǂa of the 040 field. Once the MARC record is in Connexion, it becomes available (*i.e.*, copy cataloging) to other OCLC members for adoption to their local online catalogs.

12. OCLC uses a master record system in which the creation date of an original record (*i.e.*, the master record) is never changed in the OCLC Connexion cataloging system unless the master record is replaced by another record. When a library uses a master record to create a copy cataloging record, changes made to the master record will result in a copy cataloging record, which is saved in the copy cataloging agency's account and exported into the local cataloging system and displayed in that library's online catalog, but the master record remains unchanged in the OCLC Connexion cataloging system. In most library catalogs, copy cataloging records exported from OCLC Connexion retain the creation date of the original record in Field 008, and libraries use other internal systems to keep track of the time when a copy cataloging record is added to the local cataloging system. The practice varies. Some libraries use local note fields to document their copy cataloging activities, while others use holdings records to document the time when a record is added to a local system. The catalog of Library of Congress uses a slightly different approach in that the system uses Field 008 to record the time a record, original or copy cataloging, is added to the system, and uses Field 955 to document cataloging and processing activities associated with a publication.

13. After a MARC record is created in Connexion, it also becomes searchable and viewable on WorldCat, which is a web portal to more than 10,000 libraries worldwide. The record in WorldCat, however, is not presented in MARC fields. Instead, the data elements are labeled to help users interpret the record.

14. WorldCat (http://www.worldcat.org) is "the world's largest network of library content and services" and its features are summarized in "What is WorldCat" (http://www.worldcat.org/whatis/default.jsp). Through WorldCat users can search for information in their local libraries and libraries around the world. WorldCat allows users to search for books, CDs, videos, and many new types of digital content, such as audiobooks, in many languages. Users can also retrieve research materials and article citations with links to their full text. After an item is retrieved, WorldCat helps users identify a library nearby that holds the item or all the libraries that hold the item. WorldCat is an efficient way to explore the content held by more than 10,000 libraries around the world.

15. Library online catalogs are based on MARC records that represent their collections in order to help the public understand what materials are publicly accessible in those libraries. Most libraries with online catalogs have made their catalogs freely available on the Web. These online catalogs offer user-friendly search interfaces. Strong user interest in keyword searches and the popularity of Google have led to the "googlization" of library search systems. As a result, many library catalogs now provide a single search box for users to conduct keyword searches, with additional support for searches by author, title, subject terms, and other data elements such as ISBN (International Standard Book Number). Library catalogs these days also offer features for users to narrow their search results by language, year, format, and other elements. Many libraries display MARC records on their online catalogs with labels for the data elements to help the public interpret MARC records. Many libraries also offer the option to display MARC records in MARC fields.

16. I am personally familiar with many online catalogs, databases, and search engines. In preparing for this declaration I used authoritative information systems such as WorldCat, the online catalog of the Library of Congress, the online catalog of the Massachusetts Institute of Technology (MIT) Libraries and the online catalog of the Pennsylvania State University (Penn State) Libraries to search for records. These records are identified and discussed in this declaration. Experts in the field would reasonably rely on the data described herein to form their opinions.

Exhibit-1 (Library of Congress)

17. **Exhibit-1** is a true and correct copy of Future Automotive Multimedia Subsystem Interconnect Technologies (“Mufid”), in *Automotive Electronics : Delivering Technology’s Promise, SAE Conference Proceedings*, no. 360 (2000), pp. 167-182, which I obtained from Library of Congress on May 11, 2018. When I was originally asked to prepare this declaration, I searched WorldCat (http://www.worldcat.org) for this article by its title "Future Automotive Multimedia Subsystem Interconnect Technologies" and the search results informed me that Library of Congress holds the physical volume of the conference proceedings that contains this article. I then searched the online catalog of the Library of Congress at https://catalog.loc.gov for "automotive electronics delivering technology's promise" and the search results confirmed that Library of Congress holds this publication. Library of Congress records inform me the publication is assigned "TL272.5 .I577 2000" as its call number and the library has one copy that is available for request at the "Jefferson or Adams Building Reading Rooms." I requested access to this copy and visited Library of Congress on May 11, 2018 to use it. While the physical volume was in my possession at the Jefferson Reading Room I personally scanned the cover, title page, copyright page, Conference Committee page, introduction, table of contents, and the "Mufid" article (presented as **Exhibit-1**).

18. The cover of **Exhibit-1** presents "Convergence 2000 Proceedings," "Automotive electronics delivering technology's promise," and "International Congress on Transportation Electronics" together with the date and place of the conference. The title page presents "AUTOMOTIVE ELECTRONICS Delivering Technology's Promise" as the title with a subtitle "proceedings of the 2000 International Congress on Transportation Electronics" and a number "P-360." The title page also presents the Society of Automotive Engineers, Inc. in Warrendale, PA as the publisher and lists "October 2000" as the publication date. The copyright page shows a written call number for this volume, "TL272.5 .I577 2000," an ISBN (International Standard Book Number) of "0-7680-0667-8" and an LC control number of "2001 269738." The Conference Committee page shows a date stamp of "Library of Congress December 11 2000 Copyright Office." The table of contents shows on page 8 of **Exhibit-1** "2000-01-C028 Future Automotive Multimedia Subsystem Interconnect Technologies" by "Akram M. Mufid, Visteon Automotive Systems" that appears from pages 167 to 182. Page 14 of **Exhibit-1** shows the document number "2000-01-C028," the article title, and the company "Visteon Automotive Systems" but not the name of Akram M. Mufid.

Exhibit-2 (Library of Congress)

19. **Exhibit-2** is a true and correct copy of the Bibliographic record for *Automotive Electronics : Delivering Technology's Promise, SAE Conference Proceedings*, no. 360 (2000), which contains the Mufid article, Future Automotive Multimedia Subsystem Interconnect Technologies (pp.

167-182). I personally identified and located this record on May 8, 2018, which experts in my field would reasonably rely upon when forming their opinion. **Exhibit-2** informs me Library of Congress holds the Convergence 2000 conference proceedings, which has a call number of "TL272.5 .I577 2000." Copy 1 is held at one of the reading rooms, while Copy 2 is stored offsite at Fort Meade, and users can request access to these copies at the "Jefferson or Adams Building Reading Rooms."

Exhibit-3 (Library of Congress)

20. **Exhibit-3** is a true and correct copy of the MARC record for *Automotive Electronics : Delivering Technology's Promise, SAE Conference Proceedings*, no. 360 (2000), which contains the Mufid article, Future Automotive Multimedia Subsystem Interconnect Technologies (pp. 167-182). I personally identified and located this MARC record on May 8, 2018, which experts in my field would reasonably rely upon when forming their opinion. Subfield ǂa of Field 040 of the MARC record informs me the record was originally created by "EYG," the OCLC symbol for the General Motors R&D Center Library in Michigan, according to the Directory of OCLC Members (https://www.oclc.org/en/contacts/libraries.html); and subfield ǂd indicates "DLC," the OCLC symbol for Library of Congress, modified the original record. Field 042 clarifies this record is "lccopycat" meaning the Library of Congress record is a copy cataloging record that is based on a record created earlier by another agency. While most copy cataloging agencies display their copy catalog record with the master record's creation date in Field 008, Library of Congress does not do that. Instead, Library of Congress uses Field 008 to indicate the date a record is added to the Library of Congress system and Field 955 to keep track of their cataloging activities. Field 008 shows the LC record was created on "010626" (*i.e.,* June 26, 2001) and Field 955, a field for local notes on the cataloging process at Library of Congress, shows the record was forwarded to the DDC unit on "2001-09-26" for a Dewey Decimal number to be assigned, which is typically the last step of cataloging at Library of Congress. In most academic libraries, newly cataloged books are made available soon after cataloging records are completed, usually within a week. The volume of materials for processing at Library of Congress means it may take longer than a week for a newly cataloged publication to be available to the public. My conservative estimate is that after the record was completed on September 26, 2001, the publication would have been available to the public at Library of Congress no later than December 26, 2001, three months after record completion.

21. Field 010 shows the LC control number (LCCN) for this publication is "2001269738," which is the same as the number printed on the copyright page of **Exhibit-1**. Library of Congress has used LCCN to control its cataloging records since 1898. LCCN is a unique identifier that enables users to locate a catalog record for a publication quickly. The year portion of LCCN typically represents the year when the control number was assigned. The reason that a 2000 publication carries a 2001 control number is due to the fact that Library of Congress has a Preassigned Control Number Program (PCN) that assigns "control numbers in advance of publication to those titles that may be added to the Library's collections" (see more about PCN at https://www.loc.gov/publish/pcn/about/).

22. Field 020 shows the ISBN (International Standard Book Number) for this publication is "0768006678," which is identical to the ISBN printed on the copyright page of **Exhibit-1**. Field 111 informs me the name of the conference established for cataloging purposes is "International Congress on Transportation Electronics (2000 : Detroit, Mich.)" and Field 245 shows the main title is "Automotive electronics : delivering technology's promise : proceedings of the 2000 International Congress on Transportation Electronics." Two 246 fields show the publication has two variant titles--"Proceedings of the 2000 International Congress on Transportation

Electronics" and "Convergence 2000"--and users can use these titles, in addition to the main title in Field 245, to locate this publication. Field 260 shows the Society of Automotive Engineers in Warrendale, PA published this book in 2000. Field 490 and Field 830 show the publication belongs to a series "P (Society of Automotive Engineers)" and its number is "P-360." Field 050 shows this publication has a call number by which users can request the item. Subfield ǂa of Field 050, "TL272.5" in this case, indicates the subject matter of this publication. The number is assigned from the Library of Congress Classification (LCC) system, which is used by most research and academic libraries in the United States and many other countries. LCC consists of 21 main classes covering many disciplines, such as philosophy, religion, arts, science, technology, and military science. "TL272.5" represents the "Electronic equipment" in motor vehicles category of the LCC scheme. Users interested in this topic could explore a library's materials in this topic area by entering this number in a library catalog as a keyword. The Library of Congress online catalog, for example, will retrieve materials that have been assigned this subject number when a user enter "TL272.5" in its single search box. Field 082 shows the publication is assigned a Dewey Decimal Classification (DDC) number of "629.27," which represents the "other equipment" of motor vehicles category of the DDC system. DDC is another major classification system for library materials. It was originally designed by Melvil Dewey in 1876 and has been expanded through 23 editions. DDC consists of 10 classes that represent many disciplines and subjects. It is used by more than 200,000 libraries in more than 135 countries. DDC is mainly used by public and school libraries. Users interested in a topic represented by a DDC number, such as "629.27" in this case, could search it as a keyword in the Library of Congress catalog to retrieve materials that have been assigned the same DDC number. Subjects of this publication are also represented by three Library of Congress subject headings: Automobiles with a topical subdivision, Electronic equipment; Intelligent control systems; and Intelligent transportation systems. Subfield ǂv "Congresses" indicates these topics were presented at a conference. These subject terms can be searched in library catalogs as keywords to retrieve like items. This MARC record (**Exhibit-3**) makes this publication searchable at the online catalog of Library of Congress, and users interested in the topics of the book can find it by the subject terms listed in Field 650 or the classification numbers listed in Field 050 and Field 082. Field 035 indicates this MARC record has an OCLC control number of "45252210," which makes this publication searchable on WorldCat. In other words, when users locate this publication on WorldCat, they will learn that Library of Congress holds this publication, as I did during my research on WorldCat.

23. Taken together, the date stamp, the bibliographic record and the MARC record inform my opinion that Library of Congress received their copy of *Automotive Electronics : Delivering Technology's Promise* on December 11, 2000. The records, together with my knowledge of cataloging practices and standards and the customary library practices for processing materials for user access, inform my opinion that the physical volume of *Automotive Electronics : Delivering Technology's Promise : proceedings of the 2000 International Congress on Transportation Electronics*, which contains the Mufid article, was available (e.g., searchable in the library catalog and available in the library) for public access at Library of Congress no later than Dec. 26, 2001, three months after the cataloging process was completed. The three months estimate for processing materials for user access is a conservative estimate because of the large volume of materials that are processed at Library of Congress.

Exhibit-4 (MIT Libraries)

24. **Exhibit-4** is a true and correct copy of Future Automotive Multimedia Subsystem Interconnect Technologies ("Mufid"), in *Automotive*

Electronics : Delivering Technology's Promise, SAE Conference Proceedings, no. 360 (2000), pp. 167-182, which I obtained, with the assistance of Wisconsin TechSearch (WTS), a document delivery service of the University of Wisconsin-Madison, from the Massachusetts Institute of Technology (MIT) Libraries on May 22, 2018. When I was originally asked to prepare this declaration, I searched WorldCat (http://www.worldcat.org) for the conference title "*Automotive electronics : delivering technology's promise*" and found more than 20 holding libraries. To provide evidence that the 2000 conference proceedings, which includes the "Mufid" article, was available soon after its publication in 2000, I asked WTS to deliver scanned pages from two separate libraries beyond my local libraries. **Exhibit-4** is the true and correct copy WTS obtained from the MIT Libraries according to my specifications. The file includes the cover, title page, copyright page, page with the date stamp, table of contents and the Mufid article. I have examined **Exhibit-4** and **Exhibit-1** closely, which I personally scanned at Library of Congress, and found that the two files have the same content. The only differences are that **Exhibit-4** has an MIT barcode sticker on the cover, a call number "TL272.5 .I57 2000" written on the copyright page (p.4), and a date stamp of "M.I.T. Libraries Nov 8 2000 RECEIVED" on the copyright page (p. 4).

Exhibit-5 (MIT Libraries)

25. **Exhibit-5** is a true and correct copy of the Bibliographic record for *Automotive Electronics : Delivering Technology's Promise, SAE Conference Proceedings*, no. 360 (2000), which contains the "Mufid" article, Future Automotive Multimedia Subsystem Interconnect Technologies (pp. 167-182). I personally identified and located this record from the online catalog of the MIT Libraries at http://library.mit.edu on May 22, 2018, which experts in my field would reasonably rely upon when forming their opinion. **Exhibit-5** presents bibliographic information about this publication, including the conference name, title, publisher, description, series, format, note, bibliography, subjects, other author, other title, and ISBN. In addition, it presents information specific to the MIT Libraries. A permalink informs me the record can be located consistently at http://library.mit.edu/item/000959917. The "Shelf Access" field has a link for users to find the item in the library or request it, and the "Shelf Location" field indicates it is shelved at "Barker Library - Stacks | TL272.5.I57 2000." The "local system number" indicates this item's number is "000959917."

Exhibit-6 (MIT Libraries)

26. **Exhibit-6** is a true and correct copy of the MARC record for

Automotive Electronics : Delivering Technology's Promise, SAE Conference Proceedings, no. 360 (2000), which contains the "Mufid" article, Future Automotive Multimedia Subsystem Interconnect Technologies (pp. 167-182). I personally identified and located this record from the online catalog of the MIT Libraries at http://library.mit.edu/F/37UUX4LQB1MHNPQFHSLA7TP5S212MH7YAKU66UGES4DCSECHG6-01482?func=full-set-set&set_number=018233&set_entry=000001&format=001 on May 22, 2018, which experts in my field would reasonably rely upon when forming their opinion. Subfield ǂa of Field 040 informs me the original creator of the record is "EYG" and Subfield ǂd informs me "MYG" is the library that modifies this record. According to the Directory of OCLC Members (https://www.oclc.org/en/contacts/libraries.html), "EYG" is the OCLC symbol for the General Motors R&D Center Library and "MYG" the OCLC symbol for the MIT Libraries. This means the MIT record is a copy cataloging record based on the EYG record. Field 008 informs me the original record by EYG was created on "001030" (*i.e.,* Oct. 30, 2000). Most libraries do not clearly indicate the date when a copy cataloging record is added to the cataloging system on their MARC bibliographic records. In this case, the MIT MARC record (**Exhibit-6**) itself does not indicate the copy cataloging date, but the MARC holdings record attached to the bottom of **Exhibit-6** has an 008 field date of “010623” (*i.e.,* June 23, 2001) that indicates the date the record was entered into the system.

27. Because the MIT MARC record (**Exhibit-6**), like the LC MARC record (**Exhibit-2**), is a copy cataloging record based on the record originally created by EGY, the General Motors R&D Center Library, it is not surprising that the MIT MARC record and the LC MARC record are very similar in content. From Field 111 to Field 830 the two records provide nearly identical content and encode the data in the same MARC fields. The only differences are that the MIT MARC record has “convergence 2000” included as the last part of the 245 field, and that catalogers at MIT encoded the variant title “Convergence 2000” with indicators “30” (*i.e.*, produce no note, this is portion of a title) while LC catalogers encoded that same variant title with indicators “14” (*i.e.*, produce a note, this is a cover title). Both records have the OCLC control number of “45252210” in Field 035. These data inform me that the MIT MARC record and the LC MARC record represent the same publication, *Automotive Electronics: Delivering Technology’s Promise*, which is the proceedings of the 2000 International Congress on Transportation Electronics that also contains the Mufid article.

28. Taken together, the date stamp, the bibliographic record and the MARC record inform my opinion that the MIT libraries received their copy of *Automotive Electronics : Delivering Technology's Promise* on Nov. 8, 2000. The records, together with my knowledge of library cataloging practices and standards and the customary library practices for processing materials for user access, inform my opinion that the physical volume of *Automotive Electronics : Delivering Technology's Promise : proceedings of the 2000 International Congress on Transportation Electronics*, which contains the Mufid article, was accessible (e.g., searchable in the library catalog and available in the library) to the public at the MIT Libraries by July 1, 2001, about a week after the holdings record was entered on June 23, 2001.

Exhibit-7 (Penn State Libraries)

29. **Exhibit-7** is a true and correct copy of Future Automotive Multimedia Subsystem Interconnect Technologies ("Mufid"), in *Automotive Electronics : Delivering Technology's Promise, SAE Conference Proceedings*, no. 360 (2000), pp. 167-182, which I obtained, with the assistance of Wisconsin TechSearch (WTS), a document delivery service of the University of Wisconsin-Madison, from the library of the Pennsylvania

State University (Penn State) on May 22, 2018. When I was originally asked to prepare this declaration, I searched WorldCat (http://www.worldcat.org) for the conference title "*Automotive electronics : delivering technology's promise*" and found more than 20 holding libraries. To provide evidence that the 2000 conference proceedings, which includes the "Mufid" article, was available soon after its publication in 2000, I asked WTS to deliver scanned pages from two separate libraries beyond my local libraries. **Exhibit-7** is the true and correct copy WTS obtained from the library of Penn State according to my specifications. The file includes a date stamp page, the cover, title page, copyright page, table of contents and the Mufid article. I have examined **Exhibit-7** and **Exhibit-1** closely, which I personally scanned at Library of Congress, and found that the two files have the same content. One difference is **Exhibit-7** has a date stamp of "RECEIVED SEPT 30 2001 ENGINEERING LIBRARY." The cover sheet from WTS informs me the scanned pages come from UPM, the OCLC symbol for Penn State, according to the Directory of OCLC Members, and WTS confirms the Penn State Library is the source of **Exhibit**-7.

Exhibit-8 (Penn State Libraries)

30. **Exhibit-8** is a true and correct copy of the Bibliographic record for *Automotive Electronics : Delivering Technology's Promise, SAE Conference Proceedings*, no. 360 (2000), which contains the "Mufid" article, Future Automotive Multimedia Subsystem Interconnect Technologies (pp. 167-182). I personally identified and located this record from the online catalog of the Penn State Libraries at http://cat.libraries.psu.edu on May 22, 2018, which experts in my field would reasonably rely upon when forming their opinion. **Exhibit-8** presents bibliographic information about *Automotive Electronics*, including title, author, publisher, pub date, physical description and ISBN. It also presents holdings information indicating the item has "TL272.5.I577 2000" as the call number, is a book, and is stored at the Annex.

Exhibit-9 (Penn State Libraries)

31. **Exhibit-9** is a true and correct copy of the MARC record for *Automotive Electronics : Delivering Technology's Promise, SAE Conference Proceedings*, no. 360 (2000), which contains the "Mufid" article, Future Automotive Multimedia Subsystem Interconnect Technologies (pp. 167-182). I personally identified and located this record from the online catalog of the Penn State Libraries at http://cat.libraries.psu.edu on May 22, 2018, which experts in my field would reasonably rely upon when forming their opinion. This MARC record does not display as many fields as the LC MARC record (**Exhibit-2**) or the MIT MARC record (**Exhibit-5**), but Field 035 has the same OCLC control number of "45252210" as that in the LC and MIT MARC records, indicating the Penn State MARC record is also a copy cataloging record based on the record originally created by the General Motors R&D Center Library. I have examined the Penn State MARC record (**Exhibit-9**) and the LC MARC record (**Exhibit-2**) closely and found the data content to be largely the same but the Penn State MARC record has been updated in recent years to reflect changes in cataloging standards. Both records document the same ISBN in Field 020 and use the same conference name, "International Congress on Transportation Electronics (2000 : Detroit, MI)," as the author. They present same data for the main title and variant titles, the publishing area, the bibliographic note, subject heading fields, and the other author field. The Penn State MARC record uses a series title in the form that is different from the one used in the LC MARC record, and has a notation in Field 830 indicating they were not sure if that form was the authorized form. After *Resource Description and Access*, a new cataloging standard, was adopted in spring 2013, some libraries have updated their existing records to reflect new cataloging and encoding practices. The presence of a number of MARC fields informs my opinion that the Penn

State Libraries have updated their existing records. For example, the Penn State MARC record uses Field 264, which has replaced Field 260 in recent years, to encode publishing information. It also makes use of Fields 336, 337, and 338 to encode the physical details of the publication, which is a relatively new practice. These data inform my opinion that the Penn State MARC record represents the same publication represented by the LC MARC record. The Penn State MARC record does not show Field 008 or any holdings record date, so it is not clear when the Penn State MARC record was added to the cataloging system.

32. Taken together, the date stamp, the bibliographic record and the MARC record inform my opinion that the Penn State Library received their copy of *Automotive Electronics : Delivering Technology's Promise* on Sept. 30, 2001. The records, together with my knowledge of library cataloging practices and standards and the customary library practices for processing materials for user access, inform my opinion that the physical volume of *Automotive Electronics : Delivering Technology's Promise : proceedings of the 2000 International Congress on Transportation Electronics*, which contains the Mufid article, was likely to be accessible to the public (e.g., searchable in the library catalog and available in the library) no later than on September 30, 2002 at the Penn State Libraries, 12 months after the physical volume was received by the Penn State Libraries. Copy cataloging work is fairly straightforward and usually takes less than a day to complete. The 12-month estimate is conservative in case the Penn State Libraries had an unusually large number of works to be cataloged at that time.

Summary of Opinion.

33. In view of the above, I conclude that the Mufid article, Future Automotive Multimedia Subsystem Interconnect Technologies ("Mufid"), in *Automotive Electronics : Delivering Technology's Promise, SAE Conference Proceedings*, no. 360 (2000), pp. 167-182, was sent to and received by its subscribers in the year 2000 because it was received by the Library of Congress and MIT in December and November 2000, respectively. I further conclude that it was catalogued and became available to users at least at the Library of Congress no later than December 26, 2001, and at the MIT library no later than July 1, 2001. The Penn State date stamp and records inform my opinion that the physical volume was likely to be accessible to the public by September 30, 2002, 12 months after the volume was received, because copy cataloging work would have been completed within a year in most libraries. In each case, a person reasonably familiar with library resources and/or on-line searching could have found it through a reasonably diligent subject-matter search on or before that date.

CONCLUSION

In signing this declaration, I recognize that the declaration will be filed as evidence in a contested case before the Patent Trial and Appeal Board of the United States Patent and Trademark Office. I also recognize that I may be subject to cross-examination in the case. If cross-examination is required of me, I will appear at a reasonable time and place to be agreed upon.

I hereby declare that all statements made herein on my own knowledge are true and that all statements made on information and belief are believed to be true, and further, that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Date: 6-5-2018. Executed: Ingrid Hsieh-Yee
Ingrid Hsieh-Yee, Ph.D.

Exhibit 1

INTERNATIONAL CONGRESS ON TRANSPORTATION ELECTRONICS

CONVERGENCE 2000

PROCEEDINGS

OCTOBER 16-18, 2000

DETROIT, MICHIGAN

AUTOMOTIVE ELECTRONICS
Delivering Technology's Promise

P-360

Proceedings of the
2000 International Congress on
Transportation Electronics

CONVERGENCE
2000

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Published by
Society of Automotive Engineers, Inc.
400 Commonwealth Drive
Warrendale, PA 15096-0001
U.S.A.
Phone (724) 776-4841
Fax: (724) 776-5760
www.sae.org
October 2000

ISBN 0-7680-0667-8
ISSN 98-86269

LC Control Number
2001 269738

Printed in the United States of America.

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Introduction

For the first time in over twenty years, an automotive supplier company was given the prestigious honor to host one of the world's leading automotive electronics conference — Convergence. As chairman for ***Convergence 2000***, I am honored Delphi Automotive Systems was chosen to continue the excellent tradition of Convergence.

The theme for ***Convergence 2000*** is Automotive Electronics: Delivering Technology's Promise. We have approached the millennium with a vast awakening of new, high-tech technology, and yet some think we have failed to deliver technology's promises. The Internet and e-commerce business has taken over the automotive industry, and discrepancies are still abundant in everyday technology. This conference provided a forum, where constituents participated and debated discussions related to the automotive industry. The conference also raised questions to the industry: "What must the automotive industry do to enhance and improve today's technology?" "What does the automotive industry need to do to deliver?" "What are the social repercussions?" "How is the rise of automotive electronics going to effect future generations?"

"Delivering Technology's Promise" was discussed and examined during three days of paper presentations and forums. Technical sessions investigated inclination toward future design processes for electronic systems, occupant protection, the electric cocoon, and infotronics in mobile information and entertainment in addition to dynamic route guidance. Also, we examined prior aspects of technology in comparison to future trends and customer requirements. Lastly, this conference considered issues involved in reshaping and introducing new electronic technologies into the automobile.

I hope these conference proceedings assist you in addressing these key electronics issues.

J.T. Battenberg III
Chairman, CEO & President
Delphi Automotive Systems and
Chairman, ***Convergence '00***

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2000-01-C028

Future Automotive Multimedia Subsystem Interconnect Technologies

Visteon Automotive Systems

ABSTRACT

For the past decade or so, automotive entertainment subsystem architectures have consisted of a simple Human Machine Interface (HMI), AM-FM tuner, a tape deck, an amplifier and a set of speakers. Over time, as customer demand for more entertainment features increased, automotive entertainment integrators made room for new features by allowing for the vertical integration of analog audio and adding a digital control. The new digital control came to entertainment subsystems via a low speed multiplexing scheme embedded into the entertainment subsystem components, allowing remote control of these new features. New features were typically incorporated into the entertainment subsystem by independently packaging functional modules. Examples of these modules are cellular telephone, Compact Disc Jockey (CDJ), rear-seat entertainment, Satellite Digital Audio Radio System (S-DARS) receiver, voice and navigation with its associated display and hardware. Figure 1.0 is a block diagram of typical entertainment subsystem. This paper discusses alternatives to the module-expansion of entertainment subsystem via low speed digital control and analog audio. Moreover, the discussion is expanded to cover future multimedia and infotainment subsystem interconnects technologies.

INTRODUCTION

Recently, great achievements have been reached in information, communication, entertainment, comfort, safety and security products. Moreover, new Intelligent Transport Systems (ITS) services, requiring state-of-the-art electronics, are appearing on the market to help drivers process information, make decisions, and operate vehicles more safely and effectively.

As a consequence, our cars will be equipped more and more with digital systems communicating and exchanging information. Whenever possible, the trend is to go towards a super-integration of these systems, but a number of them will always be distributed in different locations of the car. A transport bus is necessary as a backbone for all the bit-streams and commands flowing between them. Table 1.0 lists some of the most important applications that are already present or will be soon introduced into the automotive environment.

Safety & Security	Entertainment	Information and Communication
Road-side assistance Mayday	Radio (AM/FM/DAB)	Internet access
Panic call	Audio (cassette, CD player, MP3)	E-mail
Collision avoidance	S-DARS	Weather forecast Head-line News Stock quotes Traffic updates Paging
Antitheft system	Video (TV, DVD)	Tourist information
Traffic information	Games	Navigation
Tolling system		Car diagnosis
		Mobile phone

Table 1.0: Near-Future Vehicle's Features

This paper assesses the suitability of current mobile multimedia transport for the accommodation of these technological advances. In addition, this paper identifies system and functional requirements for future mobile multimedia transport as well as differences between existing networks such as Ethernet, IEEE 1394, Media Oriented System Transport (MOST).

CURRENT MOBILE ARCHITECTURE

In the beginning of the automobile era, the primary function of a vehicle was a reliable transport. Over a period of years, the desire for a basic transport has been coupled with the desire for comfort, convenience, entertainment, information, communication, safety and security. Vehicle manufacturers made room for the new

features by allowing for the vertical integration of analog audio and adding a digital control. Despite the digital nature of most of the new added modules and the introduction of Digital Signal Processor (DSP) within the mobile multimedia system, the vertical integration of audio and its transport remained analog.

The Current mobile architecture with its analog transport has the following limitations:

- Analog transport complicates the subsystem interconnects, decreases reliability, adds weight and cost. Two twisted pairs are required for cabin media, one twisted pair is required for voice module, one twisted pair is required for cellular phone module, one twisted pair is required for navigation module, 3-5 wires are required for low speed multiplex scheme and synchronization. Additionally, two more twisted pairs are required for an optional media player such as CDJ. In the case of rear seat entertainment, more wires or coaxial cables are required for video. The number of wires or coaxial cables required for video applications is proportional to the number of rear seat occupants. Moreover, these wires require wide connectors with more pins at the analog power amplifier's input connector.
- The module level expansion strategy and vertical integration of analog audio resulted in a closed architecture with limited expansion path. The number of pins available at the power amplifier's input connector bounded the expansion path. In addition, the new subsystem had a short life and is not compatible with the digital trending of future entertainment features such as digital audio, digital video, Digital Audio Broadcast (DAB) and next generation of compact disc technology, Digital Versatile Disc (DVD).
- The module level expansion strategy and vertical integration of analog audio resulted in costly subsystem architecture. Often, modules added to the subsystem exhibited wasteful redundant hardware resources in order to achieve compatibility with an analog architecture. An example of this hardware wastefulness is the addition of a digital-to-analog converter to the output of CDJ or CD player to achieve compatibility with analog integration and processing. Moreover, the hardware resources available for each module are for that modules' own use and can't be shared with other subsystem's modules. This will add cost to each module and will contribute to the overall cost of the subsystem.

Presently, the module level expansion strategy and vertical integration of analog audio has reached its upper integration limit for an HMI, AM-FM tuner, voice, cellular phone, CDJ, a media player, Steering Wheel Control (SWC), a Rear Integrated Control Panel (RICP) and navigation. The implementation of such a subsystem requires seven modules and a minimum of 31 wires. A saving of one module and four wires is possible if a media, HMI, tuner, and power amplifier is packaged in one module. However, a complicated heat dissipation

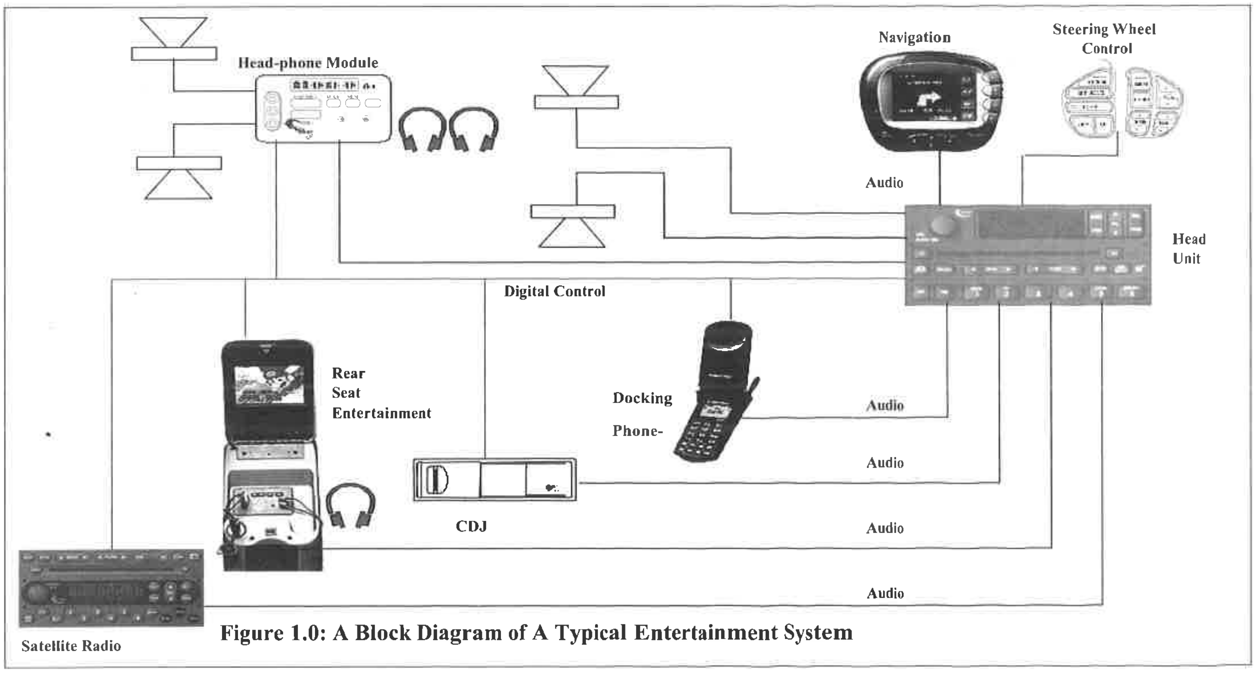


Figure 1.0: A Block Diagram of A Typical Entertainment System

and overall power management strategy is required for the success of such integration, and may limit the audio performance.

REQUIREMENTS FOR NEW TRANSPORT

Vehicles are running out of the real estate required to house new modules. Interconnect harness thickness and costs are ever increasing. This section is a discussion of both system and functional requirements for a new transport:

- Open Standard: the new transport shall be an open standard to ensure that all vehicle and electronic product manufacturers have equal access to the standard and to the market.
- Minimal Standard: the new transport standard shall be extensible and capable of migration to future technologies and different physical media with no impact on application software. A layered approach to the protocol, such as is used in the reference model of Open System Interconnect (OSI) model, shall be used.
- The new transport shall be digital to allow multiplexing of data, control, audio and video over the same media. In addition, digital transport enables open system architecture; a node can be added at anytime during the vehicle's life without modifying an existing node's connector. Moreover, a digital transport enables the natural transport of digital data from one ever increasing digital application to another without exhibited wasteful redundant hardware resources such as Digital-to Analog (DAC) and Analog-to-Digital (ADC) converters.
- Safety & Security: the new transport shall provide an environment into which devices can be plugged, unplugged, and operated in a vehicle in a manner which does not threaten the integrity of the vehicle or the devices that are being used. The new transport shall include suitable security for transactions involving the exchange of money and/or proprietary information.
- Manufacturability: the new transport compatible devices and software shall be easy to design, implement and integrate. This implies minimal specifications and unambiguous requirements. Ease of manufacture helps to assure the wide adoption of the standard and contributes to lowering the cost of the manufactured items.
- Ease of Use: the addition or removal of devices shall be easy enough for a consumer to accomplish the task with little or no expert assistance required.
- Low Cost: the incremental direct material cost to implement a new transport node shall be a fraction of the cost of the application supported.
- Graceful Degradation: the new transport's physical layer and its supported bus topology shall be designed such that any fault shall not cause any damage to the cable, the vehicle or any attached devices. Functional operation under any of these conditions may cease but shall resume within the boot/discovery time after the fault is removed. The new design shall be such that no single failure, other than a fault in the physical layer as described above, or the loss of primary power, shall cause the entire system to fail.
- Hot Plug and Play: it shall be possible to attach devices to, and remove devices from, the new transport system at any time, whether power is on or off.
- Self-Identification: devices attached to the new transport shall be able to identify themselves to other system devices and shall self configure to obtain unique addresses on the new transport. No user intervention shall be required to complete this configuration other than the provision of the appropriate application software.
- Short Boot/Discovery Time: the new transport and all attached nodes shall complete self-configuration within one second after device initialization. When a new node is added to the system while it is operating, detection of the new node and reconfiguration of the system to include it shall be completed within 2 seconds.
- Peer-to-Peer Communications: the set of devices that is likely to be attached to the new transport is unpredictable and no single device is guaranteed always to be present. Therefore, a device on the new transport shall be able to communicate directly with any other device in the system and the vehicle without need for any additional device. An application that is implemented across multiple devices may choose to implement a "master controller" for that application but this shall not be a requirement for all applications.
- Automotive Physical and Electrical Specifications: the new transport's physical layer shall meet automotive environmental (temperature, vibration, shock, EMI, etc.) and electrical specifications (reverse voltage, load dump, etc.) for the environments in which the devices are installed, e.g., passenger compartment, trunk, etc.
- Extensibility: The new transport shall be extensible to

accommodate evolving technologies and new applications. A layered approach to the protocol is required to guarantee minimum impact on existing designs as new physical layers and new applications are developed.

- Security and Authentication Services: The new transport protocol shall provide security and authentication services for access to vehicle functions. It is anticipated that additional services will require additional security measures to accommodate applications or transactions that require billing, authentication, confidentiality, confirmation, non-repudiation, etc.

- Bit Error Rate: the bit error rate shall be less than 1 x 10^{-9}. Applications requiring better than this shall be able to implement appropriate measures at higher layers of the protocol.

- Time-Critical Delivery of Packets- Deterministic Latency: Some applications may require that messages be transmitted within a given time period. The new transport shall be deterministic and it shall be possible to determine the maximum latency for any message in a given system configuration

- Private Message Service: Equipment manufacturers wish to be able to develop applications that span their own suite of products and provide competitive functions and features not achievable when products from different manufacturers are interconnected. The new transport protocol shall support the implementation of private messages that will allow such applications to be developed.

- Power Loading: the new transport gateway shall make power available for all devices connected to the new transport system. The total operating current drain of all devices connected to the new transport shall not exceed the capacity of the gateway unless power is routed directly to the device from another source or the device is self-powered (e.g., internal batteries).

- Internetworking: it is anticipated that wireless access to and from the Internet will be required for many devices attached to the new transport system. The new protocol shall not preclude the future implementation of internetworking services across multiple gateways or bridges between the new transport and other subnets such as Intelligent Transportation Data Bus (IDB).

- Explicit Device Addressability: it shall be possible to send a message from a device to a specific other device. It shall be possible for the sender to determine and use the desired recipient's unique address to deliver this message and all other devices shall ignore it.

- Broadcast Messages: it shall be possible for an application to generate a broadcast message to all devices connected to the new transport without having to address each one explicitly. A broadcast message may or may not require acknowledgment or confirmation of delivery. For example, an application may require confirmation (acknowledgment) that at least one receiving device capable of acting on the message has received the message.

- Consumer-Friendly Device Connection (No Special Tools Required): in most cases, it shall be possible for a consumer to install new transport nodes with common hand tools. There will be cases where professional installation may be required, but this should be the exception, not the rule.

- Wake/Sleep: any node shall have the ability to wake up the new transport system or put it to sleep. It shall be possible to wake up the nodes by sending a wake-up message, such as a pager. It shall be possible to put any node and all connected devices back to sleep with a sleep message. Absence of message traffic on the new transport for more than 30 minutes shall cause the new transport and all attached devices to go to sleep.

- Priority Sensitive Flow (Isochronous): consumer electronics devices such as video games, DVD and MP3 players, Dolby AC-3 audio components, etc., may require support for high speed isochronous data communications (i.e., data packets delivered at a guaranteed rate in a guaranteed order).

- Data Types: The new transport protocol shall allow any data type (ASCII, binary, bulk, etc.) to be transmitted in a message without need for any special escape characters or other similar artifacts added by the application.

- Fair Access to the new transport system: no single device shall be allowed to monopolize the new transport system.

- Message Priority Flagging: the new transport protocol shall provide a means to specify that the current message is a high or normal priority message. The protocol simply provides a mechanism to identify the message as a high priority message. It is up to the device manufacturer to determine whether support is provided and up to the application software to determine what action is to be taken when a high priority message is received or presented for transmission.

- Confirmation of Message Delivery, if required: a device sending a message to another device shall be able to explicitly request confirmation of error-free delivery of that message from the receiving device.

EXISTSING PROTOCOLS: ETHERNET, IEEE 1394 AND MOST

Fast Ethernet

Ethernet is a term commonly used to describe a variety of network implementations that share the same basic technology. Some early varieties of Ethernet are 10Base-2 and 10Base-5 which are also called 'thin net' and 'thick net' respectively. All nodes on such network tap into a single cable. A later version of Ethernet, 10Base-T, introduces the concept of a hub or a repeater. All nodes are connected directly to a single repeater, which simplifies cabling and provides buffering of electrical signals.

A newer version of Ethernet, called Fast Ethernet, operates at 10 times the speed of 10Base-T or 100 Mbit per second. It has the same star topology as 10Base-T and comes in a few different versions called 100Base-TX, 100Base-FX, and 100Base-T4. The difference between these versions is the physical layer which is electrical for TX and T4, and optical for FX. In this paper, Fast Ethernet will refer to the most common version 100Base-TX.

Ethernet Topology

Thick net Ethernet uses a single cable as a backbone for the network. Each node in the network taps into this cable through what is called a T connector. In an office environment, this cable could be routed through the ceiling with taps dropping into each office. This works well except it is difficult to add new users to the network and signal quality is sometimes difficult to control.

A Fast Ethernet uses a central repeater which connects directly to each node. This star topology enables the signal quality on the transmission line between a computer and the repeater to be well controlled and provides a relatively simple means to add users. The repeater has a number of ports which connect to each computer on the network. To add another computer, a wire is run from a free port on the repeater to the new computer. If there are no free ports, typically, another hub (or switch) can be connected to an uplink port to expand the network to virtually any size.

Ethernet Physical Layer

In a thick Ethernet, all computers are connected to one coaxial cable. This cable is used for sending and receiving messages. When the bus is idle, the voltage on the coax cable remains in a high impedance state at an intermediate level. This level is not a one or a zero, so that all nodes can easily determine if the bus is idle. When a node is transmitting, the voltage on the bus is pulled to high and low voltages depending on the data to be transmitted. Only one computer can send information at any one time. If multiple nodes try to transmit at the same time, a collision occurs, the data from both computers is corrupted, and both computers have to stop transmitting and try again when the bus is idle.

In Fast Ethernet, all nodes connect to a central repeater through two sets of twisted pairs. One pair is for transmitting and the other for receiving. Although each node has its own cable, the network operates exactly like thick Ethernet at a higher level. When a computer sends a message to the central repeater, the repeater sends the data exactly as received to all other computers connected to it. Again, if two computers try to send at the same time, a collision occurs, and both computers must try again later.

Ethernet Arbitration

Since all the computers on an Ethernet share the transmission media, only one computer can send information at any one time. If multiple nodes try to transmit at the same time, they must arbitrate for use of the bus. The rules that every node follows is called Carrier Sense Multiple Access with Collision Detection (CSMA/CD). Before a node sends a message on the bus, it sends a stream of one's and zero's called a 'carrier'. All other nodes on the network sense this carrier and do not attempt to send their own message until the original node completes its message.

There is a finite amount of time from when a node begins sending a carrier to when all nodes detect this carrier. During this time, other nodes may attempt to send a carrier. If this happens, a 'collision' will occur which corrupts the data on the bus. Transmitting nodes will both 'detect' this condition and stop transmitting. The rules then specify that each node must wait a random amount of time before attempting to transmit again. The probability that another collision will occur is low.

Ethernet Switches

Ethernet switches have become more popular than repeaters in recent years. An Ethernet switch is a more sophisticated device which prevents all messages from being sent to all computers connected to the switch. When a Fast Ethernet is implemented with a repeater, all computers connected to the repeater are said to be on the same collision domain. This is because a repeater

operates just like the coaxial cable in thick Ethernet. If two computers try to send messages at the same time, the messages collide.

An Ethernet switch divides the network into many collision domains. Each port on a switch is a different collision domain. For example, if one computer is connected to a port on an Ethernet switch, the collision domain consists of two nodes; the computer and the switch. If a port on a repeater is connected to a port on a switch, the collision domain consists of the switch and all computers connected to the repeater.

The switch has intelligence which learns the addresses of the computers connected to each port. When a message is received at one port, the destination address is determined and the message is sent out the appropriate port. Switches are typically much more efficient than repeaters. However, they cost more.

Ethernet Communication Mechanism

Information in Ethernet networks is communicated in packets. Each packet consists of a header, usable data and a checksum. The header contains information such as source and destination address, the length of usable data and possibly information about the message type. The checksum is a code sent at the end of the message so that the receiving node can determine if the packet was corrupted during transmission.

Since the header and checksum are only used to send the packet safely from the transmitting node to the receiving node, it is considered network overhead. It is not information usable by the application. In Fast Ethernet, this consumes 18 bytes. If you include the arbitration time, the total overhead is 38 bytes. In addition, the minimum usable data is 46 bytes per packet. Even if you only wish to send one byte, you still must send the 18-byte header, 46 bytes of data, and wait 20 bytes worth of time for the bus.

The efficiency of the network can be defined as the number of user data bytes per packet divided by the number of bytes in the packet plus the overhead of waiting for the bus. If only one byte of user data is sent per packet the efficiency is 1/(64+20) X 100% = 1.2%. Since the maximum user data per packet is 1500 bytes in 100BaseT, the theoretic maximum efficiency is 1500/(1518+20) X 100% = 97.5%.

The maximum efficiency is never achieved since many collisions will occur if there is a lot of activity on the bus. The effect on efficiency is difficult to predict.

Ethernet Audio Example

Let's consider a PC with a sound card connected over the network to a server which stores WAV files. A particular Wav file from the server can be played on the sound card in the following way. The client software on the PC manages a FIFO (First-In First-Out) which continually outputs audio data to the sound card. When the FIFO gets close to being empty, the client sends a message to the server to send more data. The server sends another packet to the client to fill the FIFO up again. As long as the server sends the new packet before the FIFO empties, audio can be heard. If the server responds slowly or the network is very busy, the packet may not arrive in time, the FIFO will empty and sounds will momentarily stop. This is unacceptable for most audio applications.

There is a trade off between FIFO size, the frequency of requests for more data and packet size. Since the large packets are more efficient than small packets (% overhead from header, etc), let's assume we will use the largest packet size; 1500 bytes of user data. If the audio sample rate is 48 kHz, and the audio is 16 bits/sample stereo, then we need an average of 192K bytes/second or 128 packets/sec. The overhead for the header, checksum and the required idle between packets is 38 bytes. Since the client software on the PC with the sound card must inform the server when the FIFO is nearly empty, there are another 84 bytes of overhead to send this message to the server.

The minimum total bandwidth required for one audio channel is:

1500 + 38 + 84 = 1622 bytes/packet

1622 bytes/packet * 128 packets/sec = 207616 bytes/sec

207616 bytes/sec * 8 Bits/bytes = 1.66 Mbit/sec

Since the packet size in this example is the largest allowed by Fast Ethernet, the network overhead is small compared to the audio data throughput. The disadvantage of the large packet size is the buffer size requirement in the Client. It must be 1500 bytes deep plus more for handshaking. If the extra depth is not large enough for the network to guarantee another packet will arrive prior to the buffer emptying, a loss of audio quality may occur. If the buffer empties, the audio stops. In a Fast Ethernet, it is impossible to guarantee any bandwidth. If the network has lots of traffic, you may not even be able to get the 1.66 Mbit/sec average throughput that is required. More commonly, at times of high traffic the buffer may empty no matter how large it may be.

IEEE 1394

The IEEE 1394 specification is a hardware specification that defines the serial bus architecture that Apple computer initially named FireWire. It defines serial bus specific extensions to the Control and Status Register

(CSR) Architecture for Microcomputer Buses formally adopted as ISO/IEC 13213 (ANSI/IEEE 1212).

This architecture defines a set of core features such as node architecture, address space, common transaction types, Control and Status Registers (CSR), configuration ROM format and content, message broadcast mechanism to all nodes and interrupt broadcast to all nodes. IEEE 1394 specifies how units attached to a serial bus can talk to each other, but does not define the protocols used to communicate between the nodes.

IEEE 1394 is similar to Fast Ethernet in many ways. Data is always communicated between nodes in packets. If multiple nodes try to send packets at the same time, they must arbitrate for the bus. The information in the packet headers, the packet sizes and the arbitration method, are different. However, the fundamental mechanisms are similar.

The most significant feature that IEEE 1394 provides (which Fast Ethernet does not) is guaranteed bandwidth for real time applications. These applications are allocated isochronous bandwidth which enable real time data to be communicated in packets sent at regular time intervals. This is an improvement over Fast Ethernet. However, it will be shown that there are still serious limitations.

The raw bit rate for IEEE 1394 is defined to be selectable between approximately 100, 200, and 400 Mbit/sec. Work is currently being done on an 800 Mbit specification as well. Silicon is currently being advertised to run at both 100 and 200 Mbit. However, most implementations are now at 100 Mbit/sec which is the same data rate as the large installed base of 100BaseT. Gigabit Ethernet is currently under development as well.

IEEE 1394 Physical Layer

The physical layer for IEEE 1394 consists of two sets of twisted pair wire for signals and two wires for power and ground connected between each pair of nodes. One set of twisted pairs is called data and the other is called strobe. When one node begins to send a packet, it sends Nonreturn-to-Zero (NRZ) data on the data line and transitions the strobe line only between consecutive 1's or 0's. Both sets of twisted pairs are bi-directional. Each node sends and receives data on the same sets of wires. When neither node is sending data, the twisted pairs are held in a high impedance state.

In contrast, the physical layer for Fast Ethernet consists of two sets of twisted pairs; one pair is used for transmitting data and the other pair for receiving data. This approach makes recovering data from the transmission line slightly more difficult than with IEEE 1394 since there is no strobe signal. An advantage of keeping the transmission lines unidirectional, however, is that the transmission line can be longer. The maximum cable length for Fast Ethernet is 100meters, while it is only 4.5 meters for IEEE 1394.

Each node on an IEEE 1394 bus (or in a Fast Ethernet) has its own timing source which is typically a crystal oscillator. This timing source is used by a node to transmit data and is used by a node to over sample the received data and strobe lines to recover the data. This means that all IEEE 1394 nodes are asynchronous at the lowest level. The accuracy of the timing reference in IEEE 1394 is specified to be ± 100 PPM which is typically the frequency tolerance of widely available crystal oscillators.

The nominal data rate in 100 Mbit IEEE 1394 is 98.304 Mbit. If the crystal oscillator at a particular node is operating at the high end of its frequency tolerance, it will be able to transmit data at 98.304 Mbit +100 PPM or 98.314 Mbit/sec. If it is operating at the low end of the frequency tolerance, it will transmit data at 98.294 Mbit/sec. This may seem like a trivial issue. However, the section on system timing will illustrate some important consequences for real time applications.

IEEE 1394 Topology

The physical topology for a typical IEEE 1394 network is a tree structure. Typically, a node will have a least two ports which enables multiple nodes to be daisy chained together. If a node has more than two ports, multiple branches can be created. During initialization, one node is defined to be the root node with all nodes extending down different branches. The topology can have any number of branches if no loops are created.

The tree topology, with the ability to daisy chain nodes, has the advantage of simplicity for small networks. If you have a few devices, it is easy to plug them together in a daisy chain. However, large networks can be cumbersome, particularly if network performance is optimized. To improve performance, it is desirable to minimize the propagation delay of data between any two nodes in the network. Long daisy chains can be split into many branches to reduce the delay; however, care should be taken to balance the length of the branches.

In a Fast Ethernet, a repeater or switch is required for a network with more than two nodes. This makes small networks complicated. However, it makes large networks simpler.

IEEE 1394 Arbitration

As described previously, all computers on a Fast Ethernet using a repeater (not a switch) have the same collision domain. If multiple nodes attempt to transmit at

the same time, the transmitted data is corrupted, this condition is detected, and the nodes begin to arbitrate for the bus. Likewise, all nodes on an IEEE 1394 network have the same collision domain. Only one node can send a message at one time. If multiple nodes try to send messages at the same time, only one node will gain control of the bus.

In a Fast Ethernet, if a collision between two nodes occurs, both nodes will stop transmitting and wait a variable amount of time before another attempt. If they both happen to wait the same amount of time, another collision will occur. Mechanisms are built into the network to minimize the probability of nodes colliding more than once or twice.

An IEEE 1394 network operates differently. Nodes which are closer to the root node have a higher natural priority. When two nodes attempt to transmit at the same time, the node with the higher priority wins arbitration and control of the bus. In order to prevent higher priority nodes from monopolizing the bus a fairness interval is defined. During a fairness interval, all nodes are given the opportunity to send one message.

Unlike Fast Ethernet the arbitration mechanism in IEEE 1394 is deterministic. There is zero probability that nodes will collide many times before successfully sending a message. This is important for the delivery of real time data since any unpredicted delay, no matter how unlikely, may cause buffers to overflow or underflow.
The arbitration process in IEEE 1394 consists of bus request/grant handshaking between child and parent nodes. A parent node is defined as the node on a 1394 cable which is closer to the root. The node which is further from the root, is called the child. If a child and a parent both request the bus at the same time, the parent will block the child's request and send its request to its parent. The request continues down the tree until it reaches the root node. The root node issues a bus grant which travels back up the tree to the node requesting control of the bus. Once a node receives a bus grant, it can begin sending a message.

The time that it takes to arbitrate for the bus depends on the size of the network. A bus request from a node at the end of a number of branches must propagate down the tree to the root and back up the tree to the requesting node. Information must be sent down all other branches to prevent any other node from driving the bus (through a bus request), until the granted message is sent. The total arbitration delay for a network with N hops (from parent to child or child to parent) between the furthest two nodes, is about N x 80ns in a 100 Mbit IEEE 1394 network.

IEEE 1394 Communication Mechanisms

While Ethernet treats all packet data the same, IEEE 1394 provides different types of packets. The primary packet types are asynchronous and isochronous. Asynchronous packets are functionally equivalent to Ethernet packets. Isochronous packets are only available in IEEE 1394, and provide guaranteed bandwidth to time critical applications.

IEEE 1394 Asynchronous Packets

An asynchronous packet consists of a header, a header checksum, user data and a user data checksum. The header contains information such as source address, destination address, message length, message type, etc. The size of the header and the checksums is typically 24 bytes long. The user data can be up to 512 bytes long in a 1394 network operating at 100 Mbit/sec.

When a particular node receives a message, an acknowledgement signal is automatically sent back to the sending node. If the sending node does not receive an acknowledgement signal within a specified time, it will try to re-send it a specified number of times.

The total time required for sending a minimum size message consists of the arbitration time, the time to send the packet, the time to wait for an acknowledgement, the time for the acknowledgement message and a sub-action gap time. The sub-action gap time is the time required by a node to wait after the bus is idle before it can issue a bus request. The sub-action gap time is required to ensure that no node will issue a bus request before the previous acknowledgement is received.

The total time for a one byte message in a large network (16 hops) running at 100 Mbit is about 1.4 µsec for arbitration, 2.2 µsec to send the message (28 bytes * 8 bits/byte * 10ns), and 5.6 µsec for acknowledge and sub-action gap. The total time is about 9.2 µsec. This means the efficiency is about 80 ns / 9.2 µsec X 100% or 0.9%. The total time to send a maximum size message (512 bytes) is about 50 µ sec with an efficiency of about 85%.

IEEE 1394 Isochronous Packets

The most significant improvement of IEEE 1394 over Ethernet for real time audio, video and voice applications is 1394's isochronous channels which provide guaranteed bandwidth to applications. When an application is allocated an isochronous channel, it is guaranteed to be able to send isochronous packets at regular intervals to any other nodes in the network. Each node in the network has a counter which defines these regular intervals. The Isochronous Resource Manager sends a message periodically to synchronize the counters in all nodes.

The Isochronous Resource Manager has a local counter which is clocked by a local 24.576 MHz clock and counts up to 3072. When the counter reaches 3072, the Isochronous Resource Manager resets its counter and broadcasts a message to all the nodes in the network to reset their local counters. The frequency of this synchronization message is 24.576 MHz / 3072 or 8 kHz.

After the synchronization message, all nodes that have been allocated isochronous bandwidth are allowed to send their packets. After all isochronous packets have been sent, then nodes that need to send normal asynchronous packets are allowed to do so. The time between the 8 kHz sync messages is 125 µsec. The maximum time that can be allocated to isochronous data is 100 µsec. This ensures that some bandwidth will always be available for some asynchronous packets.

IEEE 1394 Audio Example

The concept of an isochronous channel resolves the problem illustrated in the previous example of communicating audio over Fast Ethernet. Since a node that is allocated isochronous bandwidth is guaranteed to be able to send a packet every 125 µsec, the FIFO described in the Fast Ethernet example will not empty due to congestion on the network. In addition, since the audio data packets are guaranteed to arrive at fixed rate, it is intended that handshaking messages are not necessary. These are required in the Fast Ethernet example since the server needs to know when the FIFO in the PC with the sound card is nearly empty.

To send 16 bit stereo audio data at a 48 kHz-sample rate over an isochronous channel requires 24 audio data bytes per isochronous packet. This is shown below:

48 kHz * 2 bytes/sample * 2 channels = 192K bytes/sec

192k bytes/sec / 8k packets/sec = 24 bytes/packet

The header for an isochronous packet consists of eight bytes which specify the length of the data (in our case 24 bytes), the channel number, etc, It also provides a checksum for just the header. The checksum for the data consumes another 4 bytes. In total, there are 12 bytes of header and checksum overhead to send the 24 audio bytes.

Additional overhead comes in the form of arbitration time, gap time between packets and packet start and end symbols. The gap time and start and end symbols consume a fixed time equivalent to the time it takes to transmit about 3 bytes in 100 Mbit IEEE 1394. The arbitration time depends on the size of the network. For a large network that has 16 nodes between the furthest nodes, the arbitration time is approximately equivalent to 20 bytes of data.

In summary, to send the 24 bytes of audio data, a 1394 network consumes up to 35 bytes of overhead. The total time required sending such as message is about 4.7 µsec and the efficiency is about 40%. Since the maximum amount of time that can be allocated to isochronous is 100 µsec/Frame, the maximum number of audio channels that a 100 Mbit IEEE 1394 network can support is about 20.

Voice is typically sampled at 8 kHz with 8-bit resolution. The minimum data field in an isochronous packet is 4 bytes; so the packet size will be at least 16 bytes. Including the overhead described above, the time required to send this message is 4.1 µsec and the efficiency is about 2%. The total number of voice channels that a 100 Mbit IEEE 1394 network can support is about 24.

If 100 µsec per frame are consumed by isochronous packets, 25 µsec will be left for asynchronous messages. As shown in the previous section, the time to send a minimum size packet is 9.2 µsec. Consequently, a maximum of two asynchronous packets can be sent per isochronous frame. In other words, 16000 relatively small asynchronous packets can be sent per second.

As shown earlier, a 512-byte packet (largest possible in a 100 Mbit IEEE 1394 network) takes 50 µsec to send. Since only 25 µsec are available per frame for asynchronous messages, it takes two frames to send such a message. The message rate will be 4000 Bytes/second. It is possible to send such message, since the isochronous packets on the second frame are delayed until after the large asynchronous packet has been sent. If the transmit time of a packet were allowed to be larger than 50 µsec or if less than 25 µsec per frame were reserved for asynchronous packets, delivery of all the isochronous packets could not be guaranteed.

IEEE 1394 System Timing

The timing source for each node in an IEEE 1394 network is typically a crystal oscillator. As described in the physical layer section, the frequency of crystal oscillators can vary by ± 100 PPM from their nominal value. At every node a local 24.576 MHz clock is generated to clock the modulo 3072 counters used to create the 8 kHz isochronous frames. The Isochronous Resource Manager must send a synchronization message every 125 µsec to resynchronize the counters in all nodes since they are all clocked by slightly different frequencies.

If the Isochronous Resource Manager has a crystal operating slightly faster than another node, the modulo 3072 counter in the other node will sometimes count to

3072 between synchronization packets and sometimes will count to 3071. The most significant bit of this counter can be used as a synchronization signal. Its frequency will be the same as that of the Isochronous Resource Manager. However, the period will sometimes be 3071 x (1/24.576 MHz) and will sometimes be 3072 x (1/24.576 MHz).

If the crystal frequency of the Isochronous Resource Manager is slightly slower than another node, the counter in that node will sometimes count to 3072 and sometimes to 3073 (rolls over to 1) between synchronization packets. Again, the frequency of the MSB of that counter will be the same as that of the Isochronous Resource Manager (8 kHz). However, it will have 40 ns of jitter. The frequency of the jitter varies depending on the frequency difference between the two crystals. Depending on the frequency, which is unpredictable, this amplitude jitter can be clearly audible in high fidelity applications.

IEEE 1394 Computer Audio Example

Let's go back to our example of a server with a WAV file and a client PC with a sound card. If these two computers are connected together with IEEE 1394 network, then isochronous bandwidth will be allocated to communicate the audio data. The 48 kHz audio will be sent from server to client in isochronous packets. The packet rate will be 8 kHz and the audio data per packet will be 24 bytes.

If the client is the Isochronous Resource Manager, the network will operate without difficulty provided the timing in the client is designed properly. The clock for the D/A converters and the clock for the isochronous counter (24.576 MHz) must be derived from the same crystal oscillator. If this is true, the 8 kHz ischronous frame rate is exactly 6 times the 48 kHz-sample rate of the D/A converter. If the server puts 6 stereo audio samples (24 bytes) in each isochronous packet, the D/A converter receives exactly the right number of samples per second. If the client (PC with sound card) is not the Isochronous Resource Manager, problems will occur. If the server is the manager, the 8 kHz isochronous frame will be generated by its crystal oscillator. If this crystal is operating at the high end of its frequency tolerance (+100 PPM), the frame rate will be 8.0008 kHz. The server will put 6 stereo audio samples in each isochronous packet, so the number of stereo samples the client receives is 6 x 8.0008 kHz or 48.0048 kHz.
If the crystal oscillator on the sound card is operating at the low end of its frequency tolerance (-100 PPM), it will accept 47.9952K samples/second. This means the sound card gets 9.6 extra samples per second. If these samples are simply discarded, you will hear a very audible clicking sound.

A possible solution is to use the FIFO and handshaking procedure used in the Fast Ethernet example. When the FIFO in the sound card is nearly full, the client can send a message to server to send an empty packet. Since the server produces 9.6 extra samples per second, on average it would send an empty packet slightly more than 1.5 times per second. Although this method works, it requires additional hardware and/or software to implement. In other words, it costs more.
Consumer Audio Example

Consider another example of a 3-node network consisting of an HMI, a DVD player and a digital amplifier. Assume the HMI node is the Isochronous Resource Manager. Also, assume the DVD drive is decompressing the audio from disk and sending it over the network to the digital amplifier.

The DVD player will have a crystal oscillator and will nominally produce 48K stereo audio samples per second. If the crystal is operating at +100 PPM, the DVD player will generate 48004.8 stereo audio samples per second. If the HMI node has a crystal operating at exactly the nominal frequency, the isochronous frame rate will be exactly 8 kHz. Each isochronous packet from the DVD player will then contain an average of 48004.8 / 8000 or 6.0006 stereo samples/packet. This can be accomplished in different ways.

The DVD drive can send packets with seven stereo audio samples and periodically send an empty packet. In this case, six packets with seven samples will be followed by an empty packet. Once every 1.3 seconds, five packets with seven samples will be followed by an empty packet. This will produce a throughput of exactly 48.0048k samples per second.

Alternatively, the DVD drive can send most packets with six samples (24 bytes). However, occasionally a packet will contain seven samples (28 bytes). To be explicit, every 8000/4.8 (~1667) frames will contain seven samples. Although both of these procedures will put the proper number of samples per second onto the network, controlling the different packet sizes requires some effort and cost.

The digital amplifier which is receiving the audio data from the DVD player has its own crystal which is clocking the D/A converters. If this crystal is operating at –100ppm, then the D/A converter expects to receive an average of 47,995.2 stereo samples per second. Since the DVD player is producing 48,004.8 samples per second the amplifier must do something with the extra 9.6 samples each second. As mentioned previously, if these samples are simply discarded, an untrained listener will hear clicking sound.

Sample Rate Conversion

A solution to the problem in the digital amplifier described above is to convert the sample rate of the data received by the digital amplifier from 48004.8 HZ to 47,995.2 HZ. Sample rate conversion is a well-known process. However, some sort of a digital signal processor is required. This adds cost and can affect quality by producing aliasing artifacts. Sample rate conversion is significantly easier if there is a known frequency relationship between the two rates. In this example, the difference in the sample rates is unknown and must be determined by a processor in the digital amplifier.

Phase Locked Loop (PLL)

An alternative solution is slaving both the DVD player and the D/A converters to the 8 kHz isochronous frame rate. The isochronous resource manager sends synchronization messages every time it's modulo 3072 counter wraps around. The counter in the DVD player will sometimes reach 3072 when it receives the synch message and will sometimes have rolled back to 1. The MSB of this counter will have exactly the same frequency as the Isochronous Resource Manager (8.00000 kHz). However, the Least Significant Bit (LSB) will be jittered.

This jittered 8 kHz signal can go through a phase locked loop to increase the frequency by some integer factor and attenuate the jitter. This higher frequency clock can be used by the DVD drive to read data off the disk at exactly 48 kHz (instead of 48.0048 kHz). Likewise, the 8 kHz signal from the isochronous counter in the digital amplifier can go through a phase locked loop to create a 48 kHz-sample rate clock for the D/A converters. Since both the source and the destination are locked to the same timing source (isochronous frame rate), there is no need for sample rate conversion.

The issue with slaving the DVD player and the digital amplifier to the isochronous frame rate clock is complexity. The jitter on the 8 kHz clocks in the DVD player and amplifier can have a frequency anywhere between 4 kHz and DC. The jitter frequency is directly related to the frequency difference between the crystals in the DVD player (or amplifier) and the Isochronous Resource Manager. Low frequency jitter is possible to attenuate. However, very low bandwidth PLL is required. Typically, low bandwidth PLL has long lock times which may or may not be acceptable. Tricks can be played to reduce bandwidth and keep lock times to reasonable levels. However, they can easily become very complicated.

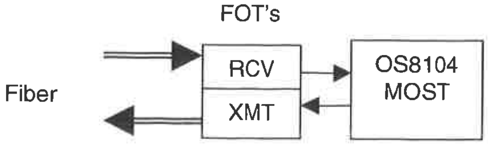
An additional problem with slaving the devices to the frame rate is that each node now has at least two asynchronous clocks. One clock is required by the 1394 interface; i.e. from a crystal. The other clock is the output of the PLL. If care is not taken in designing the digital amplifier circuitry, an aliased or mixed component of the 1394 interface clock will be heard through the speakers.

MOST

MOST (Media Oriented System Transport) is a functional specification developed specifically for interconnecting electronic devices to enable them to share electronic media, whether it is audio, video, voice or data. It defines a basic framework and provides the transport mechanisms to move media efficiently. MOST includes a hardware specification and defines the higher-level system services that need to be provided so unrelated systems can communicate with each other.

MOST Physical Layer

The physical layer is optical fiber. Each node in a MOST network has two optical ports. One for receiving data and one for transmitting. Although the transmission media can be glass fiber, it is typically plastic fiber due to lower cost and ease of installation. Fiber optic transceivers (FOT's) are available from a variety of manufacturers. The MOST network transceiver chip interfaces with the FOT units.



The physical layer of MOST is similar to that of Fast Ethernet since nodes in both technologies have separate transmit and receive ports. Data on the transmission lines for both MOST and Fast Ethernet goes in one direction. In contrast, data on a 1394 transmission line can go in both directions.

A significant difference between the physical layer of MOST and Fast Ethernet is that data is always being sent through the transmit and receive ports of a MOST node. A Fast Ethernet node only transmits data when it is sending a message. If it is not sending a message, its transmission line to the repeater (or switch) will be idle. A MOST node always bypasses the data it receives unless it is generating data. In this case, the node will multiplex its own data with the data that it receives. If no nodes are generating data, idle codes are transmitted through the network.

In a MOST network, one node is defined as the timing master. It has a crystal oscillator, which provides the timing reference for the entire network. It transmits data whether or not any node in the network is trying to communicate. If there is no useful information on the bus

the timing master, simply sends idle codes. All other nodes in the network have phase lock loops (PLLs) which recover their master clocks from the bitstream sent by the timing master.

MOST Topology

Ring

The most effective implementation of a MOST network is a ring. The ring starts with the timing master. Its optical output is connected to the optical input of the next node. The optical output of that node is connected to the optical input of the next node, and so on, until the optical output of the last node is connected to the input of the timing master.

The timing master has a crystal oscillator which generates the timing of its transmitted data. Every other node in the network (slave nodes) uses an analog PLL to recover a clock from the received data. Each slave node simply bypasses its received data if it is not interested in sending any data. When a slave node does input data to the network, it reads in the received data, multiplexes it with data it wishes to communicate, and sends the multiplexed datastream out its transmitter.

Every node in a MOST network operates at exactly the same frequency. This is fundamentally different from FAST Ethernet and 1394.

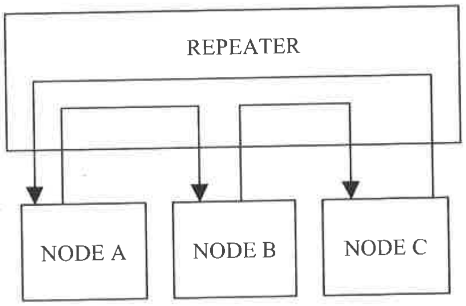


Figure 2.0: MOST with Repeater

Star

A MOST network can be implemented in a star topology (see Figure 2.0) similar to that of FAST Ethernet. A repeater box can be used for each node to connect its transmit and receive ports to. The repeater has little intelligence. If a node is not connected to a port, it is disabled. The repeater box adds cost to the system. However, it does provide fault tolerance. If one node fails, the repeater can detect this condition and bypass the faulty node.

Tree

Like IEEE 1394, a MOST network can be implemented in a daisy chain or a tree topology (see Figure 3.0). Each node can have two sets of transceivers, which enable daisy chaining. The following diagram illustrates how this works. Each node would contain a single transceiver. If a port (RX/TX pair) is not connected (nodes A and C) the transceivers that are being used are connected to the transceiver chip. If both sets are being used (node B), one pair bypasses. The logical topology is still a ring. However, physical topology is a daisy chain.

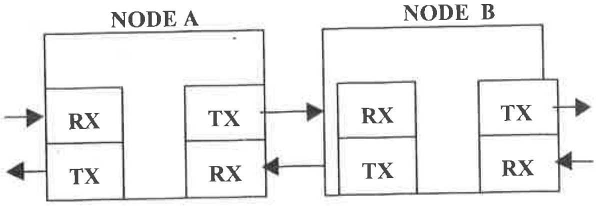


Figure 3.0: MOST with Tree Topology

If three or more transceiver pairs are implemented on a single node, a tree with multiple branches can be implemented. The daisy chain or tree topology is more expensive than a ring since the number of FOT units increase. If desired, it can be done.

MOST Communication Mechanisms

There are two different types of communication mechanisms in a MOST network. They are synchronous and packet. Both Ethernet and 1394 only support packet. Although 1394 provides a variety of packet types including asynchronous and isochronous, they are still packets. MOST provides two types of packet communication channels. They are called asynchronous and control frame. Asynchronous is functionally identical to Ethernet and can support 10 Mbit Ethernet running TCP/IP. The control channel is a unique asynchronous channel allocated its own guaranteed bandwidth.

MOST Frame Structure

MOST has a frame structure similar to a frame in telecommunications. When a long-distance telephone call is made, a number of switches are set up in central offices across the country through which the digitized voice will pass. If all the bandwidth of the network is consumed by other telephone calls, the local central

office will inform the caller that all circuits are busy; try again later. If there is bandwidth available, the call is connected and communications can begin. The connection is actually 2 connections; one in each direction. These connections are time slots in a frame that repeats at 8KHz. Voice is digitized at this rate.

A MOST frame repeats at the audio sample rate since the desired audio quality is better than that of the telephone system. The audio sample rate is typically 44.1 kHz or 48 kHz. This repeating frame is divided into 64-byte wide channels. The total bandwidth is 64x8x48KHz = 24.5 Mbit/sec. Of these 64 channels, 2 are allocated to the control channel, 2 are used for the network management functions and 60 are divided between synchronous and asynchronous channels. The boundary between the two is user defined. The useable bandwidth is 62x8x48K = 23.8 Mbit/sec.

MOST Synchronous Channels

The synchronous (sync) channels are used to communicate streaming video, audio and voice data. As in the telephone system, this data flows through the MOST network. It is not packetized, so there is no need for buffers, packet headers or for intelligence at every node to manage them.

When a CD player wants to start playing, it asks the network for bandwidth. If synchronous bandwidth is available (all circuits are not busy), the network will allocate 4 bytes to the CD player.

Each node in the MOST network acts like a central office in the telephone system. A central office is essentially a big cross point switch which routes input voice channels to output voice channels. When a telephone is dialed, a switch is set up which stays in place until the call is ended.

Likewise, a MOST node can route the synchronous data it receives from the network back out on the network or it can route the data off the network. For instance, a power amplifier could route data from the CD player off the network and to its D/A converters. The rest of the synchronous channels could simply be routed back onto the network, digitized voice from a microphone could bypass the amplifier on its way to the cell telephone.

The approach used in MOST to communicate streaming audio, video and voice data is inherently more efficient than the packet-based method in 1394 and Fast Ethernet. The synchronous approach in MOST has zero overhead or 100% efficiency. This is in comparison to the 40% efficiency for audio and 2% efficiency for voice for 1394. These efficiency numbers explain why MOST can communicate 15 stereo audio channels over the 22 Mbit usable bandwidth while 1394 can support a maximum of 20 stereo audio channels with 100 Mbit.

When the data rate of the stream decreases, MOST throughput becomes even greater than 1394, even though the raw data rate is 4 times higher. For example, 1394 can support a maximum of 24 voice channels while MOST can support at least 60. With additional hardware next to the MOST transceiver, 360 voice channels can be supported. These differences are dramatic.

The synchronous nature of MOST eliminates the problems illustrated in the previous 1394 examples of a CD player and digital amplifier. The timing of every MOST node is slaved to the master so they all operate at exactly the same frequency. The CD player will produce samples at the rate determined by the crystal in the master and the D/A converter in the digital amplifier is accepting samples at this rate as well. There is no need for the sample rate conversion or complicated PLLs. This results in higher quality and much lower cost per node.

MOST Control Channel

The control channel is used to send short messages to devices to control various functions. Examples of such messages are to change the track on a CD player or change the volume in an amplifier. The MOST specification defines a complete set of commands, or application protocols, which can be communicated over the control channel. The specification provides enough flexibility and expansion to accommodate common devices as well as unforeseen devices that may be required in the future. Space is also reserved for user-defined devices.

MOST Application Protocols

The MOST application protocols do not have to be used. However, they were developed in cooperation with major auto manufacturers and consumer equipment suppliers specifically for networking consumer devices. This does not exist in 1394 or FAST Ethernet.

Fast Ethernet and 1394 define the mechanisms for sending and receiving data; however, there is no specification for what the data means. Typically, TCP/IP is run over Fast Ethernet and standard applications, such as FTP, sendmail, etc., are provided with the operating systems. These and other applications define the messages in most computer networks.

IEEE 1394 is different. The standard simply specifies an address space. Part of the address space specifies the address of the node. The other part of the address space specifies memory locations inside a node. When messages are sent to a particular node, the data in the message is written to the specified memory locations in

that node. Some of this address space is defined in order to operate the network; however, the majority of the address space is undefined.

Some companies, such as Yamaha (M-LAN), have developed sets of protocols for audio applications. However, they are not part of the specification. This results in physical compatibility between 1394 devices but not software compatibility. Devices from different companies speak different languages.

As defined by the 1394 specification, an isochronous packet has a header, checksum and useful data. The M-LAN specification defines an additional header that goes into the useful data field. This overhead was not considered in the 1394 efficiency calculations described earlier.

MOST Bandwidth

The control channel in MOST consists of two bytes per frame. At a frame rate of 48 kHz this provides 768K bits of bandwidth. Messages can be sent once every 16 frames (block boundary). This means 3000 control messages can be sent per second independent of how much synchronous bandwidth is being used.

A MOST control message consists of a header, user data and a checksum. The user data field can be up to 17 bytes and the efficiency is 53%. As shown in the section on 1394, the total time for a 17 byte message in a large network (16 nodes) running at 100 Mbit is about 1.4 μsec for arbitration, 3.5 μsec to send the message (44bytes * 8bits/byte * 10ns), and 5.6 μsec for acknowledge and sub-action gap. The total time is about 10.5 μsec. This means the efficiency is about (17bytes * 8 bits * 10ns) / 10.5 μsec X 100% or 13%, which is 4 times worse than MOST.

MOST Arbitration

The arbitration mechanism for control frame messages is very similar to that of 1394. Nodes closer to the root node (in 1394) have a higher natural priority while nodes closer to the timing master have a higher natural priority in MOST. In both 1394 and MOST (control channel) one node always wins arbitration and sends a message, which is in contrast to the collision detection mechanism in Ethernet.

IEEE 1394 defines a fairness interval during which all nodes have an opportunity to send one message. The MOST control channel assigns a priority to all nodes (in addition to the natural priority) which decreases each time a node sends a message. Periodically the priority registers are all reset to the highest level. This periodic resetting is analogous to the 1394 fairness interval. These mechanisms are not found in Ethernet.

MOST Acknowledgement

Control frame messages have automatic acknowledgement. If a destination node receives a control frame packet properly, an acknowledge signal is automatically sent back to the transmitting node. If a destination node does not properly receive a packet because its receive buffer was full, the checksum was incorrect, the destination address was incorrect, etc., information is sent back to the sending node specifying why the message was not properly received.

IEEE 1394 provides similar low level acknowledges. However, Fast Ethernet does not. Fast Ethernet expects the higher level protocols to ensure reliable data transmission. If a Fast Ethernet packet is not received properly, the receiving node simply ignores the packet. the transmitting node does not know if the message was received or not. The higher level protocol Transport Control Protocol (TCP) ensures reliable communication. This is done through handshaking messages.

MOST Asynchronous Channel

As a quick review, a MOST frame consists of 64 bytes and repeats at the system sample rate, typically 48 kHz. Of the 64 bytes, two are used for network management, 2 are used for the control channel and the remaining 60 can be divided between synchronous and asynchronous bandwidth. The boundary between synchronous and asynchronous is user defined.

The asynchronous channel forms a packet-based network like the control frame channel. However, no higher level protocols are defined by MOST. It is intended to operate under standard protocols such as TCP/IP. Packets are similar to Fast Ethernet in that they have headers and checksums.

MOST Audio Example

Let's look at the example described in the section on IEEE 1394 of the HMI, DVD player, and digital amplifier nodes. In this case, we assumed the audio from disk was decoded in the DVD player and communicated to the digital amplifier. Since the decoded audio from the DVD player has a sample rate of 48 kHz, the sample rate for the network should be 48 kHz.

Any node in the network can be the timing master. The timing master has a crystal oscillator that generates the timing reference for all other nodes. Every node operates at exactly the same frequency. If the HMI node is the timing master, the DVD player and the digital amplifier

slave their timing to the clock recovered from the received MOST bit-stream. The recovered clock from the MOST transceiver chip drives the timing for all other circuitry on each of those nodes.

In the DVD player, the clock recovered from the MOST bit-stream (the output from the MOST transceiver) provides the master clock to the drive mechanism. Therefore data is read from the disk at a rate proportional to the 48 kHz MOST sample rate. The audio data from the decoder also has exactly the same 48 kHz-sample rate as the network. The audio data simply streams into the serial ports on the transceiver chip and onto the network.

The timing in the digital amplifier is derived from the MOST network as well. The D/A converters are operating at exactly the same audio sample rate as the data from the DVD decoder chip. The 48 kHz audio data from the DVD drive is streamed off the network through the serial ports on the MOST transceiver chip and into the D/A converters. There is no need for buffering, creating packets, converting sample rates, building complicated PLL, etc. MOST provides the simplest means to communicate streaming data.

CONCLUSION

The most cost-effective and optimum method for in-vehicle transporting of digital audio and video is synchronous transport. Asynchronous transmission is optimized for routing data, command and control. There are two digital audio interconnection standards: Audio Engineering Society (AES) and Sony-Philips Digital Interface (SPDIF). However, both of these standards are synchronous in nature and call for less than 0.25 of pulse duration of jitter. Control of jitter and delays of asynchronous transport may require proprietary complicated software solutions and additional silicon. Julian Dunn points out in his AES 106 May 1999 issue, "Sample Clock Jitter and Real-time Audio Over the IEEE 1394 High Performance Serial Bus", that CD quality audio is not realizable with current IEEE 1394 specification.

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Product/ Technology	Medium	Topology	Max. Number of Nodes		Distance (m)	Speed		
			Physical limitation (per segment)	Address-Space (Bit)		Bit Rate (Mbit/s)	Gross Rate (Mbit/s)	Net Stream Data Rate (Mbit/s)
HiQOS	POF	ring or star with passive star	60 2	60	30 10	54 108 216	36.5 44.9	32 39
IEEE1394 "FireWire"	shielded cable/POF/UTP	Tree	63	63	4.5	100 200 400 800 1600 3200	98.3 196.6 393.2 786.4 1,572.9 3,145.7	<65.5 <131 <262 <524 <1048 <2096
MOST	POF, UTP	Ring, active start, or tree	64	16	100	25 50 150	24.6 49.1 147.5	23.1 46.0 138.3
DC-BUS	DC Line Cable	Bus	16	16	12	0.562 12	0.225 6.8	0.21 6
MML	POF	Star with Coupler	10 (100 with ADN)	156	4 to star	110592	98.304	92.328 73.728 46.464
D2B	POF, UTP	Ring	64	12	100	5.6	5.6	4.2

Table 2.0: A Protocol Comparison Chart

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Detroit, Michigan USA
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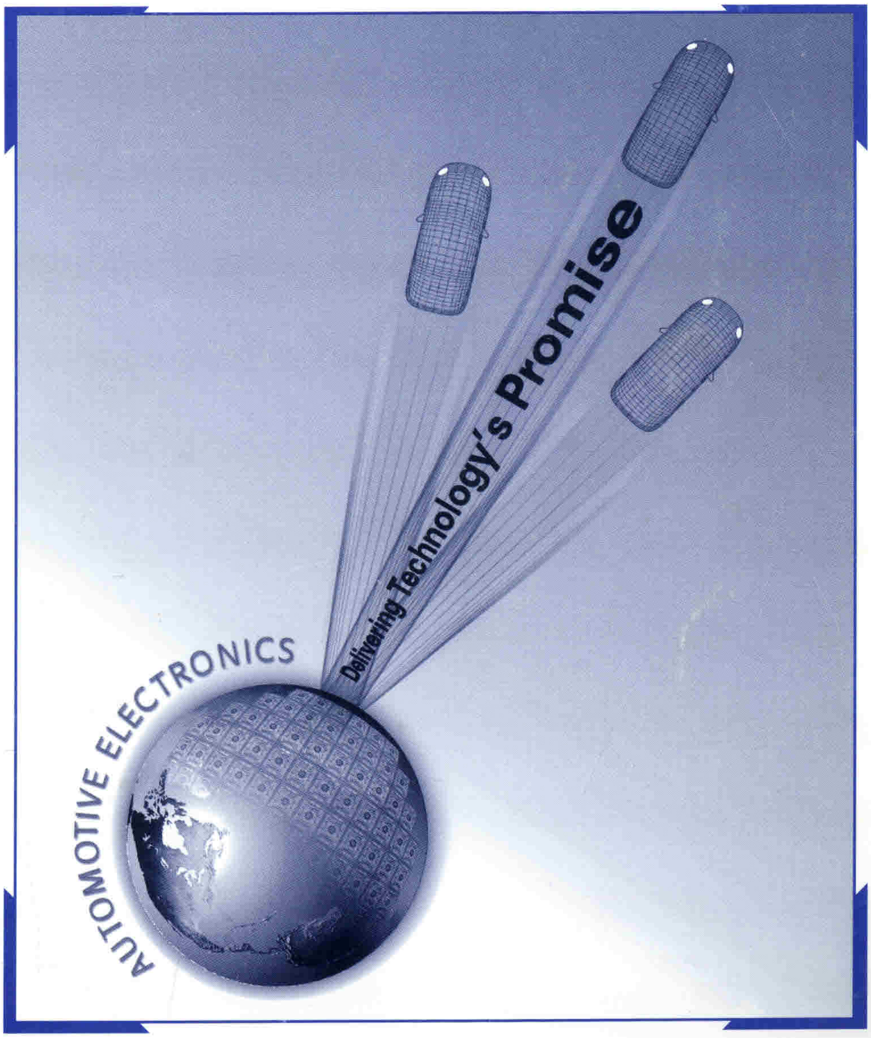

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Published by
Society of Automotive Engineers, Inc.
400 Commonwealth Drive
Warrendale, PA 15096-0001
U.S.A.
Phone (724) 776-4841
Fax: (724) 776-5760
www.sae.org
October 2000

ISBN 0-7680-0667-8
ISSN 98-86269

Printed in the United States of America.

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2000-01-C028

Future Automotive Multimedia Subsystem Interconnect Technologies

Visteon Automotive Systems

ABSTRACT

For the past decade or so, automotive entertainment subsystem architectures have consisted of a simple Human Machine Interface (HMI), AM-FM tuner, a tape deck, an amplifier and a set of speakers. Over time, as customer demand for more entertainment features increased, automotive entertainment integrators made room for new features by allowing for the vertical integration of analog audio and adding a digital control. The new digital control came to entertainment subsystems via a low speed multiplexing scheme embedded into the entertainment subsystem components, allowing remote control of these new features. New features were typically incorporated into the entertainment subsystem by independently packaging functional modules. Examples of these modules are cellular telephone, Compact Disc Jockey (CDJ), rear-seat entertainment, Satellite Digital Audio Radio System (S-DARS) receiver, voice and navigation with its associated display and hardware. Figure 1.0 is a block diagram of typical entertainment subsystem. This paper discusses alternatives to the module-expansion of entertainment subsystem via low speed digital control and analog audio. Moreover, the discussion is expanded to cover future multimedia and infotainment subsystem interconnects technologies.

INTRODUCTION

Recently, great achievements have been reached in information, communication, entertainment, comfort, safety and security products. Moreover, new Intelligent Transport Systems (ITS) services, requiring state-of-the-art electronics, are appearing on the market to help drivers process information, make decisions, and operate vehicles more safely and effectively.

As a consequence, our cars will be equipped more and more with digital systems communicating and exchanging information. Whenever possible, the trend is to go towards a super-integration of these systems, but a number of them will always be distributed in different locations of the car. A transport bus is necessary as a backbone for all the bit-streams and commands flowing between them. Table 1.0 lists some of the most important applications that are already present or will be soon introduced into the automotive environment.

Safety & Security	Entertainment	Information and Communication
Road-side assistance Mayday	Radio (AM/FM/DAB)	Internet access
Panic call	Audio (cassette, CD player, MP3)	E-mail
Collision avoidance	S-DARS	Weather forecast Head-line News Stock quotes Traffic updates Paging
Antitheft system	Video (TV, DVD)	Tourist information
Traffic information	Games	Navigation
Tolling system		Car diagnosis
		Mobile phone

Table 1.0: Near-Future Vehicle's Features

This paper assesses the suitability of current mobile multimedia transport for the accommodation of these technological advances. In addition, this paper identifies system and functional requirements for future mobile multimedia transport as well as differences between existing networks such as Ethernet, IEEE 1394, Media Oriented System Transport (MOST).

CURRENT MOBILE ARCHITECTURE

In the beginning of the automobile era, the primary function of a vehicle was a reliable transport. Over a period of years, the desire for a basic transport has been coupled with the desire for comfort, convenience, entertainment, information, communication, safety and security. Vehicle manufacturers made room for the new

features by allowing for the vertical integration of analog audio and adding a digital control. Despite the digital nature of most of the new added modules and the introduction of Digital Signal Processor (DSP) within the mobile multimedia system, the vertical integration of audio and its transport remained analog.

The Current mobile architecture with its analog transport has the following limitations:

- Analog transport complicates the subsystem interconnects, decreases reliability, adds weight and cost. Two twisted pairs are required for cabin media, one twisted pair is required for voice module, one twisted pair is required for cellular phone module, one twisted pair is required for navigation module, 3-5 wires are required for low speed multiplex scheme and synchronization. Additionally, two more twisted pairs are required for an optional media player such as CDJ. In the case of rear seat entertainment, more wires or coaxial cables are required for video. The number of wires or coaxial cables required for video applications is proportional to the number of rear seat occupants. Moreover, these wires require wide connectors with more pins at the analog power amplifier's input connector.

- The module level expansion strategy and vertical integration of analog audio resulted in a closed architecture with limited expansion path. The number of pins available at the power amplifier's input connector bounded the expansion path. In addition, the new subsystem had a short life and is not compatible with the digital trending of future entertainment features such as digital audio, digital video, Digital Audio Broadcast (DAB) and next generation of compact disc technology, Digital Versatile Disc (DVD).

- The module level expansion strategy and vertical integration of analog audio resulted in costly subsystem architecture. Often, modules added to the subsystem exhibited wasteful redundant hardware resources in order to achieve compatibility with an analog architecture. An example of this hardware wastefulness is the addition of a digital-to-analog converter to the output of CDJ or CD player to achieve compatibility with analog integration and processing. Moreover, the hardware resources available for each module are for that modules' own use and can't be shared with other subsystem's modules. This will add cost to each module and will contribute to the overall cost of the subsystem.

Presently, the module level expansion strategy and vertical integration of analog audio has reached its upper integration limit for an HMI, AM-FM tuner, voice, cellular phone, CDJ, a media player, Steering Wheel Control (SWC), a Rear Integrated Control Panel (RICP) and navigation. The implementation of such a subsystem requires seven modules and a minimum of 31 wires. A saving of one module and four wires is possible if a media, HMI, tuner, and power amplifier is packaged in one module. However, a complicated heat dissipation

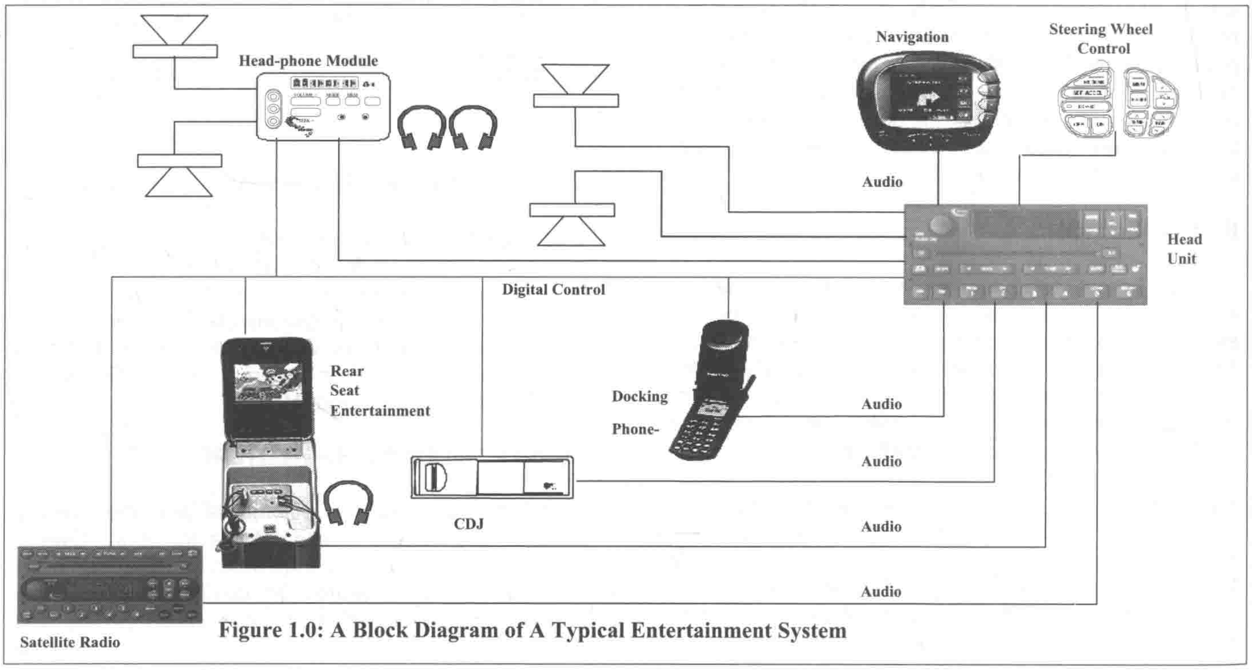


Figure 1.0: A Block Diagram of A Typical Entertainment System

and overall power management strategy is required for the success of such integration, and may limit the audio performance.

REQUIREMENTS FOR NEW TRANSPORT

Vehicles are running out of the real estate required to house new modules. Interconnect harness thickness and costs are ever increasing. This section is a discussion of both system and functional requirements for a new transport:

- Open Standard: the new transport shall be an open standard to ensure that all vehicle and electronic product manufacturers have equal access to the standard and to the market.
- Minimal Standard: the new transport standard shall be extensible and capable of migration to future technologies and different physical media with no impact on application software. A layered approach to the protocol, such as is used in the reference model of Open System Interconnect (OSI) model, shall be used.
- The new transport shall be digital to allow multiplexing of data, control, audio and video over the same media. In addition, digital transport enables open system architecture; a node can be added at anytime during the vehicle's life without modifying an existing node's connector. Moreover, a digital transport enables the natural transport of digital data from one ever increasing digital application to another without exhibited wasteful redundant hardware resources such as Digital-to Analog (DAC) and Analog-to-Digital (ADC) converters.
- Safety & Security: the new transport shall provide an environment into which devices can be plugged, unplugged, and operated in a vehicle in a manner which does not threaten the integrity of the vehicle or the devices that are being used. The new transport shall include suitable security for transactions involving the exchange of money and/or proprietary information.
- Manufacturability: the new transport compatible devices and software shall be easy to design, implement and integrate. This implies minimal specifications and unambiguous requirements. Ease of manufacture helps to assure the wide adoption of the standard and contributes to lowering the cost of the manufactured items.
- Ease of Use: the addition or removal of devices shall be easy enough for a consumer to accomplish the task with little or no expert assistance required.
- Low Cost: the incremental direct material cost to implement a new transport node shall be a fraction of the cost of the application supported.
- Graceful Degradation: the new transport's physical layer and its supported bus topology shall be designed such that any fault shall not cause any damage to the cable, the vehicle or any attached devices. Functional operation under any of these conditions may cease but shall resume within the boot/discovery time after the fault is removed. The new design shall be such that no single failure, other than a fault in the physical layer as described above, or the loss of primary power, shall cause the entire system to fail.
- Hot Plug and Play: it shall be possible to attach devices to, and remove devices from, the new transport system at any time, whether power is on or off.
- Self-Identification: devices attached to the new transport shall be able to identify themselves to other system devices and shall self configure to obtain unique addresses on the new transport. No user intervention shall be required to complete this configuration other than the provision of the appropriate application software.
- Short Boot/Discovery Time: the new transport and all attached nodes shall complete self-configuration within one second after device initialization. When a new node is added to the system while it is operating, detection of the new node and reconfiguration of the system to include it shall be completed within 2 seconds.
- Peer-to-Peer Communications: the set of devices that is likely to be attached to the new transport is unpredictable and no single device is guaranteed always to be present. Therefore, a device on the new transport shall be able to communicate directly with any other device in the system and the vehicle without need for any additional device. An application that is implemented across multiple devices may choose to implement a "master controller" for that application but this shall not be a requirement for all applications.
- Automotive Physical and Electrical Specifications: the new transport's physical layer shall meet automotive environmental (temperature, vibration, shock, EMI, etc.) and electrical specifications (reverse voltage, load dump, etc.) for the environments in which the devices are installed, e.g., passenger compartment, trunk, etc.
- Extensibility: The new transport shall be extensible to

accommodate evolving technologies and new applications. A layered approach to the protocol is required to guarantee minimum impact on existing designs as new physical layers and new applications are developed.

- Security and Authentication Services: The new transport protocol shall provide security and authentication services for access to vehicle functions. It is anticipated that additional services will require additional security measures to accommodate applications or transactions that require billing, authentication, confidentiality, confirmation, non-repudiation, etc.

- Bit Error Rate: the bit error rate shall be less than 1 x 10^{-9}. Applications requiring better than this shall be able to implement appropriate measures at higher layers of the protocol.

- Time-Critical Delivery of Packets- Deterministic Latency: Some applications may require that messages be transmitted within a given time period. The new transport shall be deterministic and it shall be possible to determine the maximum latency for any message in a given system configuration

- Private Message Service: Equipment manufacturers wish to be able to develop applications that span their own suite of products and provide competitive functions and features not achievable when products from different manufacturers are interconnected. The new transport protocol shall support the implementation of private messages that will allow such applications to be developed.

- Power Loading: the new transport gateway shall make power available for all devices connected to the new transport system. The total operating current drain of all devices connected to the new transport shall not exceed the capacity of the gateway unless power is routed directly to the device from another source or the device is self-powered (e.g., internal batteries).

- Internetworking: it is anticipated that wireless access to and from the Internet will be required for many devices attached to the new transport system. The new protocol shall not preclude the future implementation of internetworking services across multiple gateways or bridges between the new transport and other subnets such as Intelligent Transportation Data Bus (IDB).

- Explicit Device Addressability: it shall be possible to send a message from a device to a specific other device. It shall be possible for the sender to determine and use the desired recipient's unique address to deliver this message and all other devices shall ignore it.

- Broadcast Messages: it shall be possible for an application to generate a broadcast message to all devices connected to the new transport without having to address each one explicitly. A broadcast message may or may not require acknowledgment or confirmation of delivery. For example, an application may require confirmation (acknowledgment) that at least one receiving device capable of acting on the message has received the message.

- Consumer-Friendly Device Connection (No Special Tools Required): in most cases, it shall be possible for a consumer to install new transport nodes with common hand tools. There will be cases where professional installation may be required, but this should be the exception, not the rule.

- Wake/Sleep: any node shall have the ability to wake up the new transport system or put it to sleep. It shall be possible to wake up the nodes by sending a wake-up message, such as a pager. It shall be possible to put any node and all connected devices back to sleep with a sleep message. Absence of message traffic on the new transport for more than 30 minutes shall cause the new transport and all attached devices to go to sleep.

- Priority Sensitive Flow (Isochronous): consumer electronics devices such as video games, DVD and MP3 players, Dolby AC-3 audio components, etc., may require support for high speed isochronous data communications (i.e., data packets delivered at a guaranteed rate in a guaranteed order).

- Data Types: The new transport protocol shall allow any data type (ASCII, binary, bulk, etc.) to be transmitted in a message without need for any special escape characters or other similar artifacts added by the application.

- Fair Access to the new transport system: no single device shall be allowed to monopolize the new transport system.

- Message Priority Flagging: the new transport protocol shall provide a means to specify that the current message is a high or normal priority message. The protocol simply provides a mechanism to identify the message as a high priority message. It is up to the device manufacturer to determine whether support is provided and up to the application software to determine what action is to be taken when a high priority message is received or presented for transmission.

- Confirmation of Message Delivery, if required: a device sending a message to another device shall be able to explicitly request confirmation of error-free delivery of that message from the receiving device.

EXISTSING PROTOCOLS: ETHERNET, IEEE 1394 AND MOST

Fast Ethernet

Ethernet is a term commonly used to describe a variety of network implementations that share the same basic technology. Some early varieties of Ethernet are 10Base-2 and 10Base-5 which are also called 'thin net' and 'thick net' respectively. All nodes on such network tap into a single cable. A later version of Ethernet, 10Base-T, introduces the concept of a hub or a repeater. All nodes are connected directly to a single repeater, which simplifies cabling and provides buffering of electrical signals.

A newer version of Ethernet, called Fast Ethernet, operates at 10 times the speed of 10Base-T or 100 Mbit per second. It has the same star topology as 10Base-T and comes in a few different versions called 100Base-TX, 100Base-FX, and 100Base-T4. The difference between these versions is the physical layer which is electrical for TX and T4, and optical for FX. In this paper, Fast Ethernet will refer to the most common version 100Base-TX.

Ethernet Topology

Thick net Ethernet uses a single cable as a backbone for the network. Each node in the network taps into this cable through what is called a T connector. In an office environment, this cable could be routed through the ceiling with taps dropping into each office. This works well except it is difficult to add new users to the network and signal quality is sometimes difficult to control.

A Fast Ethernet uses a central repeater which connects directly to each node. This star topology enables the signal quality on the transmission line between a computer and the repeater to be well controlled and provides a relatively simple means to add users. The repeater has a number of ports which connect to each computer on the network. To add another computer, a wire is run from a free port on the repeater to the new computer. If there are no free ports, typically, another hub (or switch) can be connected to an uplink port to expand the network to virtually any size.

Ethernet Physical Layer

In a thick Ethernet, all computers are connected to one coaxial cable. This cable is used for sending and receiving messages. When the bus is idle, the voltage on the coax cable remains in a high impedance state at an intermediate level. This level is not a one or a zero, so that all nodes can easily determine if the bus is idle. When a node is transmitting, the voltage on the bus is pulled to high and low voltages depending on the data to be transmitted. Only one computer can send information at any one time. If multiple nodes try to transmit at the same time, a collision occurs, the data from both computers is corrupted, and both computers have to stop transmitting and try again when the bus is idle.

In Fast Ethernet, all nodes connect to a central repeater through two sets of twisted pairs. One pair is for transmitting and the other for receiving. Although each node has its own cable, the network operates exactly like thick Ethernet at a higher level. When a computer sends a message to the central repeater, the repeater sends the data exactly as received to all other computers connected to it. Again, if two computers try to send at the same time, a collision occurs, and both computers must try again later.

Ethernet Arbitration

Since all the computers on an Ethernet share the transmission media, only one computer can send information at any one time. If multiple nodes try to transmit at the same time, they must arbitrate for use of the bus. The rules that every node follows is called Carrier Sense Multiple Access with Collision Detection (CSMA/CD). Before a node sends a message on the bus, it sends a stream of one's and zero's called a 'carrier'. All other nodes on the network sense this carrier and do not attempt to send their own message until the original node completes its message.

There is a finite amount of time from when a node begins sending a carrier to when all nodes detect this carrier. During this time, other nodes may attempt to send a carrier. If this happens, a 'collision' will occur which corrupts the data on the bus. Transmitting nodes will both 'detect' this condition and stop transmitting. The rules then specify that each node must wait a random amount of time before attempting to transmit again. The probability that another collision will occur is low.

Ethernet Switches

Ethernet switches have become more popular than repeaters in recent years. An Ethernet switch is a more sophisticated device which prevents all messages from being sent to all computers connected to the switch. When a Fast Ethernet is implemented with a repeater, all computers connected to the repeater are said to be on the same collision domain. This is because a repeater

operates just like the coaxial cable in thick Ethernet. If two computers try to send messages at the same time, the messages collide.

An Ethernet switch divides the network into many collision domains. Each port on a switch is a different collision domain. For example, if one computer is connected to a port on an Ethernet switch, the collision domain consists of two nodes; the computer and the switch. If a port on a repeater is connected to a port on a switch, the collision domain consists of the switch and all computers connected to the repeater.

The switch has intelligence which learns the addresses of the computers connected to each port. When a message is received at one port, the destination address is determined and the message is sent out the appropriate port. Switches are typically much more efficient than repeaters. However, they cost more.

Ethernet Communication Mechanism

Information in Ethernet networks is communicated in packets. Each packet consists of a header, usable data and a checksum. The header contains information such as source and destination address, the length of usable data and possibly information about the message type. The checksum is a code sent at the end of the message so that the receiving node can determine if the packet was corrupted during transmission.

Since the header and checksum are only used to send the packet safely from the transmitting node to the receiving node, it is considered network overhead. It is not information usable by the application. In Fast Ethernet, this consumes 18 bytes. If you include the arbitration time, the total overhead is 38 bytes. In addition, the minimum usable data is 46 bytes per packet. Even if you only wish to send one byte, you still must send the 18-byte header, 46 bytes of data, and wait 20 bytes worth of time for the bus.

The efficiency of the network can be defined as the number of user data bytes per packet divided by the number of bytes in the packet plus the overhead of waiting for the bus. If only one byte of user data is sent per packet the efficiency is 1/(64+20) X 100% = 1.2%. Since the maximum user data per packet is 1500 bytes in 100BaseT, the theoretic maximum efficiency is 1500/(1518+20) X 100% = 97.5%.

The maximum efficiency is never achieved since many collisions will occur if there is a lot of activity on the bus. The effect on efficiency is difficult to predict.

Ethernet Audio Example

Let's consider a PC with a sound card connected over the network to a server which stores WAV files. A particular Wav file from the server can be played on the sound card in the following way. The client software on the PC manages a FIFO (First-In First-Out) which continually outputs audio data to the sound card. When the FIFO gets close to being empty, the client sends a message to the server to send more data. The server sends another packet to the client to fill the FIFO up again. As long as the server sends the new packet before the FIFO empties, audio can be heard. If the server responds slowly or the network is very busy, the packet may not arrive in time, the FIFO will empty and sounds will momentarily stop. This is unacceptable for most audio applications.

There is a trade off between FIFO size, the frequency of requests for more data and packet size. Since the large packets are more efficient than small packets (% overhead from header, etc), let's assume we will use the largest packet size; 1500 bytes of user data. If the audio sample rate is 48 kHz, and the audio is 16 bits/sample stereo, then we need an average of 192K bytes/second or 128 packets/sec. The overhead for the header, checksum and the required idle between packets is 38 bytes. Since the client software on the PC with the sound card must inform the server when the FIFO is nearly empty, there are another 84 bytes of overhead to send this message to the server.

The minimum total bandwidth required for one audio channel is:

1500 + 38 + 84 = 1622 bytes/packet

1622 bytes/packet * 128 packets/sec = 207616 bytes/sec

207616 bytes/sec * 8 Bits/bytes = 1.66 Mbit/sec

Since the packet size in this example is the largest allowed by Fast Ethernet, the network overhead is small compared to the audio data throughput. The disadvantage of the large packet size is the buffer size requirement in the Client. It must be 1500 bytes deep plus more for handshaking. If the extra depth is not large enough for the network to guarantee another packet will arrive prior to the buffer emptying, a loss of audio quality may occur. If the buffer empties, the audio stops. In a Fast Ethernet, it is impossible to guarantee any bandwidth. If the network has lots of traffic, you may not even be able to get the 1.66 Mbit/sec average throughput that is required. More commonly, at times of high traffic the buffer may empty no matter how large it may be.

IEEE 1394

The IEEE 1394 specification is a hardware specification that defines the serial bus architecture that Apple computer initially named FireWire. It defines serial bus specific extensions to the Control and Status Register

(CSR) Architecture for Microcomputer Buses formally adopted as ISO/IEC 13213 (ANSI/IEEE 1212).

This architecture defines a set of core features such as node architecture, address space, common transaction types, Control and Status Registers (CSR), configuration ROM format and content, message broadcast mechanism to all nodes and interrupt broadcast to all nodes. IEEE 1394 specifies how units attached to a serial bus can talk to each other, but does not define the protocols used to communicate between the nodes.

IEEE 1394 is similar to Fast Ethernet in many ways. Data is always communicated between nodes in packets. If multiple nodes try to send packets at the same time, they must arbitrate for the bus. The information in the packet headers, the packet sizes and the arbitration method, are different. However, the fundamental mechanisms are similar.

The most significant feature that IEEE 1394 provides (which Fast Ethernet does not) is guaranteed bandwidth for real time applications. These applications are allocated isochronous bandwidth which enable real time data to be communicated in packets sent at regular time intervals. This is an improvement over Fast Ethernet. However, it will be shown that there are still serious limitations.

The raw bit rate for IEEE 1394 is defined to be selectable between approximately 100, 200, and 400 Mbit/sec. Work is currently being done on an 800 Mbit specification as well. Silicon is currently being advertised to run at both 100 and 200 Mbit. However, most implementations are now at 100 Mbit/sec which is the same data rate as the large installed base of 100BaseT. Gigabit Ethernet is currently under development as well.

IEEE 1394 Physical Layer

The physical layer for IEEE 1394 consists of two sets of twisted pair wire for signals and two wires for power and ground connected between each pair of nodes. One set of twisted pairs is called data and the other is called strobe. When one node begins to send a packet, it sends Nonreturn-to-Zero (NRZ) data on the data line and transitions the strobe line only between consecutive 1's or 0's. Both sets of twisted pairs are bi-directional. Each node sends and receives data on the same sets of wires. When neither node is sending data, the twisted pairs are held in a high impedance state.

In contrast, the physical layer for Fast Ethernet consists of two sets of twisted pairs; one pair is used for transmitting data and the other pair for receiving data. This approach makes recovering data from the transmission line slightly more difficult than with IEEE 1394 since there is no strobe signal. An advantage of keeping the transmission lines unidirectional, however, is that the transmission line can be longer. The maximum cable length for Fast Ethernet is 100meters, while it is only 4.5 meters for IEEE 1394.

Each node on an IEEE 1394 bus (or in a Fast Ethernet) has its own timing source which is typically a crystal oscillator. This timing source is used by a node to transmit data and is used by a node to over sample the received data and strobe lines to recover the data. This means that all IEEE 1394 nodes are asynchronous at the lowest level. The accuracy of the timing reference in IEEE 1394 is specified to be ± 100 PPM which is typically the frequency tolerance of widely available crystal oscillators.

The nominal data rate in 100 Mbit IEEE 1394 is 98.304 Mbit. If the crystal oscillator at a particular node is operating at the high end of its frequency tolerance, it will be able to transmit data at 98.304 Mbit +100 PPM or 98.314 Mbit/sec. If it is operating at the low end of the frequency tolerance, it will transmit data at 98.294 Mbit/sec. This may seem like a trivial issue. However, the section on system timing will illustrate some important consequences for real time applications.

IEEE 1394 Topology

The physical topology for a typical IEEE 1394 network is a tree structure. Typically, a node will have a least two ports which enables multiple nodes to be daisy chained together. If a node has more than two ports, multiple branches can be created. During initialization, one node is defined to be the root node with all nodes extending down different branches. The topology can have any number of branches if no loops are created.

The tree topology, with the ability to daisy chain nodes, has the advantage of simplicity for small networks. If you have a few devices, it is easy to plug them together in a daisy chain. However, large networks can be cumbersome, particularly if network performance is optimized. To improve performance, it is desirable to minimize the propagation delay of data between any two nodes in the network. Long daisy chains can be split into many branches to reduce the delay; however, care should be taken to balance the length of the branches.

In a Fast Ethernet, a repeater or switch is required for a network with more than two nodes. This makes small networks complicated. However, it makes large networks simpler.

IEEE 1394 Arbitration

As described previously, all computers on a Fast Ethernet using a repeater (not a switch) have the same collision domain. If multiple nodes attempt to transmit at

the same time, the transmitted data is corrupted, this condition is detected, and the nodes begin to arbitrate for the bus. Likewise, all nodes on an IEEE 1394 network have the same collision domain. Only one node can send a message at one time. If multiple nodes try to send messages at the same time, only one node will gain control of the bus.

In a Fast Ethernet, if a collision between two nodes occurs, both nodes will stop transmitting and wait a variable amount of time before another attempt. If they both happen to wait the same amount of time, another collision will occur. Mechanisms are built into the network to minimize the probability of nodes colliding more than once or twice.

An IEEE 1394 network operates differently. Nodes which are closer to the root node have a higher natural priority. When two nodes attempt to transmit at the same time, the node with the higher priority wins arbitration and control of the bus. In order to prevent higher priority nodes from monopolizing the bus a fairness interval is defined. During a fairness interval, all nodes are given the opportunity to send one message.

Unlike Fast Ethernet the arbitration mechanism in IEEE 1394 is deterministic. There is zero probability that nodes will collide many times before successfully sending a message. This is important for the delivery of real time data since any unpredicted delay, no matter how unlikely, may cause buffers to overflow or underflow.

The arbitration process in IEEE 1394 consists of bus request/grant handshaking between child and parent nodes. A parent node is defined as the node on a 1394 cable which is closer to the root. The node which is further from the root, is called the child. If a child and a parent both request the bus at the same time, the parent will block the child's request and send its request to its parent. The request continues down the tree until it reaches the root node. The root node issues a bus grant which travels back up the tree to the node requesting control of the bus. Once a node receives a bus grant, it can begin sending a message.

The time that it takes to arbitrate for the bus depends on the size of the network. A bus request from a node at the end of a number of branches must propagate down the tree to the root and back up the tree to the requesting node. Information must be sent down all other branches to prevent any other node from driving the bus (through a bus request), until the granted message is sent. The total arbitration delay for a network with N hops (from parent to child or child to parent) between the furthest two nodes, is about N x 80ns in a 100 Mbit IEEE 1394 network.

IEEE 1394 Communication Mechanisms

While Ethernet treats all packet data the same, IEEE 1394 provides different types of packets. The primary packet types are asynchronous and isochronous. Asynchronous packets are functionally equivalent to Ethernet packets. Isochronous packets are only available in IEEE 1394, and provide guaranteed bandwidth to time critical applications.

IEEE 1394 Asynchronous Packets

An asynchronous packet consists of a header, a header checksum, user data and a user data checksum. The header contains information such as source address, destination address, message length, message type, etc. The size of the header and the checksums is typically 24 bytes long. The user data can be up to 512 bytes long in a 1394 network operating at 100 Mbit/sec.

When a particular node receives a message, an acknowledgement signal is automatically sent back to the sending node. If the sending node does not receive an acknowledgement signal within a specified time, it will try to re-send it a specified number of times.

The total time required for sending a minimum size message consists of the arbitration time, the time to send the packet, the time to wait for an acknowledgement, the time for the acknowledgement message and a sub-action gap time. The sub-action gap time is the time required by a node to wait after the bus is idle before it can issue a bus request. The sub-action gap time is required to ensure that no node will issue a bus request before the previous acknowledgement is received.

The total time for a one byte message in a large network (16 hops) running at 100 Mbit is about 1.4 µsec for arbitration, 2.2 µsec to send the message (28 bytes * 8 bits/byte * 10ns), and 5.6 µsec for acknowledge and sub-action gap. The total time is about 9.2 µsec. This means the efficiency is about 80 ns / 9.2 µsec X 100% or 0.9%. The total time to send a maximum size message (512 bytes) is about 50 µ sec with an efficiency of about 85%.

IEEE 1394 Isochronous Packets

The most significant improvement of IEEE 1394 over Ethernet for real time audio, video and voice applications is 1394's isochronous channels which provide guaranteed bandwidth to applications. When an application is allocated an isochronous channel, it is guaranteed to be able to send isochronous packets at regular intervals to any other nodes in the network. Each node in the network has a counter which defines these regular intervals. The Isochronous Resource Manager sends a message periodically to synchronize the counters in all nodes.

The Isochronous Resource Manager has a local counter which is clocked by a local 24.576 MHz clock and counts up to 3072. When the counter reaches 3072, the Isochronous Resource Manager resets its counter and broadcasts a message to all the nodes in the network to reset their local counters. The frequency of this synchronization message is 24.576 MHz / 3072 or 8 kHz.

After the synchronization message, all nodes that have been allocated isochronous bandwidth are allowed to send their packets. After all isochronous packets have been sent, then nodes that need to send normal asynchronous packets are allowed to do so. The time between the 8 kHz sync messages is 125 µsec. The maximum time that can be allocated to isochronous data is 100 µsec. This ensures that some bandwidth will always be available for some asynchronous packets.

IEEE 1394 Audio Example

The concept of an isochronous channel resolves the problem illustrated in the previous example of communicating audio over Fast Ethernet. Since a node that is allocated isochronous bandwidth is guaranteed to be able to send a packet every 125 µsec, the FIFO described in the Fast Ethernet example will not empty due to congestion on the network. In addition, since the audio data packets are guaranteed to arrive at fixed rate, it is intended that handshaking messages are not necessary. These are required in the Fast Ethernet example since the server needs to know when the FIFO in the PC with the sound card is nearly empty.

To send 16 bit stereo audio data at a 48 kHz-sample rate over an isochronous channel requires 24 audio data bytes per isochronous packet. This is shown below:

48 kHz * 2 bytes/sample * 2 channels = 192K bytes/sec

192k bytes/sec / 8k packets/sec = 24 bytes/packet

The header for an isochronous packet consists of eight bytes which specify the length of the data (in our case 24 bytes), the channel number, etc, It also provides a checksum for just the header. The checksum for the data consumes another 4 bytes. In total, there are 12 bytes of header and checksum overhead to send the 24 audio bytes.

Additional overhead comes in the form of arbitration time, gap time between packets and packet start and end symbols. The gap time and start and end symbols consume a fixed time equivalent to the time it takes to transmit about 3 bytes in 100 Mbit IEEE 1394. The arbitration time depends on the size of the network. For a large network that has 16 nodes between the furthest nodes, the arbitration time is approximately equivalent to 20 bytes of data.

In summary, to send the 24 bytes of audio data, a 1394 network consumes up to 35 bytes of overhead. The total time required sending such as message is about 4.7 µsec and the efficiency is about 40%. Since the maximum amount of time that can be allocated to isochronous is 100 µsec/Frame, the maximum number of audio channels that a 100 Mbit IEEE 1394 network can support is about 20.

Voice is typically sampled at 8 kHz with 8-bit resolution. The minimum data field in an isochronous packet is 4 bytes; so the packet size will be at least 16 bytes. Including the overhead described above, the time required to send this message is 4.1 µsec and the efficiency is about 2%. The total number of voice channels that a 100 Mbit IEEE 1394 network can support is about 24.

If 100 µsec per frame are consumed by isochronous packets, 25 µsec will be left for asynchronous messages. As shown in the previous section, the time to send a minimum size packet is 9.2 µsec. Consequently, a maximum of two asynchronous packets can be sent per isochronous frame. In other words, 16000 relatively small asynchronous packets can be sent per second.

As shown earlier, a 512-byte packet (largest possible in a 100 Mbit IEEE 1394 network) takes 50 µsec to send. Since only 25 µsec are available per frame for asynchronous messages, it takes two frames to send such a message. The message rate will be 4000 Bytes/second. It is possible to send such message, since the isochronous packets on the second frame are delayed until after the large asynchronous packet has been sent. If the transmit time of a packet were allowed to be larger than 50 µsec or if less than 25 µsec per frame were reserved for asynchronous packets, delivery of all the isochronous packets could not be guaranteed.

IEEE 1394 System Timing

The timing source for each node in an IEEE 1394 network is typically a crystal oscillator. As described in the physical layer section, the frequency of crystal oscillators can vary by ± 100 PPM from their nominal value. At every node a local 24.576 MHz clock is generated to clock the modulo 3072 counters used to create the 8 kHz isochronous frames. The Isochronous Resource Manager must send a synchronization message every 125 µsec to resynchronize the counters in all nodes since they are all clocked by slightly different frequencies.

If the Isochronous Resource Manager has a crystal operating slightly faster than another node, the modulo 3072 counter in the other node will sometimes count to

3072 between synchronization packets and sometimes will count to 3071. The most significant bit of this counter can be used as a synchronization signal. Its frequency will be the same as that of the Isochronous Resource Manager. However, the period will sometimes be 3071 x (1/24.576 MHz) and will sometimes be 3072 x (1/24.576 MHz).

If the crystal frequency of the Isochronous Resource Manager is slightly slower than another node, the counter in that node will sometimes count to 3072 and sometimes to 3073 (rolls over to 1) between synchronization packets. Again, the frequency of the MSB of that counter will be the same as that of the Isochronous Resource Manager (8 kHz). However, it will have 40 ns of jitter. The frequency of the jitter varies depending on the frequency difference between the two crystals. Depending on the frequency, which is unpredictable, this amplitude jitter can be clearly audible in high fidelity applications.

IEEE 1394 Computer Audio Example

Let's go back to our example of a server with a WAV file and a client PC with a sound card. If these two computers are connected together with IEEE 1394 network, then isochronous bandwidth will be allocated to communicate the audio data. The 48 kHz audio will be sent from server to client in isochronous packets. The packet rate will be 8 kHz and the audio data per packet will be 24 bytes.

If the client is the Isochronous Resource Manager, the network will operate without difficulty provided the timing in the client is designed properly. The clock for the D/A converters and the clock for the isochronous counter (24.576 MHz) must be derived from the same crystal oscillator. If this is true, the 8 kHz ischronous frame rate is exactly 6 times the 48 kHz-sample rate of the D/A converter. If the server puts 6 stereo audio samples (24 bytes) in each isochronous packet, the D/A converter receives exactly the right number of samples per second. If the client (PC with sound card) is not the Isochronous Resource Manager, problems will occur. If the server is the manager, the 8 kHz isochronous frame will be generated by its crystal oscillator. If this crystal is operating at the high end of its frequency tolerance (+100 PPM), the frame rate will be 8.0008 kHz. The server will put 6 stereo audio samples in each isochronous packet, so the number of stereo samples the client receives is 6 x 8.0008 kHz or 48.0048 kHz.
If the crystal oscillator on the sound card is operating at the low end of its frequency tolerance (-100 PPM), it will accept 47.9952K samples/second. This means the sound card gets 9.6 extra samples per second. If these samples are simply discarded, you will hear a very audible clicking sound.

A possible solution is to use the FIFO and handshaking procedure used in the Fast Ethernet example. When the FIFO in the sound card is nearly full, the client can send a message to server to send an empty packet. Since the server produces 9.6 extra samples per second, on average it would send an empty packet slightly more than 1.5 times per second. Although this method works, it requires additional hardware and/or software to implement. In other words, it costs more.

Consumer Audio Example

Consider another example of a 3-node network consisting of an HMI, a DVD player and a digital amplifier. Assume the HMI node is the Isochronous Resource Manager. Also, assume the DVD drive is decompressing the audio from disk and sending it over the network to the digital amplifier.

The DVD player will have a crystal oscillator and will nominally produce 48K stereo audio samples per second. If the crystal is operating at +100 PPM, the DVD player will generate 48004.8 stereo audio samples per second. If the HMI node has a crystal operating at exactly the nominal frequency, the isochronous frame rate will be exactly 8 kHz. Each isochronous packet from the DVD player will then contain an average of 48004.8 / 8000 or 6.0006 stereo samples/packet. This can be accomplished in different ways.

The DVD drive can send packets with seven stereo audio samples and periodically send an empty packet. In this case, six packets with seven samples will be followed by an empty packet. Once every 1.3 seconds, five packets with seven samples will be followed by an empty packet. This will produce a throughput of exactly 48.0048k samples per second.

Alternatively, the DVD drive can send most packets with six samples (24 bytes). However, occasionally a packet will contain seven samples (28 bytes). To be explicit, every 8000/4.8 (~1667) frames will contain seven samples. Although both of these procedures will put the proper number of samples per second onto the network, controlling the different packet sizes requires some effort and cost.

The digital amplifier which is receiving the audio data from the DVD player has its own crystal which is clocking the D/A converters. If this crystal is operating at –100ppm, then the D/A converter expects to receive an average of 47,995.2 stereo samples per second. Since the DVD player is producing 48,004.8 samples per second the amplifier must do something with the extra 9.6 samples each second. As mentioned previously, if these samples are simply discarded, an untrained listener will hear clicking sound.

Sample Rate Conversion

A solution to the problem in the digital amplifier described above is to convert the sample rate of the data received by the digital amplifier from 48004.8 HZ to 47,995.2 HZ. Sample rate conversion is a well-known process. However, some sort of a digital signal processor is required. This adds cost and can affect quality by producing aliasing artifacts. Sample rate conversion is significantly easier if there is a known frequency relationship between the two rates. In this example, the difference in the sample rates is unknown and must be determined by a processor in the digital amplifier.

Phase Locked Loop (PLL)

An alternative solution is slaving both the DVD player and the D/A converters to the 8 kHz isochronous frame rate. The isochronous resource manager sends synchronization messages every time it's modulo 3072 counter wraps around. The counter in the DVD player will sometimes reach 3072 when it receives the synch message and will sometimes have rolled back to 1. The MSB of this counter will have exactly the same frequency as the Isochronous Resource Manager (8.00000 kHz). However, the Least Significant Bit (LSB) will be jittered.

This jittered 8 kHz signal can go through a phase locked loop to increase the frequency by some integer factor and attenuate the jitter. This higher frequency clock can be used by the DVD drive to read data off the disk at exactly 48 kHz (instead of 48.0048 kHz). Likewise, the 8 kHz signal from the isochronous counter in the digital amplifier can go through a phase locked loop to create a 48 kHz-sample rate clock for the D/A converters. Since both the source and the destination are locked to the same timing source (isochronous frame rate), there is no need for sample rate conversion.

The issue with slaving the DVD player and the digital amplifier to the isochronous frame rate clock is complexity. The jitter on the 8 kHz clocks in the DVD player and amplifier can have a frequency anywhere between 4 kHz and DC. The jitter frequency is directly related to the frequency difference between the crystals in the DVD player (or amplifier) and the Isochronous Resource Manager. Low frequency jitter is possible to attenuate. However, very low bandwidth PLL is required. Typically, low bandwidth PLL has long lock times which may or may not be acceptable. Tricks can be played to reduce bandwidth and keep lock times to reasonable levels. However, they can easily become very complicated.

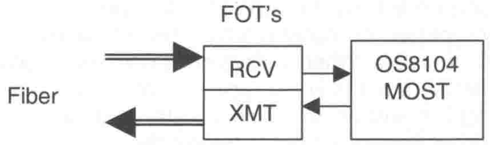
An additional problem with slaving the devices to the frame rate is that each node now has at least two asynchronous clocks. One clock is required by the 1394 interface; i.e. from a crystal. The other clock is the output of the PLL. If care is not taken in designing the digital amplifier circuitry, an aliased or mixed component of the 1394 interface clock will be heard through the speakers.

MOST

MOST (Media Oriented System Transport) is a functional specification developed specifically for interconnecting electronic devices to enable them to share electronic media, whether it is audio, video, voice or data. It defines a basic framework and provides the transport mechanisms to move media efficiently. MOST includes a hardware specification and defines the higher-level system services that need to be provided so unrelated systems can communicate with each other.

MOST Physical Layer

The physical layer is optical fiber. Each node in a MOST network has two optical ports. One for receiving data and one for transmitting. Although the transmission media can be glass fiber, it is typically plastic fiber due to lower cost and ease of installation. Fiber optic transceivers (FOT's) are available from a variety of manufacturers. The MOST network transceiver chip interfaces with the FOT units.



The physical layer of MOST is similar to that of Fast Ethernet since nodes in both technologies have separate transmit and receive ports. Data on the transmission lines for both MOST and Fast Ethernet goes in one direction. In contrast, data on a 1394 transmission line can go in both directions.

A significant difference between the physical layer of MOST and Fast Ethernet is that data is always being sent through the transmit and receive ports of a MOST node. A Fast Ethernet node only transmits data when it is sending a message. If it is not sending a message, its transmission line to the repeater (or switch) will be idle. A MOST node always bypasses the data it receives unless it is generating data. In this case, the node will multiplex its own data with the data that it receives. If no nodes are generating data, idle codes are transmitted through the network.

In a MOST network, one node is defined as the timing master. It has a crystal oscillator, which provides the timing reference for the entire network. It transmits data whether or not any node in the network is trying to communicate. If there is no useful information on the bus

the timing master, simply sends idle codes. All other nodes in the network have phase lock loops (PLLs) which recover their master clocks from the bitstream sent by the timing master.

MOST Topology

Ring

The most effective implementation of a MOST network is a ring. The ring starts with the timing master. Its optical output is connected to the optical input of the next node. The optical output of that node is connected to the optical input of the next node, and so on, until the optical output of the last node is connected to the input of the timing master.

The timing master has a crystal oscillator which generates the timing of its transmitted data. Every other node in the network (slave nodes) uses an analog PLL to recover a clock from the received data. Each slave node simply bypasses its received data if it is not interested in sending any data. When a slave node does input data to the network, it reads in the received data, multiplexes it with data it wishes to communicate, and sends the multiplexed datastream out its transmitter.

Every node in a MOST network operates at exactly the same frequency. This is fundamentally different from FAST Ethernet and 1394.

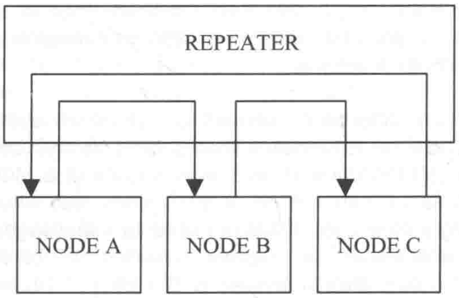


Figure 2.0: MOST with Repeater

Star

A MOST network can be implemented in a star topology (see Figure 2.0) similar to that of FAST Ethernet. A repeater box can be used for each node to connect its transmit and receive ports to. The repeater has little intelligence. If a node is not connected to a port, it is disabled. The repeater box adds cost to the system. However, it does provide fault tolerance. If one node fails, the repeater can detect this condition and bypass the faulty node.

Tree

Like IEEE 1394, a MOST network can be implemented in a daisy chain or a tree topology (see Figure 3.0). Each node can have two sets of transceivers, which enable daisy chaining. The following diagram illustrates how this works. Each node would contain a single transceiver. If a port (RX/TX pair) is not connected (nodes A and C) the transceivers that are being used are connected to the transceiver chip. If both sets are being used (node B), one pair bypasses. The logical topology is still a ring. However, physical topology is a daisy chain.

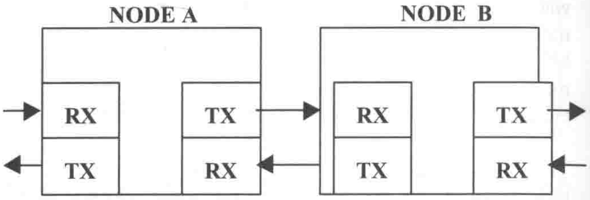


Figure 3.0: MOST with Tree Topology

If three or more transceiver pairs are implemented on a single node, a tree with multiple branches can be implemented. The daisy chain or tree topology is more expensive than a ring since the number of FOT units increase. If desired, it can be done.

MOST Communication Mechanisms

There are two different types of communication mechanisms in a MOST network. They are synchronous and packet. Both Ethernet and 1394 only support packet. Although 1394 provides a variety of packet types including asynchronous and isochronous, they are still packets. MOST provides two types of packet communication channels. They are called asynchronous and control frame. Asynchronous is functionally identical to Ethernet and can support 10 Mbit Ethernet running TCP/IP. The control channel is a unique asynchronous channel allocated its own guaranteed bandwidth.

MOST Frame Structure

MOST has a frame structure similar to a frame in telecommunications. When a long-distance telephone call is made, a number of switches are set up in central offices across the country through which the digitized voice will pass. If all the bandwidth of the network is consumed by other telephone calls, the local central

office will inform the caller that all circuits are busy; try again later. If there is bandwidth available, the call is connected and communications can begin. The connection is actually 2 connections; one in each direction. These connections are time slots in a frame that repeats at 8KHz. Voice is digitized at this rate.

A MOST frame repeats at the audio sample rate since the desired audio quality is better than that of the telephone system. The audio sample rate is typically 44.1 kHz or 48 kHz. This repeating frame is divided into 64-byte wide channels. The total bandwidth is 64x8x48KHz = 24.5 Mbit/sec. Of these 64 channels, 2 are allocated to the control channel, 2 are used for the network management functions and 60 are divided between synchronous and asynchronous channels. The boundary between the two is user defined. The useable bandwidth is 62x8x48K = 23.8 Mbit/sec.

MOST Synchronous Channels

The synchronous (sync) channels are used to communicate streaming video, audio and voice data. As in the telephone system, this data flows through the MOST network. It is not packetized, so there is no need for buffers, packet headers or for intelligence at every node to manage them.

When a CD player wants to start playing, it asks the network for bandwidth. If synchronous bandwidth is available (all circuits are not busy), the network will allocate 4 bytes to the CD player.

Each node in the MOST network acts like a central office in the telephone system. A central office is essentially a big cross point switch which routes input voice channels to output voice channels. When a telephone is dialed, a switch is set up which stays in place until the call is ended.

Likewise, a MOST node can route the synchronous data it receives from the network back out on the network or it can route the data off the network. For instance, a power amplifier could route data from the CD player off the network and to its D/A converters. The rest of the synchronous channels could simply be routed back onto the network, digitized voice from a microphone could bypass the amplifier on its way to the cell telephone.

The approach used in MOST to communicate streaming audio, video and voice data is inherently more efficient than the packet-based method in 1394 and Fast Ethernet. The synchronous approach in MOST has zero overhead or 100% efficiency. This is in comparison to the 40% efficiency for audio and 2% efficiency for voice for 1394. These efficiency numbers explain why MOST can communicate 15 stereo audio channels over the 22 Mbit usable bandwidth while 1394 can support a maximum of 20 stereo audio channels with 100 Mbit.

When the data rate of the stream decreases, MOST throughput becomes even greater than 1394, even though the raw data rate is 4 times higher. For example, 1394 can support a maximum of 24 voice channels while MOST can support at least 60. With additional hardware next to the MOST transceiver, 360 voice channels can be supported. These differences are dramatic.

The synchronous nature of MOST eliminates the problems illustrated in the previous 1394 examples of a CD player and digital amplifier. The timing of every MOST node is slaved to the master so they all operate at exactly the same frequency. The CD player will produce samples at the rate determined by the crystal in the master and the D/A converter in the digital amplifier is accepting samples at this rate as well. There is no need for the sample rate conversion or complicated PLLs. This results in higher quality and much lower cost per node.

MOST Control Channel

The control channel is used to send short messages to devices to control various functions. Examples of such messages are to change the track on a CD player or change the volume in an amplifier. The MOST specification defines a complete set of commands, or application protocols, which can be communicated over the control channel. The specification provides enough flexibility and expansion to accommodate common devices as well as unforeseen devices that may be required in the future. Space is also reserved for user-defined devices.

MOST Application Protocols

The MOST application protocols do not have to be used. However, they were developed in cooperation with major auto manufacturers and consumer equipment suppliers specifically for networking consumer devices. This does not exist in 1394 or FAST Ethernet.

Fast Ethernet and 1394 define the mechanisms for sending and receiving data; however, there is no specification for what the data means. Typically, TCP/IP is run over Fast Ethernet and standard applications, such as FTP, sendmail, etc., are provided with the operating systems. These and other applications define the messages in most computer networks.

IEEE 1394 is different. The standard simply specifies an address space. Part of the address space specifies the address of the node. The other part of the address space specifies memory locations inside a node. When messages are sent to a particular node, the data in the message is written to the specified memory locations in

that node. Some of this address space is defined in order to operate the network; however, the majority of the address space is undefined.

Some companies, such as Yamaha (M-LAN), have developed sets of protocols for audio applications. However, they are not part of the specification. This results in physical compatibility between 1394 devices but not software compatibility. Devices from different companies speak different languages.

As defined by the 1394 specification, an isochronous packet has a header, checksum and useful data. The M-LAN specification defines an additional header that goes into the useful data field. This overhead was not considered in the 1394 efficiency calculations described earlier.

MOST Bandwidth

The control channel in MOST consists of two bytes per frame. At a frame rate of 48 kHz this provides 768K bits of bandwidth. Messages can be sent once every 16 frames (block boundary). This means 3000 control messages can be sent per second independent of how much synchronous bandwidth is being used.

A MOST control message consists of a header, user data and a checksum. The user data field can be up to 17 bytes and the efficiency is 53%. As shown in the section on 1394, the total time for a 17 byte message in a large network (16 nodes) running at 100 Mbit is about 1.4 μsec for arbitration, 3.5 μsec to send the message (44bytes * 8bits/byte * 10ns), and 5.6 μsec for acknowledge and sub-action gap. The total time is about 10.5 μsec. This means the efficiency is about (17bytes * 8 bits * 10ns) / 10.5 μsec X 100% or 13%, which is 4 times worse than MOST.

MOST Arbitration

The arbitration mechanism for control frame messages is very similar to that of 1394. Nodes closer to the root node (in 1394) have a higher natural priority while nodes closer to the timing master have a higher natural priority in MOST. In both 1394 and MOST (control channel) one node always wins arbitration and sends a message, which is in contrast to the collision detection mechanism in Ethernet.

IEEE 1394 defines a fairness interval during which all nodes have an opportunity to send one message. The MOST control channel assigns a priority to all nodes (in addition to the natural priority) which decreases each time a node sends a message. Periodically the priority registers are all reset to the highest level. This periodic resetting is analogous to the 1394 fairness interval. These mechanisms are not found in Ethernet.

MOST Acknowledgement

Control frame messages have automatic acknowledgement. If a destination node receives a control frame packet properly, an acknowledge signal is automatically sent back to the transmitting node. If a destination node does not properly receive a packet because its receive buffer was full, the checksum was incorrect, the destination address was incorrect, etc., information is sent back to the sending node specifying why the message was not properly received.

IEEE 1394 provides similar low level acknowledges. However, Fast Ethernet does not. Fast Ethernet expects the higher level protocols to ensure reliable data transmission. If a Fast Ethernet packet is not received properly, the receiving node simply ignores the packet. the transmitting node does not know if the message was received or not. The higher level protocol Transport Control Protocol (TCP) ensures reliable communication. This is done through handshaking messages.

MOST Asynchronous Channel

As a quick review, a MOST frame consists of 64 bytes and repeats at the system sample rate, typically 48 kHz. Of the 64 bytes, two are used for network management, 2 are used for the control channel and the remaining 60 can be divided between synchronous and asynchronous bandwidth. The boundary between synchronous and asynchronous is user defined.

The asynchronous channel forms a packet-based network like the control frame channel. However, no higher level protocols are defined by MOST. It is intended to operate under standard protocols such as TCP/IP. Packets are similar to Fast Ethernet in that they have headers and checksums.

MOST Audio Example

Let's look at the example described in the section on IEEE 1394 of the HMI, DVD player, and digital amplifier nodes. In this case, we assumed the audio from disk was decoded in the DVD player and communicated to the digital amplifier. Since the decoded audio from the DVD player has a sample rate of 48 kHz, the sample rate for the network should be 48 kHz.

Any node in the network can be the timing master. The timing master has a crystal oscillator that generates the timing reference for all other nodes. Every node operates at exactly the same frequency. If the HMI node is the timing master, the DVD player and the digital amplifier

slave their timing to the clock recovered from the received MOST bit-stream. The recovered clock from the MOST transceiver chip drives the timing for all other circuitry on each of those nodes.

In the DVD player, the clock recovered from the MOST bit-stream (the output from the MOST transceiver) provides the master clock to the drive mechanism. Therefore data is read from the disk at a rate proportional to the 48 kHz MOST sample rate. The audio data from the decoder also has exactly the same 48 kHz-sample rate as the network. The audio data simply streams into the serial ports on the transceiver chip and onto the network.

The timing in the digital amplifier is derived from the MOST network as well. The D/A converters are operating at exactly the same audio sample rate as the data from the DVD decoder chip. The 48 kHz audio data from the DVD drive is streamed off the network through the serial ports on the MOST transceiver chip and into the D/A converters. There is no need for buffering, creating packets, converting sample rates, building complicated PLL, etc. MOST provides the simplest means to communicate streaming data.

CONCLUSION

The most cost-effective and optimum method for in-vehicle transporting of digital audio and video is synchronous transport. Asynchronous transmission is optimized for routing data, command and control. There are two digital audio interconnection standards: Audio Engineering Society (AES) and Sony-Philips Digital Interface (SPDIF). However, both of these standards are synchronous in nature and call for less than 0.25 of pulse duration of jitter. Control of jitter and delays of asynchronous transport may require proprietary complicated software solutions and additional silicon. Julian Dunn points out in his AES 106 May 1999 issue, "Sample Clock Jitter and Real-time Audio Over the IEEE 1394 High Performance Serial Bus", that CD quality audio is not realizable with current IEEE 1394 specification.

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Product/ Technology	Medium	Topology	Max. Number of Nodes		Distance (m)	Speed		
			Physical limitation (per segment)	Address-Space (Bit)		Bit Rate (Mbit/s)	Gross Rate (Mbit/s)	Net Stream Data Rate (Mbit/s)
HiQOS	POF	ring or star with passive star	60 2	60	30 10	54 108 216	36.5 44.9	32 39
IEEE1394 "FireWire"	shielded cable/POF/UTP	Tree	63	63	4.5	100	98.3	<65.5
						200	196.6	<131
						400	393.2	<262
						800	786.4	<524
						1600	1,572.9	<1048
						3200	3,145.7	<2096
MOST	POF, UTP	Ring, active start, or tree	64	16	100	25	24.6	23.1
						50	49.1	46.0
						150	147.5	138.3
DC-BUS	DC Line Cable	Bus	16	16	12	0.562	0.225	0.21
						12	6.8	6
MML	POF	Star with Coupler	10 (100 with ADN)	156	4 to star	110592	98.304	92.328 73.728 46.464
D2B	POF, UTP	Ring	64	12	100	5.6	5.6	4.2

Table 2.0: A Protocol Comparison Chart

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Shelf Access	Find it in the library/Request item
Shelf Location	Barker Library - Stacks | TL272.5.I57 2000
Published	Warrendale, PA : Society of Automotive Engineers, c2000.
Description	603 p. : ill. ; 28 cm.
Series	P (Society of Automotive Engineers) ; P-360.
Format	Book
Note	"Proceedings, October 16-18, 2000"--Cover.
Bibliography	Includes bibliographical references.
Subject	Automobiles -- Electronic equipment -- Congresses. Intelligent control systems -- Congresses. Intelligent transportation systems -- Congresses.
Other Author	Society of Automotive Engineers.
Other Title	Proceedings of the 2000 International Congress on Transportation Electronics. Convergence 2000.
ISBN	0768006678
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24630  |a Proceedings of the 2000 International Congress on Transportation Electronics
24630  |a Convergence 2000
260    |a Warrendale, PA : |b Society of Automotive Engineers, |c c2000.
300    |a 603 p. : |b ill. ; |c 28 cm.
4901   |a P ; |v 360
500    |a "Proceedings, October 16-18, 2000"--Cover.
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650 0  |a Intelligent control systems |v Congresses.
650 0  |a Intelligent transportation systems |v Congresses.
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830 0  |a P (Society of Automotive Engineers) ; |v P-360.
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CAT    |a lti0904 |b 00 |c 20090524 |l MIT01 |h 0040
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910    |a mjy010105
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Order #141639

Standard

Request Date:	05/16/2018 12:51pm
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Phone:	410-263-9355
Reference:	
Delivery email:	**ihsiehyee@hotmail.com**
Instructions:	**Already have this from Library of Congress; need it from 2 more libraries: cover, title page, date stamp page, copyright page, TOC, and the article.**

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05/18/2018 01:00pm

Maxcost: $150

Citation:

Mufid AM. Future automotive multimedia subsystem interconnect technologies. (No. 2000-01-C028). SAE Technical Paper series; 2000 Nov 1. (document no. 2000-01-C028).

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Published by
Society of Automotive Engineers, Inc.
400 Commonwealth Drive
Warrendale, PA 15096-0001
U.S.A.
Phone (724) 776-4841
Fax: (724) 776-5760
www.sae.org
October 2000

ISBN 0-7680-0667-8
ISSN 98-86269

Printed in the United States of America.

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2000-01-C028

Future Automotive Multimedia Subsystem Interconnect Technologies

Visteon Automotive Systems

ABSTRACT

For the past decade or so, automotive entertainment subsystem architectures have consisted of a simple Human Machine Interface (HMI), AM-FM tuner, a tape deck, an amplifier and a set of speakers. Over time, as customer demand for more entertainment features increased, automotive entertainment integrators made room for new features by allowing for the vertical integration of analog audio and adding a digital control. The new digital control came to entertainment subsystems via a low speed multiplexing scheme embedded into the entertainment subsystem components, allowing remote control of these new features. New features were typically incorporated into the entertainment subsystem by independently packaging functional modules. Examples of these modules are cellular telephone, Compact Disc Jockey (CDJ), rear-seat entertainment, Satellite Digital Audio Radio System (S-DARS) receiver, voice and navigation with its associated display and hardware. Figure 1.0 is a block diagram of typical entertainment subsystem. This paper discusses alternatives to the module-expansion of entertainment subsystem via low speed digital control and analog audio. Moreover, the discussion is expanded to cover future multimedia and infotainment subsystem interconnects technologies.

INTRODUCTION

Recently, great achievements have been reached in information, communication, entertainment, comfort, safety and security products. Moreover, new Intelligent Transport Systems (ITS) services, requiring state-of-the-art electronics, are appearing on the market to help drivers process information, make decisions, and operate vehicles more safely and effectively.

As a consequence, our cars will be equipped more and more with digital systems communicating and exchanging information. Whenever possible, the trend is to go towards a super-integration of these systems, but a number of them will always be distributed in different locations of the car. A transport bus is necessary as a backbone for all the bit-streams and commands flowing between them. Table 1.0 lists some of the most important applications that are already present or will be soon introduced into the automotive environment.

Safety & Security	Entertainment	Information and Communication
Road-side assistance Mayday	Radio (AM/FM/DAB)	Internet access
Panic call	Audio (cassette, CD player, MP3)	E-mail
Collision avoidance	S-DARS	Weather forecast Head-line News Stock quotes Traffic updates Paging
Antitheft system	Video (TV, DVD)	Tourist information
Traffic information	Games	Navigation
Tolling system		Car diagnosis
		Mobile phone

Table 1.0: Near-Future Vehicle's Features

This paper assesses the suitability of current mobile multimedia transport for the accommodation of these technological advances. In addition, this paper identifies system and functional requirements for future mobile multimedia transport as well as differences between existing networks such as Ethernet, IEEE 1394, Media Oriented System Transport (MOST).

CURRENT MOBILE ARCHITECTURE

In the beginning of the automobile era, the primary function of a vehicle was a reliable transport. Over a period of years, the desire for a basic transport has been coupled with the desire for comfort, convenience, entertainment, information, communication, safety and security. Vehicle manufacturers made room for the new

features by allowing for the vertical integration of analog audio and adding a digital control. Despite the digital nature of most of the new added modules and the introduction of Digital Signal Processor (DSP) within the mobile multimedia system, the vertical integration of audio and its transport remained analog.

The Current mobile architecture with its analog transport has the following limitations:

- Analog transport complicates the subsystem interconnects, decreases reliability, adds weight and cost. Two twisted pairs are required for cabin media, one twisted pair is required for voice module, one twisted pair is required for cellular phone module, one twisted pair is required for navigation module, 3-5 wires are required for low speed multiplex scheme and synchronization. Additionally, two more twisted pairs are required for an optional media player such as CDJ. In the case of rear seat entertainment, more wires or coaxial cables are required for video. The number of wires or coaxial cables required for video applications is proportional to the number of rear seat occupants. Moreover, these wires require wide connectors with more pins at the analog power amplifier's input connector.
- The module level expansion strategy and vertical integration of analog audio resulted in a closed architecture with limited expansion path. The number of pins available at the power amplifier's input connector bounded the expansion path. In addition, the new subsystem had a short life and is not compatible with the digital trending of future entertainment features such as digital audio, digital video, Digital Audio Broadcast (DAB) and next generation of compact disc technology, Digital Versatile Disc (DVD).
- The module level expansion strategy and vertical integration of analog audio resulted in costly subsystem architecture. Often, modules added to the subsystem exhibited wasteful redundant hardware resources in order to achieve compatibility with an analog architecture. An example of this hardware wastefulness is the addition of a digital-to-analog converter to the output of CDJ or CD player to achieve compatibility with analog integration and processing. Moreover, the hardware resources available for each module are for that modules' own use and can't be shared with other subsystem's modules. This will add cost to each module and will contribute to the overall cost of the subsystem.

Presently, the module level expansion strategy and vertical integration of analog audio has reached its upper integration limit for an HMI, AM-FM tuner, voice, cellular phone, CDJ, a media player, Steering Wheel Control (SWC), a Rear Integrated Control Panel (RICP) and navigation. The implementation of such a subsystem requires seven modules and a minimum of 31 wires. A saving of one module and four wires is possible if a media, HMI, tuner, and power amplifier is packaged in one module. However, a complicated heat dissipation

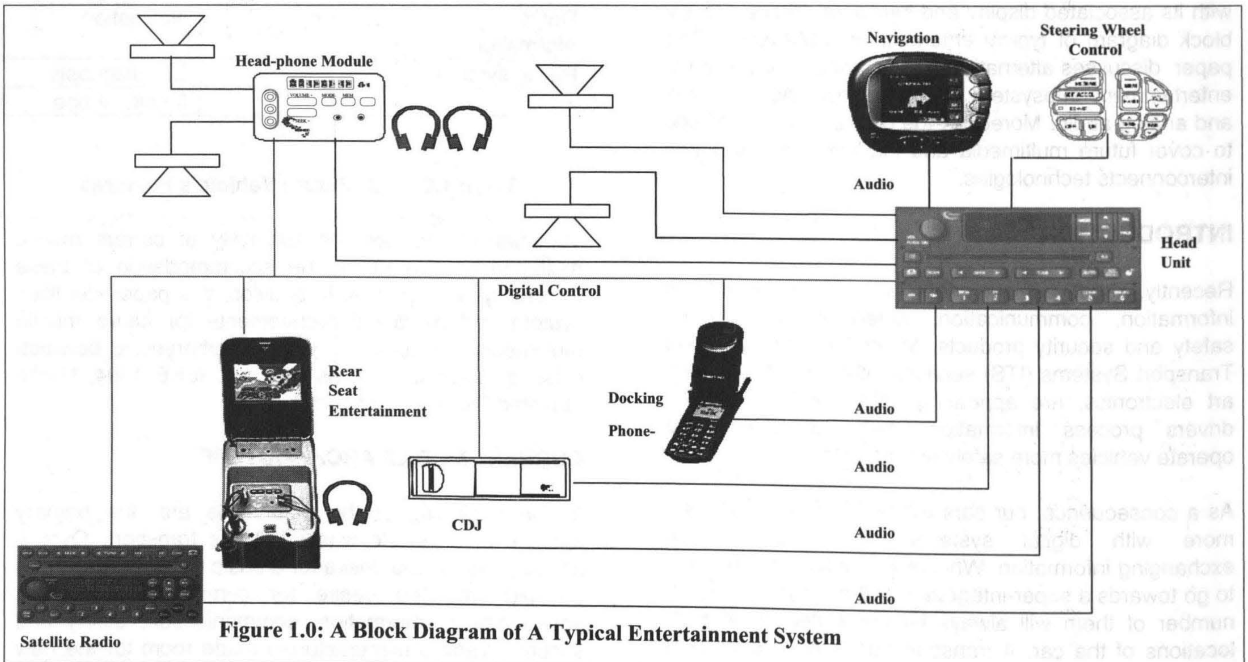


Figure 1.0: A Block Diagram of A Typical Entertainment System

and overall power management strategy is required for the success of such integration, and may limit the audio performance.

REQUIREMENTS FOR NEW TRANSPORT

Vehicles are running out of the real estate required to house new modules. Interconnect harness thickness and costs are ever increasing. This section is a discussion of both system and functional requirements for a new transport:

- Open Standard: the new transport shall be an open standard to ensure that all vehicle and electronic product manufacturers have equal access to the standard and to the market.
- Minimal Standard: the new transport standard shall be extensible and capable of migration to future technologies and different physical media with no impact on application software. A layered approach to the protocol, such as is used in the reference model of Open System Interconnect (OSI) model, shall be used.
- The new transport shall be digital to allow multiplexing of data, control, audio and video over the same media. In addition, digital transport enables open system architecture; a node can be added at anytime during the vehicle's life without modifying an existing node's connector. Moreover, a digital transport enables the natural transport of digital data from one ever increasing digital application to another without exhibited wasteful redundant hardware resources such as Digital-to Analog (DAC) and Analog-to-Digital (ADC) converters.
- Safety & Security: the new transport shall provide an environment into which devices can be plugged, unplugged, and operated in a vehicle in a manner which does not threaten the integrity of the vehicle or the devices that are being used. The new transport shall include suitable security for transactions involving the exchange of money and/or proprietary information.
- Manufacturability: the new transport compatible devices and software shall be easy to design, implement and integrate. This implies minimal specifications and unambiguous requirements. Ease of manufacture helps to assure the wide adoption of the standard and contributes to lowering the cost of the manufactured items.
- Ease of Use: the addition or removal of devices shall be easy enough for a consumer to accomplish the task with little or no expert assistance required.
- Low Cost: the incremental direct material cost to implement a new transport node shall be a fraction of the cost of the application supported.
- Graceful Degradation: the new transport's physical layer and its supported bus topology shall be designed such that any fault shall not cause any damage to the cable, the vehicle or any attached devices. Functional operation under any of these conditions may cease but shall resume within the boot/discovery time after the fault is removed. The new design shall be such that no single failure, other than a fault in the physical layer as described above, or the loss of primary power, shall cause the entire system to fail.
- Hot Plug and Play: it shall be possible to attach devices to, and remove devices from, the new transport system at any time, whether power is on or off.
- Self-Identification: devices attached to the new transport shall be able to identify themselves to other system devices and shall self configure to obtain unique addresses on the new transport. No user intervention shall be required to complete this configuration other than the provision of the appropriate application software.
- Short Boot/Discovery Time: the new transport and all attached nodes shall complete self-configuration within one second after device initialization. When a new node is added to the system while it is operating, detection of the new node and reconfiguration of the system to include it shall be completed within 2 seconds.
- Peer-to-Peer Communications: the set of devices that is likely to be attached to the new transport is unpredictable and no single device is guaranteed always to be present. Therefore, a device on the new transport shall be able to communicate directly with any other device in the system and the vehicle without need for any additional device. An application that is implemented across multiple devices may choose to implement a "master controller" for that application but this shall not be a requirement for all applications.
- Automotive Physical and Electrical Specifications: the new transport's physical layer shall meet automotive environmental (temperature, vibration, shock, EMI, etc.) and electrical specifications (reverse voltage, load dump, etc.) for the environments in which the devices are installed, e.g., passenger compartment, trunk, etc.
- Extensibility: The new transport shall be extensible to

accommodate evolving technologies and new applications. A layered approach to the protocol is required to guarantee minimum impact on existing designs as new physical layers and new applications are developed.

- Security and Authentication Services: The new transport protocol shall provide security and authentication services for access to vehicle functions. It is anticipated that additional services will require additional security measures to accommodate applications or transactions that require billing, authentication, confidentiality, confirmation, non-repudiation, etc.

- Bit Error Rate: the bit error rate shall be less than 1 x 10^{-9}. Applications requiring better than this shall be able to implement appropriate measures at higher layers of the protocol.

- Time-Critical Delivery of Packets- Deterministic Latency: Some applications may require that messages be transmitted within a given time period. The new transport shall be deterministic and it shall be possible to determine the maximum latency for any message in a given system configuration

- Private Message Service: Equipment manufacturers wish to be able to develop applications that span their own suite of products and provide competitive functions and features not achievable when products from different manufacturers are interconnected. The new transport protocol shall support the implementation of private messages that will allow such applications to be developed.

- Power Loading: the new transport gateway shall make power available for all devices connected to the new transport system. The total operating current drain of all devices connected to the new transport shall not exceed the capacity of the gateway unless power is routed directly to the device from another source or the device is self-powered (e.g., internal batteries).

- Internetworking: it is anticipated that wireless access to and from the Internet will be required for many devices attached to the new transport system. The new protocol shall not preclude the future implementation of internetworking services across multiple gateways or bridges between the new transport and other subnets such as Intelligent Transportation Data Bus (IDB).

- Explicit Device Addressability: it shall be possible to send a message from a device to a specific other device. It shall be possible for the sender to determine and use the desired recipient's unique address to deliver this message and all other devices shall ignore it.

- Broadcast Messages: it shall be possible for an application to generate a broadcast message to all devices connected to the new transport without having to address each one explicitly. A broadcast message may or may not require acknowledgment or confirmation of delivery. For example, an application may require confirmation (acknowledgment) that at least one receiving device capable of acting on the message has received the message.

- Consumer-Friendly Device Connection (No Special Tools Required): in most cases, it shall be possible for a consumer to install new transport nodes with common hand tools. There will be cases where professional installation may be required, but this should be the exception, not the rule.

- Wake/Sleep: any node shall have the ability to wake up the new transport system or put it to sleep. It shall be possible to wake up the nodes by sending a wake-up message, such as a pager. It shall be possible to put any node and all connected devices back to sleep with a sleep message. Absence of message traffic on the new transport for more than 30 minutes shall cause the new transport and all attached devices to go to sleep.

- Priority Sensitive Flow (Isochronous): consumer electronics devices such as video games, DVD and MP3 players, Dolby AC-3 audio components, etc., may require support for high speed isochronous data communications (i.e., data packets delivered at a guaranteed rate in a guaranteed order).

- Data Types: The new transport protocol shall allow any data type (ASCII, binary, bulk, etc.) to be transmitted in a message without need for any special escape characters or other similar artifacts added by the application.

- Fair Access to the new transport system: no single device shall be allowed to monopolize the new transport system.

- Message Priority Flagging: the new transport protocol shall provide a means to specify that the current message is a high or normal priority message. The protocol simply provides a mechanism to identify the message as a high priority message. It is up to the device manufacturer to determine whether support is provided and up to the application software to determine what action is to be taken when a high priority message is received or presented for transmission.

- Confirmation of Message Delivery, if required: a device sending a message to another device shall be able to explicitly request confirmation of error-free delivery of that message from the receiving device.

EXISTSING PROTOCOLS: ETHERNET, IEEE 1394 AND MOST

Fast Ethernet

Ethernet is a term commonly used to describe a variety of network implementations that share the same basic technology. Some early varieties of Ethernet are 10Base-2 and 10Base-5 which are also called 'thin net' and 'thick net' respectively. All nodes on such network tap into a single cable. A later version of Ethernet, 10Base-T, introduces the concept of a hub or a repeater. All nodes are connected directly to a single repeater, which simplifies cabling and provides buffering of electrical signals.

A newer version of Ethernet, called Fast Ethernet, operates at 10 times the speed of 10Base-T or 100 Mbit per second. It has the same star topology as 10Base-T and comes in a few different versions called 100Base-TX, 100Base-FX, and 100Base-T4. The difference between these versions is the physical layer which is electrical for TX and T4, and optical for FX. In this paper, Fast Ethernet will refer to the most common version 100Base-TX.

Ethernet Topology

Thick net Ethernet uses a single cable as a backbone for the network. Each node in the network taps into this cable through what is called a T connector. In an office environment, this cable could be routed through the ceiling with taps dropping into each office. This works well except it is difficult to add new users to the network and signal quality is sometimes difficult to control.

A Fast Ethernet uses a central repeater which connects directly to each node. This star topology enables the signal quality on the transmission line between a computer and the repeater to be well controlled and provides a relatively simple means to add users. The repeater has a number of ports which connect to each computer on the network. To add another computer, a wire is run from a free port on the repeater to the new computer. If there are no free ports, typically, another hub (or switch) can be connected to an uplink port to expand the network to virtually any size.

Ethernet Physical Layer

In a thick Ethernet, all computers are connected to one coaxial cable. This cable is used for sending and receiving messages. When the bus is idle, the voltage on the coax cable remains in a high impedance state at an intermediate level. This level is not a one or a zero, so that all nodes can easily determine if the bus is idle. When a node is transmitting, the voltage on the bus is pulled to high and low voltages depending on the data to be transmitted. Only one computer can send information at any one time. If multiple nodes try to transmit at the same time, a collision occurs, the data from both computers is corrupted, and both computers have to stop transmitting and try again when the bus is idle.

In Fast Ethernet, all nodes connect to a central repeater through two sets of twisted pairs. One pair is for transmitting and the other for receiving. Although each node has its own cable, the network operates exactly like thick Ethernet at a higher level. When a computer sends a message to the central repeater, the repeater sends the data exactly as received to all other computers connected to it. Again, if two computers try to send at the same time, a collision occurs, and both computers must try again later.

Ethernet Arbitration

Since all the computers on an Ethernet share the transmission media, only one computer can send information at any one time. If multiple nodes try to transmit at the same time, they must arbitrate for use of the bus. The rules that every node follows is called Carrier Sense Multiple Access with Collision Detection (CSMA/CD). Before a node sends a message on the bus, it sends a stream of one's and zero's called a 'carrier'. All other nodes on the network sense this carrier and do not attempt to send their own message until the original node completes its message.

There is a finite amount of time from when a node begins sending a carrier to when all nodes detect this carrier. During this time, other nodes may attempt to send a carrier. If this happens, a 'collision' will occur which corrupts the data on the bus. Transmitting nodes will both 'detect' this condition and stop transmitting. The rules then specify that each node must wait a random amount of time before attempting to transmit again. The probability that another collision will occur is low.

Ethernet Switches

Ethernet switches have become more popular than repeaters in recent years. An Ethernet switch is a more sophisticated device which prevents all messages from being sent to all computers connected to the switch. When a Fast Ethernet is implemented with a repeater, all computers connected to the repeater are said to be on the same collision domain. This is because a repeater

operates just like the coaxial cable in thick Ethernet. If two computers try to send messages at the same time, the messages collide.

An Ethernet switch divides the network into many collision domains. Each port on a switch is a different collision domain. For example, if one computer is connected to a port on an Ethernet switch, the collision domain consists of two nodes; the computer and the switch. If a port on a repeater is connected to a port on a switch, the collision domain consists of the switch and all computers connected to the repeater.

The switch has intelligence which learns the addresses of the computers connected to each port. When a message is received at one port, the destination address is determined and the message is sent out the appropriate port. Switches are typically much more efficient than repeaters. However, they cost more.

Ethernet Communication Mechanism

Information in Ethernet networks is communicated in packets. Each packet consists of a header, usable data and a checksum. The header contains information such as source and destination address, the length of usable data and possibly information about the message type. The checksum is a code sent at the end of the message so that the receiving node can determine if the packet was corrupted during transmission.

Since the header and checksum are only used to send the packet safely from the transmitting node to the receiving node, it is considered network overhead. It is not information usable by the application. In Fast Ethernet, this consumes 18 bytes. If you include the arbitration time, the total overhead is 38 bytes. In addition, the minimum usable data is 46 bytes per packet. Even if you only wish to send one byte, you still must send the 18-byte header, 46 bytes of data, and wait 20 bytes worth of time for the bus.

The efficiency of the network can be defined as the number of user data bytes per packet divided by the number of bytes in the packet plus the overhead of waiting for the bus. If only one byte of user data is sent per packet the efficiency is 1/(64+20) X 100% = 1.2%. Since the maximum user data per packet is 1500 bytes in 100BaseT, the theoretic maximum efficiency is 1500/(1518+20) X 100% = 97.5%.

The maximum efficiency is never achieved since many collisions will occur if there is a lot of activity on the bus. The effect on efficiency is difficult to predict.

Ethernet Audio Example

Let's consider a PC with a sound card connected over the network to a server which stores WAV files. A particular Wav file from the server can be played on the sound card in the following way. The client software on the PC manages a FIFO (First-In First-Out) which continually outputs audio data to the sound card. When the FIFO gets close to being empty, the client sends a message to the server to send more data. The server sends another packet to the client to fill the FIFO up again. As long as the server sends the new packet before the FIFO empties, audio can be heard. If the server responds slowly or the network is very busy, the packet may not arrive in time, the FIFO will empty and sounds will momentarily stop. This is unacceptable for most audio applications.

There is a trade off between FIFO size, the frequency of requests for more data and packet size. Since the large packets are more efficient than small packets (% overhead from header, etc), let's assume we will use the largest packet size; 1500 bytes of user data. If the audio sample rate is 48 kHz, and the audio is 16 bits/sample stereo, then we need an average of 192K bytes/second or 128 packets/sec. The overhead for the header, checksum and the required idle between packets is 38 bytes. Since the client software on the PC with the sound card must inform the server when the FIFO is nearly empty, there are another 84 bytes of overhead to send this message to the server.

The minimum total bandwidth required for one audio channel is:

1500 + 38 + 84 = 1622 bytes/packet

1622 bytes/packet * 128 packets/sec = 207616 bytes/sec

207616 bytes/sec * 8 Bits/bytes = 1.66 Mbit/sec

Since the packet size in this example is the largest allowed by Fast Ethernet, the network overhead is small compared to the audio data throughput. The disadvantage of the large packet size is the buffer size requirement in the Client. It must be 1500 bytes deep plus more for handshaking. If the extra depth is not large enough for the network to guarantee another packet will arrive prior to the buffer emptying, a loss of audio quality may occur. If the buffer empties, the audio stops. In a Fast Ethernet, it is impossible to guarantee any bandwidth. If the network has lots of traffic, you may not even be able to get the 1.66 Mbit/sec average throughput that is required. More commonly, at times of high traffic the buffer may empty no matter how large it may be.

IEEE 1394

The IEEE 1394 specification is a hardware specification that defines the serial bus architecture that Apple computer initially named FireWire. It defines serial bus specific extensions to the Control and Status Register

(CSR) Architecture for Microcomputer Buses formally adopted as ISO/IEC 13213 (ANSI/IEEE 1212).

This architecture defines a set of core features such as node architecture, address space, common transaction types, Control and Status Registers (CSR), configuration ROM format and content, message broadcast mechanism to all nodes and interrupt broadcast to all nodes. IEEE 1394 specifies how units attached to a serial bus can talk to each other, but does not define the protocols used to communicate between the nodes.

IEEE 1394 is similar to Fast Ethernet in many ways. Data is always communicated between nodes in packets. If multiple nodes try to send packets at the same time, they must arbitrate for the bus. The information in the packet headers, the packet sizes and the arbitration method, are different. However, the fundamental mechanisms are similar.

The most significant feature that IEEE 1394 provides (which Fast Ethernet does not) is guaranteed bandwidth for real time applications. These applications are allocated isochronous bandwidth which enable real time data to be communicated in packets sent at regular time intervals. This is an improvement over Fast Ethernet. However, it will be shown that there are still serious limitations.

The raw bit rate for IEEE 1394 is defined to be selectable between approximately 100, 200, and 400 Mbit/sec. Work is currently being done on an 800 Mbit specification as well. Silicon is currently being advertised to run at both 100 and 200 Mbit. However, most implementations are now at 100 Mbit/sec which is the same data rate as the large installed base of 100BaseT. Gigabit Ethernet is currently under development as well.

IEEE 1394 Physical Layer

The physical layer for IEEE 1394 consists of two sets of twisted pair wire for signals and two wires for power and ground connected between each pair of nodes. One set of twisted pairs is called data and the other is called strobe. When one node begins to send a packet, it sends Nonreturn-to-Zero (NRZ) data on the data line and transitions the strobe line only between consecutive 1's or 0's. Both sets of twisted pairs are bi-directional. Each node sends and receives data on the same sets of wires. When neither node is sending data, the twisted pairs are held in a high impedance state.

In contrast, the physical layer for Fast Ethernet consists of two sets of twisted pairs; one pair is used for transmitting data and the other pair for receiving data. This approach makes recovering data from the transmission line slightly more difficult than with IEEE 1394 since there is no strobe signal. An advantage of keeping the transmission lines unidirectional, however, is that the transmission line can be longer. The maximum cable length for Fast Ethernet is 100meters, while it is only 4.5 meters for IEEE 1394.

Each node on an IEEE 1394 bus (or in a Fast Ethernet) has its own timing source which is typically a crystal oscillator. This timing source is used by a node to transmit data and is used by a node to over sample the received data and strobe lines to recover the data. This means that all IEEE 1394 nodes are asynchronous at the lowest level. The accuracy of the timing reference in IEEE 1394 is specified to be ± 100 PPM which is typically the frequency tolerance of widely available crystal oscillators.

The nominal data rate in 100 Mbit IEEE 1394 is 98.304 Mbit. If the crystal oscillator at a particular node is operating at the high end of its frequency tolerance, it will be able to transmit data at 98.304 Mbit +100 PPM or 98.314 Mbit/sec. If it is operating at the low end of the frequency tolerance, it will transmit data at 98.294 Mbit/sec. This may seem like a trivial issue. However, the section on system timing will illustrate some important consequences for real time applications.

IEEE 1394 Topology

The physical topology for a typical IEEE 1394 network is a tree structure. Typically, a node will have a least two ports which enables multiple nodes to be daisy chained together. If a node has more than two ports, multiple branches can be created. During initialization, one node is defined to be the root node with all nodes extending down different branches. The topology can have any number of branches if no loops are created.

The tree topology, with the ability to daisy chain nodes, has the advantage of simplicity for small networks. If you have a few devices, it is easy to plug them together in a daisy chain. However, large networks can be cumbersome, particularly if network performance is optimized. To improve performance, it is desirable to minimize the propagation delay of data between any two nodes in the network. Long daisy chains can be split into many branches to reduce the delay; however, care should be taken to balance the length of the branches.

In a Fast Ethernet, a repeater or switch is required for a network with more than two nodes. This makes small networks complicated. However, it makes large networks simpler.

IEEE 1394 Arbitration

As described previously, all computers on a Fast Ethernet using a repeater (not a switch) have the same collision domain. If multiple nodes attempt to transmit at

the same time, the transmitted data is corrupted, this condition is detected, and the nodes begin to arbitrate for the bus. Likewise, all nodes on an IEEE 1394 network have the same collision domain. Only one node can send a message at one time. If multiple nodes try to send messages at the same time, only one node will gain control of the bus.

In a Fast Ethernet, if a collision between two nodes occurs, both nodes will stop transmitting and wait a variable amount of time before another attempt. If they both happen to wait the same amount of time, another collision will occur. Mechanisms are built into the network to minimize the probability of nodes colliding more than once or twice.

An IEEE 1394 network operates differently. Nodes which are closer to the root node have a higher natural priority. When two nodes attempt to transmit at the same time, the node with the higher priority wins arbitration and control of the bus. In order to prevent higher priority nodes from monopolizing the bus a fairness interval is defined. During a fairness interval, all nodes are given the opportunity to send one message.

Unlike Fast Ethernet the arbitration mechanism in IEEE 1394 is deterministic. There is zero probability that nodes will collide many times before successfully sending a message. This is important for the delivery of real time data since any unpredicted delay, no matter how unlikely, may cause buffers to overflow or underflow.
The arbitration process in IEEE 1394 consists of bus request/grant handshaking between child and parent nodes. A parent node is defined as the node on a 1394 cable which is closer to the root. The node which is further from the root, is called the child. If a child and a parent both request the bus at the same time, the parent will block the child's request and send its request to its parent. The request continues down the tree until it reaches the root node. The root node issues a bus grant which travels back up the tree to the node requesting control of the bus. Once a node receives a bus grant, it can begin sending a message.

The time that it takes to arbitrate for the bus depends on the size of the network. A bus request from a node at the end of a number of branches must propagate down the tree to the root and back up the tree to the requesting node. Information must be sent down all other branches to prevent any other node from driving the bus (through a bus request), until the granted message is sent. The total arbitration delay for a network with N hops (from parent to child or child to parent) between the furthest two nodes, is about N x 80ns in a 100 Mbit IEEE 1394 network.

IEEE 1394 Communication Mechanisms

While Ethernet treats all packet data the same, IEEE 1394 provides different types of packets. The primary packet types are asynchronous and isochronous. Asynchronous packets are functionally equivalent to Ethernet packets. Isochronous packets are only available in IEEE 1394, and provide guaranteed bandwidth to time critical applications.

IEEE 1394 Asynchronous Packets

An asynchronous packet consists of a header, a header checksum, user data and a user data checksum. The header contains information such as source address, destination address, message length, message type, etc. The size of the header and the checksums is typically 24 bytes long. The user data can be up to 512 bytes long in a 1394 network operating at 100 Mbit/sec.

When a particular node receives a message, an acknowledgement signal is automatically sent back to the sending node. If the sending node does not receive an acknowledgement signal within a specified time, it will try to re-send it a specified number of times.

The total time required for sending a minimum size message consists of the arbitration time, the time to send the packet, the time to wait for an acknowledgement, the time for the acknowledgement message and a sub-action gap time. The sub-action gap time is the time required by a node to wait after the bus is idle before it can issue a bus request. The sub-action gap time is required to ensure that no node will issue a bus request before the previous acknowledgement is received.

The total time for a one byte message in a large network (16 hops) running at 100 Mbit is about 1.4 μsec for arbitration, 2.2 μsec to send the message (28 bytes * 8 bits/byte * 10ns), and 5.6 μsec for acknowledge and sub-action gap. The total time is about 9.2 μsec. This means the efficiency is about 80 ns / 9.2 μsec X 100% or 0.9%. The total time to send a maximum size message (512 bytes) is about 50 μ sec with an efficiency of about 85%.

IEEE 1394 Isochronous Packets

The most significant improvement of IEEE 1394 over Ethernet for real time audio, video and voice applications is 1394's isochronous channels which provide guaranteed bandwidth to applications. When an application is allocated an isochronous channel, it is guaranteed to be able to send isochronous packets at regular intervals to any other nodes in the network. Each node in the network has a counter which defines these regular intervals. The Isochronous Resource Manager sends a message periodically to synchronize the counters in all nodes.

The Isochronous Resource Manager has a local counter which is clocked by a local 24.576 MHz clock and counts up to 3072. When the counter reaches 3072, the Isochronous Resource Manager resets its counter and broadcasts a message to all the nodes in the network to reset their local counters. The frequency of this synchronization message is 24.576 MHz / 3072 or 8 kHz.

After the synchronization message, all nodes that have been allocated isochronous bandwidth are allowed to send their packets. After all isochronous packets have been sent, then nodes that need to send normal asynchronous packets are allowed to do so. The time between the 8 kHz sync messages is 125 µsec. The maximum time that can be allocated to isochronous data is 100 µsec. This ensures that some bandwidth will always be available for some asynchronous packets.

IEEE 1394 Audio Example

The concept of an isochronous channel resolves the problem illustrated in the previous example of communicating audio over Fast Ethernet. Since a node that is allocated isochronous bandwidth is guaranteed to be able to send a packet every 125 µsec, the FIFO described in the Fast Ethernet example will not empty due to congestion on the network. In addition, since the audio data packets are guaranteed to arrive at fixed rate, it is intended that handshaking messages are not necessary. These are required in the Fast Ethernet example since the server needs to know when the FIFO in the PC with the sound card is nearly empty.

To send 16 bit stereo audio data at a 48 kHz-sample rate over an isochronous channel requires 24 audio data bytes per isochronous packet. This is shown below:

48 kHz * 2 bytes/sample * 2 channels = 192K bytes/sec

192k bytes/sec / 8k packets/sec = 24 bytes/packet

The header for an isochronous packet consists of eight bytes which specify the length of the data (in our case 24 bytes), the channel number, etc, It also provides a checksum for just the header. The checksum for the data consumes another 4 bytes. In total, there are 12 bytes of header and checksum overhead to send the 24 audio bytes.

Additional overhead comes in the form of arbitration time, gap time between packets and packet start and end symbols. The gap time and start and end symbols consume a fixed time equivalent to the time it takes to transmit about 3 bytes in 100 Mbit IEEE 1394. The arbitration time depends on the size of the network. For a large network that has 16 nodes between the furthest nodes, the arbitration time is approximately equivalent to 20 bytes of data.

In summary, to send the 24 bytes of audio data, a 1394 network consumes up to 35 bytes of overhead. The total time required sending such as message is about 4.7 µsec and the efficiency is about 40%. Since the maximum amount of time that can be allocated to isochronous is 100 µsec/Frame, the maximum number of audio channels that a 100 Mbit IEEE 1394 network can support is about 20.

Voice is typically sampled at 8 kHz with 8-bit resolution. The minimum data field in an isochronous packet is 4 bytes; so the packet size will be at least 16 bytes. Including the overhead described above, the time required to send this message is 4.1 µsec and the efficiency is about 2%. The total number of voice channels that a 100 Mbit IEEE 1394 network can support is about 24.

If 100 µsec per frame are consumed by isochronous packets, 25 µsec will be left for asynchronous messages. As shown in the previous section, the time to send a minimum size packet is 9.2 µsec. Consequently, a maximum of two asynchronous packets can be sent per isochronous frame. In other words, 16000 relatively small asynchronous packets can be sent per second.

As shown earlier, a 512-byte packet (largest possible in a 100 Mbit IEEE 1394 network) takes 50 µsec to send. Since only 25 µsec are available per frame for asynchronous messages, it takes two frames to send such a message. The message rate will be 4000 Bytes/second. It is possible to send such message, since the isochronous packets on the second frame are delayed until after the large asynchronous packet has been sent. If the transmit time of a packet were allowed to be larger than 50 µsec or if less than 25 µsec per frame were reserved for asynchronous packets, delivery of all the isochronous packets could not be guaranteed.

IEEE 1394 System Timing

The timing source for each node in an IEEE 1394 network is typically a crystal oscillator. As described in the physical layer section, the frequency of crystal oscillators can vary by ± 100 PPM from their nominal value. At every node a local 24.576 MHz clock is generated to clock the modulo 3072 counters used to create the 8 kHz isochronous frames. The Isochronous Resource Manager must send a synchronization message every 125 µsec to resynchronize the counters in all nodes since they are all clocked by slightly different frequencies.

If the Isochronous Resource Manager has a crystal operating slightly faster than another node, the modulo 3072 counter in the other node will sometimes count to

3072 between synchronization packets and sometimes will count to 3071. The most significant bit of this counter can be used as a synchronization signal. Its frequency will be the same as that of the Isochronous Resource Manager. However, the period will sometimes be 3071 x (1/24.576 MHz) and will sometimes be 3072 x (1/24.576 MHz).

If the crystal frequency of the Isochronous Resource Manager is slightly slower than another node, the counter in that node will sometimes count to 3072 and sometimes to 3073 (rolls over to 1) between synchronization packets. Again, the frequency of the MSB of that counter will be the same as that of the Isochronous Resource Manager (8 kHz). However, it will have 40 ns of jitter. The frequency of the jitter varies depending on the frequency difference between the two crystals. Depending on the frequency, which is unpredictable, this amplitude jitter can be clearly audible in high fidelity applications.

IEEE 1394 Computer Audio Example

Let's go back to our example of a server with a WAV file and a client PC with a sound card. If these two computers are connected together with IEEE 1394 network, then isochronous bandwidth will be allocated to communicate the audio data. The 48 kHz audio will be sent from server to client in isochronous packets. The packet rate will be 8 kHz and the audio data per packet will be 24 bytes.

If the client is the Isochronous Resource Manager, the network will operate without difficulty provided the timing in the client is designed properly. The clock for the D/A converters and the clock for the isochronous counter (24.576 MHz) must be derived from the same crystal oscillator. If this is true, the 8 kHz ischronous frame rate is exactly 6 times the 48 kHz-sample rate of the D/A converter. If the server puts 6 stereo audio samples (24 bytes) in each isochronous packet, the D/A converter receives exactly the right number of samples per second. If the client (PC with sound card) is not the Isochronous Resource Manager, problems will occur. If the server is the manager, the 8 kHz isochronous frame will be generated by its crystal oscillator. If this crystal is operating at the high end of its frequency tolerance (+100 PPM), the frame rate will be 8.0008 kHz. The server will put 6 stereo audio samples in each isochronous packet, so the number of stereo samples the client receives is 6 x 8.0008 kHz or 48.0048 kHz.
If the crystal oscillator on the sound card is operating at the low end of its frequency tolerance (-100 PPM), it will accept 47.9952K samples/second. This means the sound card gets 9.6 extra samples per second. If these samples are simply discarded, you will hear a very audible clicking sound.

A possible solution is to use the FIFO and handshaking procedure used in the Fast Ethernet example. When the FIFO in the sound card is nearly full, the client can send a message to server to send an empty packet. Since the server produces 9.6 extra samples per second, on average it would send an empty packet slightly more than 1.5 times per second. Although this method works, it requires additional hardware and/or software to implement. In other words, it costs more.

Consumer Audio Example

Consider another example of a 3-node network consisting of an HMI, a DVD player and a digital amplifier. Assume the HMI node is the Isochronous Resource Manager. Also, assume the DVD drive is decompressing the audio from disk and sending it over the network to the digital amplifier.

The DVD player will have a crystal oscillator and will nominally produce 48K stereo audio samples per second. If the crystal is operating at +100 PPM, the DVD player will generate 48004.8 stereo audio samples per second. If the HMI node has a crystal operating at exactly the nominal frequency, the isochronous frame rate will be exactly 8 kHz. Each isochronous packet from the DVD player will then contain an average of 48004.8 / 8000 or 6.0006 stereo samples/packet. This can be accomplished in different ways.

The DVD drive can send packets with seven stereo audio samples and periodically send an empty packet. In this case, six packets with seven samples will be followed by an empty packet. Once every 1.3 seconds, five packets with seven samples will be followed by an empty packet. This will produce a throughput of exactly 48.0048k samples per second.

Alternatively, the DVD drive can send most packets with six samples (24 bytes). However, occasionally a packet will contain seven samples (28 bytes). To be explicit, every 8000/4.8 (~1667) frames will contain seven samples. Although both of these procedures will put the proper number of samples per second onto the network, controlling the different packet sizes requires some effort and cost.

The digital amplifier which is receiving the audio data from the DVD player has its own crystal which is clocking the D/A converters. If this crystal is operating at -100ppm, then the D/A converter expects to receive an average of 47,995.2 stereo samples per second. Since the DVD player is producing 48,004.8 samples per second the amplifier must do something with the extra 9.6 samples each second. As mentioned previously, if these samples are simply discarded, an untrained listener will hear clicking sound.

Sample Rate Conversion

A solution to the problem in the digital amplifier described above is to convert the sample rate of the data received by the digital amplifier from 48004.8 HZ to 47,995.2 HZ. Sample rate conversion is a well-known process. However, some sort of a digital signal processor is required. This adds cost and can affect quality by producing aliasing artifacts. Sample rate conversion is significantly easier if there is a known frequency relationship between the two rates. In this example, the difference in the sample rates is unknown and must be determined by a processor in the digital amplifier.

Phase Locked Loop (PLL)

An alternative solution is slaving both the DVD player and the D/A converters to the 8 kHz isochronous frame rate. The isochronous resource manager sends synchronization messages every time it's modulo 3072 counter wraps around. The counter in the DVD player will sometimes reach 3072 when it receives the synch message and will sometimes have rolled back to 1. The MSB of this counter will have exactly the same frequency as the Isochronous Resource Manager (8.00000 kHz). However, the Least Significant Bit (LSB) will be jittered.

This jittered 8 kHz signal can go through a phase locked loop to increase the frequency by some integer factor and attenuate the jitter. This higher frequency clock can be used by the DVD drive to read data off the disk at exactly 48 kHz (instead of 48.0048 kHz). Likewise, the 8 kHz signal from the isochronous counter in the digital amplifier can go through a phase locked loop to create a 48 kHz-sample rate clock for the D/A converters. Since both the source and the destination are locked to the same timing source (isochronous frame rate), there is no need for sample rate conversion.

The issue with slaving the DVD player and the digital amplifier to the isochronous frame rate clock is complexity. The jitter on the 8 kHz clocks in the DVD player and amplifier can have a frequency anywhere between 4 kHz and DC. The jitter frequency is directly related to the frequency difference between the crystals in the DVD player (or amplifier) and the Isochronous Resource Manager. Low frequency jitter is possible to attenuate. However, very low bandwidth PLL is required. Typically, low bandwidth PLL has long lock times which may or may not be acceptable. Tricks can be played to reduce bandwidth and keep lock times to reasonable levels. However, they can easily become very complicated.

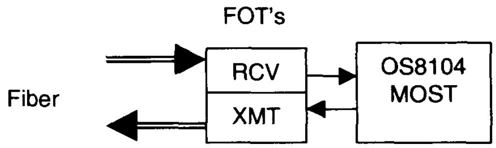
An additional problem with slaving the devices to the frame rate is that each node now has at least two asynchronous clocks. One clock is required by the 1394 interface; i.e. from a crystal. The other clock is the output of the PLL. If care is not taken in designing the digital amplifier circuitry, an aliased or mixed component of the 1394 interface clock will be heard through the speakers.

MOST

MOST (Media Oriented System Transport) is a functional specification developed specifically for interconnecting electronic devices to enable them to share electronic media, whether it is audio, video, voice or data. It defines a basic framework and provides the transport mechanisms to move media efficiently. MOST includes a hardware specification and defines the higher-level system services that need to be provided so unrelated systems can communicate with each other.

MOST Physical Layer

The physical layer is optical fiber. Each node in a MOST network has two optical ports. One for receiving data and one for transmitting. Although the transmission media can be glass fiber, it is typically plastic fiber due to lower cost and ease of installation. Fiber optic transceivers (FOT's) are available from a variety of manufacturers. The MOST network transceiver chip interfaces with the FOT units.



The physical layer of MOST is similar to that of Fast Ethernet since nodes in both technologies have separate transmit and receive ports. Data on the transmission lines for both MOST and Fast Ethernet goes in one direction. In contrast, data on a 1394 transmission line can go in both directions.

A significant difference between the physical layer of MOST and Fast Ethernet is that data is always being sent through the transmit and receive ports of a MOST node. A Fast Ethernet node only transmits data when it is sending a message. If it is not sending a message, its transmission line to the repeater (or switch) will be idle. A MOST node always bypasses the data it receives unless it is generating data. In this case, the node will multiplex its own data with the data that it receives. If no nodes are generating data, idle codes are transmitted through the network.

In a MOST network, one node is defined as the timing master. It has a crystal oscillator, which provides the timing reference for the entire network. It transmits data whether or not any node in the network is trying to communicate. If there is no useful information on the bus

the timing master, simply sends idle codes. All other nodes in the network have phase lock loops (PLLs) which recover their master clocks from the bitstream sent by the timing master.

MOST Topology

Ring

The most effective implementation of a MOST network is a ring. The ring starts with the timing master. Its optical output is connected to the optical input of the next node. The optical output of that node is connected to the optical input of the next node, and so on, until the optical output of the last node is connected to the input of the timing master.

The timing master has a crystal oscillator which generates the timing of its transmitted data. Every other node in the network (slave nodes) uses an analog PLL to recover a clock from the received data. Each slave node simply bypasses its received data if it is not interested in sending any data. When a slave node does input data to the network, it reads in the received data, multiplexes it with data it wishes to communicate, and sends the multiplexed datastream out its transmitter.

Every node in a MOST network operates at exactly the same frequency. This is fundamentally different from FAST Ethernet and 1394.

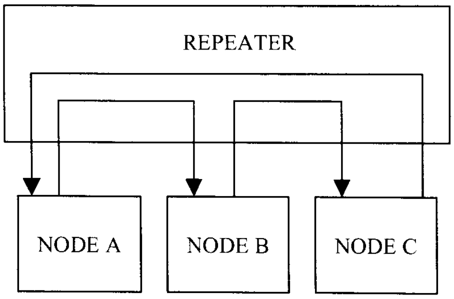


Figure 2.0: MOST with Repeater

Star

A MOST network can be implemented in a star topology (see Figure 2.0) similar to that of FAST Ethernet. A repeater box can be used for each node to connect its transmit and receive ports to. The repeater has little intelligence. If a node is not connected to a port, it is disabled. The repeater box adds cost to the system. However, it does provide fault tolerance. If one node fails, the repeater can detect this condition and bypass the faulty node.

Tree

Like IEEE 1394, a MOST network can be implemented in a daisy chain or a tree topology (see Figure 3.0). Each node can have two sets of transceivers, which enable daisy chaining. The following diagram illustrates how this works. Each node would contain a single transceiver. If a port (RX/TX pair) is not connected (nodes A and C) the transceivers that are being used are connected to the transceiver chip. If both sets are being used (node B), one pair bypasses. The logical topology is still a ring. However, physical topology is a daisy chain.

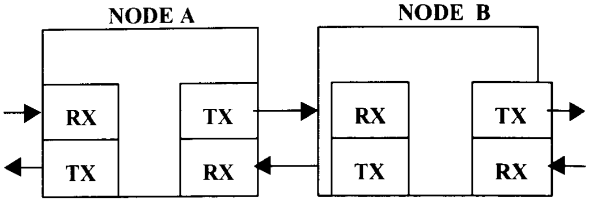


Figure 3.0: MOST with Tree Topology

If three or more transceiver pairs are implemented on a single node, a tree with multiple branches can be implemented. The daisy chain or tree topology is more expensive than a ring since the number of FOT units increase. If desired, it can be done.

MOST Communication Mechanisms

There are two different types of communication mechanisms in a MOST network. They are synchronous and packet. Both Ethernet and 1394 only support packet. Although 1394 provides a variety of packet types including asynchronous and isochronous, they are still packets. MOST provides two types of packet communication channels. They are called asynchronous and control frame. Asynchronous is functionally identical to Ethernet and can support 10 Mbit Ethernet running TCP/IP. The control channel is a unique asynchronous channel allocated its own guaranteed bandwidth.

MOST Frame Structure

MOST has a frame structure similar to a frame in telecommunications. When a long-distance telephone call is made, a number of switches are set up in central offices across the country through which the digitized voice will pass. If all the bandwidth of the network is consumed by other telephone calls, the local central

office will inform the caller that all circuits are busy; try again later. If there is bandwidth available, the call is connected and communications can begin. The connection is actually 2 connections; one in each direction. These connections are time slots in a frame that repeats at 8KHz. Voice is digitized at this rate.

A MOST frame repeats at the audio sample rate since the desired audio quality is better than that of the telephone system. The audio sample rate is typically 44.1 kHz or 48 kHz. This repeating frame is divided into 64-byte wide channels. The total bandwidth is 64x8x48KHz = 24.5 Mbit/sec. Of these 64 channels, 2 are allocated to the control channel, 2 are used for the network management functions and 60 are divided between synchronous and asynchronous channels. The boundary between the two is user defined. The useable bandwidth is 62x8x48K = 23.8 Mbit/sec.

MOST Synchronous Channels

The synchronous (sync) channels are used to communicate streaming video, audio and voice data. As in the telephone system, this data flows through the MOST network. It is not packetized, so there is no need for buffers, packet headers or for intelligence at every node to manage them.

When a CD player wants to start playing, it asks the network for bandwidth. If synchronous bandwidth is available (all circuits are not busy), the network will allocate 4 bytes to the CD player.

Each node in the MOST network acts like a central office in the telephone system. A central office is essentially a big cross point switch which routes input voice channels to output voice channels. When a telephone is dialed, a switch is set up which stays in place until the call is ended.

Likewise, a MOST node can route the synchronous data it receives from the network back out on the network or it can route the data off the network. For instance, a power amplifier could route data from the CD player off the network and to its D/A converters. The rest of the synchronous channels could simply be routed back onto the network, digitized voice from a microphone could bypass the amplifier on its way to the cell telephone.

The approach used in MOST to communicate streaming audio, video and voice data is inherently more efficient than the packet-based method in 1394 and Fast Ethernet. The synchronous approach in MOST has zero overhead or 100% efficiency. This is in comparison to the 40% efficiency for audio and 2% efficiency for voice for 1394. These efficiency numbers explain why MOST can communicate 15 stereo audio channels over the 22 Mbit usable bandwidth while 1394 can support a maximum of 20 stereo audio channels with 100 Mbit.

When the data rate of the stream decreases, MOST throughput becomes even greater than 1394, even though the raw data rate is 4 times higher. For example, 1394 can support a maximum of 24 voice channels while MOST can support at least 60. With additional hardware next to the MOST transceiver, 360 voice channels can be supported. These differences are dramatic.

The synchronous nature of MOST eliminates the problems illustrated in the previous 1394 examples of a CD player and digital amplifier. The timing of every MOST node is slaved to the master so they all operate at exactly the same frequency. The CD player will produce samples at the rate determined by the crystal in the master and the D/A converter in the digital amplifier is accepting samples at this rate as well. There is no need for the sample rate conversion or complicated PLLs. This results in higher quality and much lower cost per node.

MOST Control Channel

The control channel is used to send short messages to devices to control various functions. Examples of such messages are to change the track on a CD player or change the volume in an amplifier. The MOST specification defines a complete set of commands, or application protocols, which can be communicated over the control channel. The specification provides enough flexibility and expansion to accommodate common devices as well as unforeseen devices that may be required in the future. Space is also reserved for user-defined devices.

MOST Application Protocols

The MOST application protocols do not have to be used. However, they were developed in cooperation with major auto manufacturers and consumer equipment suppliers specifically for networking consumer devices. This does not exist in 1394 or FAST Ethernet.

Fast Ethernet and 1394 define the mechanisms for sending and receiving data; however, there is no specification for what the data means. Typically, TCP/IP is run over Fast Ethernet and standard applications, such as FTP, sendmail, etc., are provided with the operating systems. These and other applications define the messages in most computer networks.

IEEE 1394 is different. The standard simply specifies an address space. Part of the address space specifies the address of the node. The other part of the address space specifies memory locations inside a node. When messages are sent to a particular node, the data in the message is written to the specified memory locations in

that node. Some of this address space is defined in order to operate the network; however, the majority of the address space is undefined.

Some companies, such as Yamaha (M-LAN), have developed sets of protocols for audio applications. However, they are not part of the specification. This results in physical compatibility between 1394 devices but not software compatibility. Devices from different companies speak different languages.

As defined by the 1394 specification, an isochronous packet has a header, checksum and useful data. The M-LAN specification defines an additional header that goes into the useful data field. This overhead was not considered in the 1394 efficiency calculations described earlier.

MOST Bandwidth

The control channel in MOST consists of two bytes per frame. At a frame rate of 48 kHz this provides 768K bits of bandwidth. Messages can be sent once every 16 frames (block boundary). This means 3000 control messages can be sent per second independent of how much synchronous bandwidth is being used.

A MOST control message consists of a header, user data and a checksum. The user data field can be up to 17 bytes and the efficiency is 53%. As shown in the section on 1394, the total time for a 17 byte message in a large network (16 nodes) running at 100 Mbit is about 1.4 µsec for arbitration, 3.5 µsec to send the message (44bytes * 8bits/byte * 10ns), and 5.6 µsec for acknowledge and sub-action gap. The total time is about 10.5 µsec. This means the efficiency is about (17bytes * 8 bits * 10ns) / 10.5 µsec X 100% or 13%, which is 4 times worse than MOST.

MOST Arbitration

The arbitration mechanism for control frame messages is very similar to that of 1394. Nodes closer to the root node (in 1394) have a higher natural priority while nodes closer to the timing master have a higher natural priority in MOST. In both 1394 and MOST (control channel) one node always wins arbitration and sends a message, which is in contrast to the collision detection mechanism in Ethernet.

IEEE 1394 defines a fairness interval during which all nodes have an opportunity to send one message. The MOST control channel assigns a priority to all nodes (in addition to the natural priority) which decreases each time a node sends a message. Periodically the priority registers are all reset to the highest level. This periodic resetting is analogous to the 1394 fairness interval. These mechanisms are not found in Ethernet.

MOST Acknowledgement

Control frame messages have automatic acknowledgement. If a destination node receives a control frame packet properly, an acknowledge signal is automatically sent back to the transmitting node. If a destination node does not properly receive a packet because its receive buffer was full, the checksum was incorrect, the destination address was incorrect, etc., information is sent back to the sending node specifying why the message was not properly received.

IEEE 1394 provides similar low level acknowledges. However, Fast Ethernet does not. Fast Ethernet expects the higher level protocols to ensure reliable data transmission. If a Fast Ethernet packet is not received properly, the receiving node simply ignores the packet. the transmitting node does not know if the message was received or not. The higher level protocol Transport Control Protocol (TCP) ensures reliable communication. This is done through handshaking messages.

MOST Asynchronous Channel

As a quick review, a MOST frame consists of 64 bytes and repeats at the system sample rate, typically 48 kHz. Of the 64 bytes, two are used for network management, 2 are used for the control channel and the remaining 60 can be divided between synchronous and asynchronous bandwidth. The boundary between synchronous and asynchronous is user defined.

The asynchronous channel forms a packet-based network like the control frame channel. However, no higher level protocols are defined by MOST. It is intended to operate under standard protocols such as TCP/IP. Packets are similar to Fast Ethernet in that they have headers and checksums.

MOST Audio Example

Let's look at the example described in the section on IEEE 1394 of the HMI, DVD player, and digital amplifier nodes. In this case, we assumed the audio from disk was decoded in the DVD player and communicated to the digital amplifier. Since the decoded audio from the DVD player has a sample rate of 48 kHz, the sample rate for the network should be 48 kHz.

Any node in the network can be the timing master. The timing master has a crystal oscillator that generates the timing reference for all other nodes. Every node operates at exactly the same frequency. If the HMI node is the timing master, the DVD player and the digital amplifier

slave their timing to the clock recovered from the received MOST bit-stream. The recovered clock from the MOST transceiver chip drives the timing for all other circuitry on each of those nodes.

In the DVD player, the clock recovered from the MOST bit-stream (the output from the MOST transceiver) provides the master clock to the drive mechanism. Therefore data is read from the disk at a rate proportional to the 48 kHz MOST sample rate. The audio data from the decoder also has exactly the same 48 kHz-sample rate as the network. The audio data simply streams into the serial ports on the transceiver chip and onto the network.

The timing in the digital amplifier is derived from the MOST network as well. The D/A converters are operating at exactly the same audio sample rate as the data from the DVD decoder chip. The 48 kHz audio data from the DVD drive is streamed off the network through the serial ports on the MOST transceiver chip and into the D/A converters. There is no need for buffering, creating packets, converting sample rates, building complicated PLL, etc. MOST provides the simplest means to communicate streaming data.

CONCLUSION

The most cost-effective and optimum method for in-vehicle transporting of digital audio and video is synchronous transport. Asynchronous transmission is optimized for routing data, command and control. There are two digital audio interconnection standards: Audio Engineering Society (AES) and Sony-Philips Digital Interface (SPDIF). However, both of these standards are synchronous in nature and call for less than 0.25 of pulse duration of jitter. Control of jitter and delays of asynchronous transport may require proprietary complicated software solutions and additional silicon. Julian Dunn points out in his AES 106 May 1999 issue, "Sample Clock Jitter and Real-time Audio Over the IEEE 1394 High Performance Serial Bus", that CD quality audio is not realizable with current IEEE 1394 specification.

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Product/ Technology	Medium	Topology	Max. Number of Nodes		Distance (m)	Speed		
			Physical limitation (per segment)	Address-Space (Bit)		Bit Rate (Mbit/s)	Gross Rate (Mbit/s)	Net Stream Data Rate (Mbit/s)
HiQOS	POF	ring or star with passive star	60 2	60	30 10	54 108 216	36.5 44.9	32 39
IEEE1394 "FireWire"	shielded cable/POF/UTP	Tree	63	63	4.5	100 200 400 800 1600 3200	98.3 196.6 393.2 786.4 1,572.9 3,145.7	<65.5 <131 <262 <524 <1048 <2096
MOST	POF, UTP	Ring, active start, or tree	64	16	100	25 50 150	24.6 49.1 147.5	23.1 46.0 138.3
DC-BUS	DC Line Cable	Bus	16	16	12	0.562 12	0.225 6.8	0.21 6
MML	POF	Star with Coupler	10 (100 with ADN)	156	4 to star	110592	98.304	92.328 73.728 46.464
D2B	POF, UTP	Ring	64	12	100	5.6	5.6	4.2

Table 2.0: A Protocol Comparison Chart

Exhibit 8

Item Details

Bibliographic Information

Title

Automotive electronics - : Delivering technology's promise - proceedings

Author

International Congress on Transportation Electronics (2000 : Detroit, MI)

Publisher:

Society of Automotive Engineers,

Pub date:

[2000]

Physical Description

xiv, 603 pages :

ISBN:

0768006678

Limited view (search only)

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Holdings

Annex (UP)		
Call number	**Material**	**Location**
TL272.5.I577 2000	Book	Annexed Material

Exhibit 9

Item Details

MARC Record

Automotive electronics - : Delivering technology's promise - proceedings

International Congress on Transportation Electronics (2000 : Detroit, MI)
020:
: 0768006678
035:
: LIAS2471695
035:
: (Sirsi) LIAS2471695
035:
: (OCoLC)45252210
111: 2
: International Congress on Transportation Electronics|d(2000 :|cDetroit, MI)
245: 10
: Automotive electronics - :|bDelivering technology's promise - proceedings.
246: 30
: Proceedings of the 2000 International Congress on Transportation Electronics
246: 01
: Convergence '2000
264: 1
: Warrendale, PA :|bSociety of Automotive Engineers,|c[2000]
264: 4
: |c©2000
300:
: xiv, 603 pages :|billustrations ;|c28 cm.
336:
: text|btxt|2rdacontent
337:
: unmediated|bn|2rdamedia
338:
: volume|bnc|2rdacarrier
490: 1
: Society of Automotive Engineers ; P-360
500:
: Proceedings held October 16 - 18, 2000.
650: 0
: Automobiles|xElectronic equipment|vCongresses.
650: 0
: Intelligent control systems|vCongresses.
650: 0
: Intelligent transportation systems|vCongresses.
710: 2
: Society of Automotive Engineers.
830: 0
: Society of Automotive Engineers ; P-360.|?UNAUTHORIZED

Appendix A

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Grants & Honors

Cultural Heritage Information Management Project. IMLS grant. Amount: $498,741. Period: Aug. 2012 to July 2015. Co-PI with Dr. Youngok Choi.

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Hsieh-Yee, I. and Lawton, P. (2015, February). *Crowdsourcing terms for thematic exploration in the Catholic Portal.* Poster presented at the 7th Annual Bridging the Spectrum Symposium, Washington, D.C.

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Hsieh-Yee, I. (2014, January). *Health Information Technology Program: Educational entrepreneurship in action*. Presented at the 2014 annual Conference of the Association for Library and Information Science Education, Philadelphia, PA

Hsieh-Yee, I., Zhang, S., Lin, K., and Cherry, S. (2014, January). *Discovering information through Summon: An analysis of user search strategies and search success*. Paper presented at the 6th Bridging the Spectrum Symposium, Washington, D.C.

Hsieh-Yee, I. (2012, December). *National Digital Stewardship Alliance and SLIS at CUA: An Educational Partnership*. Paper presented at Best Practices Exchange: Acquiring, Preserving, and Providing Access to Government Information in the Digital Era, Annapolis, MD

Choi, Y. and Hsieh-Yee, I. (2010, January). *Finding Images in an OPAC: Analysis of User Queries, Subject Headings, and Description Notes*. Paper presented at 2nd Annual Bridging the Spectrum Symposium, Catholic University of America, Washington, D.C.

Hsieh-Yee, I. and Coogan, J. (2010, January). *Google Scholar vs. Academic Search Premier: What Libraries and Searchers Need to Know*. Paper presented at 2nd Annual Bridging the Spectrum Symposium, Catholic University of America, Washington, D.C.

Hsieh-Yee, I. (2009, November). *Information Science Education: An LIS School's Perspective*. Paper presented at Annual Meeting of the American Society for Information Science and Technology, Vancouver, British Columbia, Canada.

Hsieh-Yee, I., Menard, E., Ya-Ning Chen, A., Shu-Jiun Chen, S., Kalfatovic, M. R., Wisser. K. M. (2009, November). *Information Organization in Libraries, Archives and Museums: Converging Practices and Collaboration Opportunities*. Presented at Annual Meeting of the American Society for Information Science and Technology, Vancouver, British Columbia, Canada. (Organizer and moderator of this panel.)

Hsieh-Yee, I. and Coogan, J. (2009, July). *Catching up to Google Scholar: The Retrieval Power of Academic Search Premier and Google Scholar*. Poster presented at American Library Association Conference, Chicago, Illinois.

Hsieh-Yee, I., with the CUA Scholarly Communications Project Team. (2009, January). *Digital Scholarship@CUA: Developing an Institutional Repository for CUA*. Poster presented at 1st Annual Bridging the Spectrum Symposium, Catholic University of America, Washington, D.C.

Wise, M., Cylke, K., and Hsieh-Yee, I. (2009, January). *Digital Talking Books: Meeting the Needs of the Blind and the Handicapped*. Paper presented at the Bridging the Spectrum Symposium, Catholic University of America, Washington, D.C.

Hsieh-Yee, I. (2009, January). *User Expectations of MERIC*. Presented at the Information Organization Competencies for the 21st Century Discussion Session of the 2009 Conference of the Association for Library and Information Science Education, Denver, Colorado.

Choi, Y., and Hsieh-Yee, I. (2008,November). *Subject Access for Images in an OPAC.* Annual Meeting of the American Society for Information Science and Technology, Columbus, Ohio. (Also co-organized a panel on Retrieving and Using Visual Resources: Challenges and Opportunities for Research and Education.)

Hsieh-Yee, I. (2008, June). *Educating Cataloging Professionals in a Changing Information Environment*. National Taiwan University, Taipei, Taiwan.

Vellucci, S. L., Moen, W.E., Hsieh-Yee, I., Marson, B., and Wisser, K. (2008, January) *Building a Metadata Education and Research Community through MERIC (Metadata Education and Research Information Commons): Demo and Stakeholder Input*. A panel presented at the 2008 Conference of the Association for Library and Information Science Education, Philadelphia, Pennsylvania.

Hsieh-Yee, I., Choi,Y. and Kules, B. (2007, October). *Searching for Books and Images in OPAC: Effects of LCSH, TOC and Subject Domains.* A poster presented at the American Society for Information Science and Technology Annual Meeting, Milwaukee, Wisconsin.

Hsieh-Yee, I. and Coogan, J. (2007, August) *Google Scholar vs. Academic Search Premier: A Comparative Analysis.* Presented to the Faculty and Staff of the University of the District of Columbia.

Hsieh-Yee, I. and Coogan, J. (2007, June). *Google Scholar vs. Academic Search Premier: A Comparative Analysis*. Presented to the Washington Research Library Consortium Community, Catholic University of America, Washington, D.C.

Hsieh-Yee, I., Choi, Y., and Kules, B.. (2007, June). *What Users Need for Subject Access: Table of Contents or Subject Headings?* A poster presented at the 2007 American Library Association Annual Conference, Washington, D.C., June 2007.

Choi, Y., Hsieh-Yee, I., and Kules, B. (2007, June). *Retrieval Effectiveness of TOC and LCSH.* A paper presented at the Joint Conference on Digital Libraries 2007, Vancouver, Canada.

Vellucci, S. L., Hsieh-Yee, I., and Moen, W.E. (2007, May). *If We Build It, Will They Come? Building a Community of Practice for Metadata Stakeholders.* A poster presented at the Rutgers University Research Day, Bridgeton, New Jersey.

Hsieh-Yee, I. (2007, May). *Federated Searching: User Experience & Perceptions.* International Conference on Information Organization & Retrieval, National Taiwan University, Taipei, Taiwan.

Hsieh-Yee, I. (2007, May). *Search Performance of Google Scholar and Academic Search Premier.* International Conference on Information Organization & Retrieval, National Taiwan University, Taipei, Taiwan.

Hsieh-Yee, I. (2007, May) *MERIC: Building a Digital Commons for Metadata Education & Research.* International Conference on Information Organization & Retrieval, National Taiwan University, Taipei, Taiwan.

Hsieh-Yee, I., and Coogan, J. (2007, March/April). *A Comparative Analysis of Google Scholar and Academic Search Premier.* Poster presented at the Association of College & Research Libraries 13th National Conference, Baltimore, Maryland.

Vellucci, S. L. and Hsieh-Yee, I. (2007, March/April) *They Didn't Teach Me That in Library School! Building a Digital Teaching Commons to Enhance Metadata Teaching, Learning and Research*. On-site presentation and Webcast by Elluminate. A contributed paper presented at the Association of College & Research Libraries 13th National Conference, Baltimore, Maryland. The acceptance rate for contributed paper was 20%. This paper was one of 10 conference papers chosen for live webcast during the conference.

Moen, W., Hsieh-Yee, I. and Vellucci, S.L. (2007, January) *A DSpace Foundation for a Teaching & Research Commons: The Metadata Education and Research Information Commons.* A poster session presented at the Open Repositories Conference 2007, San Antonio, Texas.

Tang, R., Hsieh-Yee, I., and Zhang, S. (2006, November) *User Perception of MetaLib Combined Search*. Paper presented at the Annual Meeting of the American Society for Information Science and Technology, Austin, Texas, Nov. 2006.

Hsieh-Yee, I. (2006, November). *Federated Searching: User Perceptions, System Design, and Library Instructions.* Paper presented at the Annual Meeting of the American Society for Information Science and Technology, Austin, Texas. (Panel organizer, moderator, presenter).

Hsieh-Yee, I. (2006, November). *Building a Digital Teaching Commons to Enhance Teaching and Learning: The MERIC Experience and Challenges.* Paper presented at the Annual Meeting of the American Society for Information Science and Technology, Austin, Texas. (Panel organizer, moderator, presenter)

Hsieh-Yee, I. (2006, September). *Search Performance of Google Scholar and Academic Search Premier.* Paper presented at the ERIC Publishers Meeting, Washington, D.C.

Hsieh-Yee, I., Zhang, S., and Rong Tang, R. (2006, June). *User Perceptions of a Federated Search System*. Poster presented at Joint Conference on Digital Libraries, Chapel Hill, North Carolina.

Hsieh-Yee, I. and Zhang, S. (2006, June). *Preparing Users for Federated Search: Implications of a MetaLib User Perceptions Study.* Paper presented at the 2006 Ex Libris User Groups of North America Conference, Knoxville, Tennessee.

Hsieh-Yee, I. (2006, January). *MERIC Organizations and Navigation*. Paper presented at the 2006 ALISE Annual Conference, San Antonio, Texas.

Hsieh-Yee, I. (2006, January). *Metadata and Cataloging Education: Recommended Competencies.* Paper presented at the 2006 ALISE Annual Conference, San Antonio, Texas.

Hsieh-Yee, I. (2005, November). *Digital Library Evaluation: Progress & Next Steps.* Presentation at the Annual Meeting of the American Society for Information Science & Technology, Charlotte, North Carolina.

Hsieh-Yee, I. (2005, August). *Providing Access to Digital Content: Issues for DL Managers.* Presentation at MDK12 Digital Library Steering Committee Meeting, Columbia, Maryland.

Hsieh-Yee, I. (2005, April). *Enhancing Teaching and Learning: The Role of School Library Media Specialists.* Presentation at Meeting of the Baltimore County Public School System School Media Specialists, Baltimore, Maryland.

Hsieh-Yee, I. (2005, January). *Subject Access and Users: Insights & Inspirations from Marcia J. Bates.* Paper presented at the Historical Perspectives SIG, 2005 Conference of the Association for Library and Information Science Education, Boston, Massachusetts.

Hsieh-Yee, I. (2005, January). *Electronic Resource Management: Practice, Employer Expectations, & CE Interests.* Paper presented at Technical Services Education SIG, 2005 Conference of the Association for Library and Information Science Education, Boston, Massachusetts.

Hsieh-Yee, I. (2004, October). *Library Professionals for the Digital Age: Competencies & Preparation.* Paper presented at Bibliographic Access Management Team meeting, Library of Congress, Washington, D.C.

Hsieh-Yee, I. (2004, January). *Cataloging and metadata expertise for the digital era.* Presented at Preparing 21st Century Cataloging and Metadata Professionals: A Workshop for Educators and Trainers, San Diego and sponsored by ALCTS, ALISE, LC, and OCLC.

Hsieh-Yee, I. (2004, January). *Educating catalogers for the digital era.* Paper presented at the Technical Services SIG, 2004 Conference of the Association for Library and Information Science Education, San Diego.

Hsieh-Yee, I. (2003, July). *Cataloging Education for the 21st Century.* A presentation at the Library of Congress, Washington, D.C.

Hsieh-Yee, I. (2002, January) *Metadata Education and Research Priorities: A Delphi Study of*

Metadata Experts. Presentation at the 2002 Conference of the Association for Library and Information Science Education, New Orleans.

Hsieh-Yee, I. (2001, November). *A Delphi Study of Metadata: Preliminary Findings.* Poster session at the 2001 Annual Meeting of the American Society for Information Science & Technology, Washington, D.C.

Hsieh-Yee, I. (2001, June). *Resources on Asian American Children: Analysis of Retrieval by Search Engines and WorldCat.* Presentation at the National Conference on Asian Pacific American Librarians, San Francisco.

Hsieh-Yee, I. (2001, January). *Delphi Study on Metadata: Project Design.* Presentation at Research Awards Session, Association for Library & Information Science Education, Washington, D.C.

Hsieh-Yee, I. (2000, May). *Web Search Behavior Research: Progress and Implications.* Presentation at the Symposium on Evaluating Library and Information Science Research, University of Wisconsin-Madison, Madison, Wisconsin.

Hsieh-Yee, I. (2000, March). *ERIC User Services: Evaluation in a Decentralized Environment.* Presentation at the National ERIC Joint Directors/Technical Meeting, Arlington, Virginia.

Hsieh-Yee, I. (2000, January). *Enhancing Learning with Web Technology.* Presentation at Faculty Conversations, Catholic University of America, Washington, D.C.

Hsieh-Yee, I. (2000, January). *From Surrogates to Objects: CUA's Approaches to Organizing Electronic Resources.* Paper presentation at the Annual Conference of the Association for Library and Information Science Education, San Antonio, Texas.

Yee, P., and Hsieh-Yee, I. (1997, November). *Individual Differences in Search Behavior on the WWW.* A poster session presented at the 38th Annual Meeting of the Psychonomic Society, Philadelphia, Pennsylvania.

Hsieh-Yee, I. (1997, April). *Research + Marketing + Preparation = Job!* Presented at the "Workshop on Resume and Interview Techniques," Special Libraries Association, Student Chapter, Catholic University of America, Washington, D.C.

Hsieh-Yee, I. (1997, February). *Creating CyberCatalogers: Education and Training.* Presentation at ALA's Midwinter Meeting, Washington, D.C.

Hsieh-Yee, I. (1997, February). *Search Tactics of Web Users in Searching for Texts, Graphics, Known Items and Subjects: A Search Simulation Study.* Presented at the Conference of the Association for Library and Information Science Education, Washington, D.C.

Hsieh-Yee, Ingrid. "Beginning Your Special Library/Information Center Career." Presented at SLA's "Career Day," Jan. 11, 1997, Catholic University of America.

Hsieh-Yee, I. (1996, September). *The Roles of Library and Information Scientists in Managing Electronic Information.* Presentation at Hamilton College, Clinton, New York.

Hsieh-Yee, I. (1996, May). *The Future of Cataloging as a Profession.* Presented at "The Cataloging Forum, Library of Congress, Washington, D.C.

Hsieh-Yee, I. (1994, October). *The Impact of the Internet on OPACs.* Presented at the Third Workshop on User Interfaces for OPACs, Library of Congress, Washington, D.C.

Reports

Hsieh-Yee, I., with Knowledge Management Competencies and Performance Action Group of the Federal Knowledge Management Initiative. “From Knowledge Management Competencies to Improved Organizational Performance.” April 9, 2009.

Hsieh-Yee, I., with Knowledge Practices Action Group of the Federal Knowledge Management Initiative. “KM Practice in Government Agencies: Findings and Recommendations.” April 9, 2009.

Hsieh-Yee, I. “Delphi Study on Metadata.” 2001. Three quarterly reports submitted to the Association for Library and Information Science Education.

Hsieh-Yee, I. “College Students' Information Channels: Patterns of Use and Possible Factors in Channel Selection.” 1995. Submitted to the Catholic University of America.

Hsieh-Yee, I. “The Information-Seeking Patterns of Scholars and Their Use of an Online Information System.” 1994. Submitted to the Council on Library Resources.

Book Reviews

Review of *The Measurement and Evaluation of Library Services*, by Sharon L. Baker and F. Wilfrid Lancaster. *Information Processing and Management* 30 (1994): 450-52.

Review of *Subject Access to Films and Videos, by Sheila S. Intner and William E. Studwell; and Cataloging Unpublished Nonprint Materials*, by Verna Urbanski with Bao Chu Chang and Bernard L. Karon. *Information Processing and Management* 30 (1994): 449-50.

Review of *Automated Information Retrieval in Libraries: A Management Handbook*, by Vicki Anders. *Journal of Library and Information Science* 19 (1993): 98-100.

Review of *Full Text Databases*, by Carol Tenopir and Jung Soon Ro. *Information Processing and Management* 28 (1992): 667-68.

Review of *Descriptive Cataloging for the AACR2R And USMARC: A How-to-Do It Workbook*, by Larry Millsap and Terry Ellen Ferl. *Information Processing and Management* 28 (1992): 809-11.

Review of *MARC Manual: Understanding and Using MARC Records*, by Deborah J. Byrne. *Information Processing and Management* 28 (1992): 537-38.

Service

Professional Associations and Societies

- Library of Congress. RDA Training Program for the Profession. Co-authored with Tim Carlton. 2013-2014.
- 2014 Digital Preservation Outreach & Education Survey. Contributed to the design of the survey, 2014.
- National Digital Stewardship Alliance. Outreach Committee. 2011-2014.
- National Digital Stewardship Residency Program. Advisory Group, 2012-2013.
- FEDLINK Health Information Technology Advisory Council, 2011-2015.
- 2012 Joint Conference on Digital Libraries. Program Planning Committee, Pre-Conference Proposals Review Committee, 2012
- Catholic Research Resources Alliance. Five-Year Strategic Plan Task Force, 2011-2012
- Institute of Museum and Library Services. Grant reviewer. 2004, 2005, 2010.

- Association for Library and Information Science Education.
  * ALISE Bodan Wynar Research Paper Award Committee, 2015, 2016, 2017
  * ALISE Eugene Garfield Dissertation Award Competition, Jury, 2013, 2014
  * ALISE Research Grant Competition Committee. Chair, 2012
  * Pratt-Severn Faculty Innovation Award. Chair, 2009, 2010
  * ALISE Doctoral Poster Jury, 2012
  * "Information Organization Competencies for the 21st Century" Discussion session leader. 2009 Conference of the Association for Library and Information Science Education.
  * Assisted Technical Services SIG Convener in organizing a program, ""Building a Metadata Education and Research Community through MERIC (Metadata Education and Research Information Commons): Demo and Stakeholder Input" for the 2008 ALISE conference.
  * Association for Library Collections and Technical Services/Association for Library and Information Science Education (ALCTS/ALISE) Metadata Education and Research Information Center (MERIC) Advisory Board, Co-Chair (with Sherry Vellucci), 2005-2007. Chair, 2008-2009 (leading the effort to build MERIC, a repository and collaborative space for metadata educators, practitioners, and researchers)

* Technical Services SIG, Convener, 2004-2005. Organized a program on "Electronic Resources Management: Current Practices, Employer Expectations, and Teaching Strategies" for the 2005 conference in Boston, Massachusetts.
* Technical Services SIG, Convener, 2003-2004. Organized a program on "Organizing Information with Metadata: Desired Competencies and Teaching Innovations" for the 2004 conference.
* Technical Services SIG, Convener, 1999-2000. Organized a program on "Teaching the Organization of Electronic Resources" for the 2000 conference.
* Curriculum SIG, Co-convener (with Sibyl Moses), 1996-97. Organized a program on "Government Information Policy" for the 1997 conference.

- American Society for Information Science & Technology.
  * Reviewer, Conference program panel submissions and poster submissions, 2005, 2006, 2007, 2009, 2011, 2012, 2013, 2014, 2015, 2016, 2017
  * Nomination Committee, 2009-2011
  * Information Science Education Special Interest Group. American Society for Information Science and Technology. Chair-Elect, 2007-2008. Chair 2008-2009.
  * Committee on Information Science Education. 1999-2006.
  * Committee on Information Science Education. Organizing Committee for an orientation program for students at ASIS annual meetings, 1999-2001
  * Committee on Information Science Education. Sub-committee on Student Welfare (focusing on issues related to master's education), 1998-2001
  * SIG ED. Organizing Committee for the "Seminar on Research and Career Development" for junior researchers. 1995-96 (chair), 1997-2001
  * ISI Doctoral Dissertation Proposal Scholarship Jury, 1997; 2001, 2002
  * Pratt-Severn Best Student Research Paper Award Jury. Chair. 1997
  * 1998 Midyear Meeting (referee of contributed papers), 1997
  * Organizer and moderator of the ASIS Doctoral Forum and the Doctoral Research Seminar 1994-1995
  * SIG Human Computer Interaction. Chair-Elect, Chair, 1993-1995
  * Doctoral Forum Award Jury, 1995
  * Best Student Paper Award Jury, 1995

- American Library Association.
  * Committee on Accreditation, External Review Panelist, 2009- (site visiting team 2013-2014; site visiting team 2016-2017)
  * Association for Library Collections and Technical Services Task Force on Competencies and Education for a Career in Cataloging, member, 2008-2009
  * Facilitator for "What They Don't Teach in Library School: Competencies, Education and Employer Expectations for a Career in Cataloging," an Association for Library Collections and Technical Services Preconference, June 22, 2007 in Washington, D.C. Also a local liaison for bringing this program to the Catholic University of America.
  * Facilitator for a discussion on "Effect of Electronic Resources on Technical Services" at ALA's Midwinter Meeting held in Feb. 1997 in Washington, D.C.

* International Relations Committee, Subcommittee Task Force for IFLA and China, 1994-1997

- Virginia Association of School Librarians. Scholarships and Awards Committee. 2010-2012

- Federal Knowledge Management Initiative, Knowledge Management Practices Action Group. Member. 2009 (leading the effort to build a knowledge management repository)
- Federal Knowledge Management Initiative, Knowledge Management Competencies & Learning Action Group. Member. 2009 (developing an action plan for helping government knowledge workers and government agencies to develop knowledge management competencies)
- National Center for Education Statistics. Technical Review Panel. 2008.
- External evaluator for a case of promotion to full professorship. University of Tennessee. 2008.
- National Information Standards Organization (NISO). Advisory Board, Revision of "IMLS Framework of Guidance for Building Good Digital Collections," 2004, 2007.
- Library of Congress, Bibliographic Control of Web Resources: A Library of Congress Action Plan. Principal Investigator of Action Item 5.1, focusing on cataloging and metadata education for students and new librarians, 2002-2003. (worked with the Association for Library Collections and Technical Services, Education Task Force)

- Chinese American Librarians Association
  * Chinese American Librarians Association Outstanding Library Leadership Award in Memory of Dr. Margaret Chang Fung, Award Committee, 2016-2017
  * Achievement Award Jury, 2000-2001
  * CALA Goal 2000 Task Force, 1997
  * Scholarship Committee, 1995, 1996-1997 (chair)
  * Board of Directors, 1994-1997
  * Publication Committee, 1993-1995
  * International Relations Committee, 1993-1996

- Sailor^{SM} Assessment Advisory Group (An impact study of Sailor, Maryland's Public Information Network), 1995

- Editorial boards
  Journal of Library and Information Science. Editorial Board, 2012-
  Chinese American Librarians Association, *Occasional Papers Series*. Editorial Board, 2009-2016.
  Library Quarterly. Editorial Board, 2003-2008
  Bulletin of the Medical Library Association, 1994-97
  Newsletter editor for the Chinese American Librarians Association, 1989-92

- Referee for the following journals
  Information Processing and Management

Journal of Digital Information
Journal of Education for Library and Information Science
Journal of Information Science
Journal of Library & Information Science
Journal of Library Metadata
Journal of the American Society for Information Science & Technology
Library and Information Science Research
Library Quarterly

- Expert reviewer, "Digital Library" course, Evaluation module, University of North Carolina, Chapel Hill, 2007-2008.
- Expert reviewer, "Information Organization" course, University of Michigan, Ann Arbor. 2007.

Catholic University of America

- School of Arts & Sciences, Academic Senate representative, 2017-2020
- School of Arts & Sciences, Committee on Appointments and Promotions, 2015-2019
- School of Arts & Sciences, Academic Council, 2015-2016.
- School of Arts & Sciences, Ordinary Professor Group, 2013-
- Doctoral Dissertation Defense Committee, Chair, Dept. of Psychology, 2016, 2017, 2018
- Doctoral Dissertation Defense Committee, Chair, Dept. of Education, 2014, 2015, 2017
- President's Administrative Council, 2010-2012
- Deans' Council, 2010-2012
- Academic Leadership Group, 2010-2012
- Academic Senate, 2003-2012
- Academic Senate, Committee on Committees and Rules, 2009-2012
- Academic Senate, Committee on Appointments and Promotions, 2005-2008
- Graduate Board, 2010-2012
- CUA Scholarly Communication Project Team, Member (2007), Chair, 2008-2009
- Academic Senate Library Committee, Interim Chair (2007), Member, 2008-2012
- Doctoral Dissertation Defense Committee, Chair, School of Nursing, 2006, 2008
- Dean Search Committee, 1992-1994, 1998-1999, 2002-2003, 2006-2007
- Fulbright Review Panel, 2006
- Academic Senate Committee on Computing, 1995-2003
- CUA Service Learning Advisory Board, 2001-2002
- CUA Faculty Conversations on Enhancing Teaching and Learning through Technology, Planning Group, 1999-2001
- CUA Initiative on Technology and Teaching, 1998-2001

Dept. of Library and Information Science

- Symposium and Colloquium Committee, fall 2016-May 2018, Chair, May 2018-

- Admissions Committee, 2007-2009, Chair 2010-2012, Member 2013-2015, Member 2018-
- Accreditation presentation, Chair, June 2015-August 2016
- Interim Co-Chair, June 2015-August 2016.
- Appointments and Promotions Committee, 1991-
- Blended/OWL Learning Committee, spring 2016-2018
- Scholarship and Awards Committee, fall 2016-
- Technology Committee, fall 2016-2017
- Comprehensive examination editor, 2016-2017, reader (every year since 1990)
- LIS Advisory Board, 2015-2016 (chair); fall 2016- May 2018 (member)
- Committee on Planning and Assessment, 2015-2016 (chair)
- Senior Faculty Committee, 2014-2016.
- Accreditation Steering Committee, 2014-2016 (Chair, 2015-2016)
- Accreditation Students Standard Committee, co-chair, 2014-2016
- Accreditation Mission, Goals, and Objectives Standard Committee, co-chair, 2014-2016
- Accreditation Curriculum Standard, member 2014-2-16
- Accreditation Administration and Finance Standard, member 2014-2016
- Cultural Heritage Information Management Project (IMLS-funded), Co-PI, 2012-2015
- Cultural Heritage Information Management Forum (scheduled for June 2015), Co-Organizer, 2013-2015
- Health Information Technology Interim Review Committee, 2015 (chair)
- Health Sciences Librarianship Advisory Group, 2015- (chair)
- Comprehensive examination editors, 2013-2014, 2016-2017
- National Digital Stewardship Alliance liaison, 2011-2014
- Advisory Board, Chair 2010-2012
- Academic Honesty Committee, Chair, 2008-2012
- Blended Learning Committee, 2010-2012
- Colloquium Committee, 2010-2012
- Comprehensive Examination Administration, 2010-2012
- Cultural Heritage Information Management Advisory Committee, 2010-2012 (chair), 2013-
- Curriculum Committee, 1991-2003, 2007-2009, Chair 2010-2012, member 2013-
- Curriculum Subcommittee on Comprehensive Examination, Chair 2009-2012
- Health Information Technology Advisory Board, Chair 2010-2012. Member 2013-
- Health Sciences Advisory Committee, 2009, Chair 2010-2012. Member 2013-
- HIT Expert Forum, Chair 2012. Member 2013-
- Health Information Technology Student Group Advisor, 2011-2012
- State Council for Higher Education of Virginia, SLIS Representative, 2010-2012
- Symposium Planning Committee, 2010-2012
- Website Management Team, Chair, 2010-2012
- Urban School Librarianship Project (IMLS-Funded), PI, 2007-2011 (chair, 2010-11)
- Failing Grades Committee, 1995-1997 (chair), 2000-2001 (chair), 2004-2005 (chair), 2007 (chair)-2011

- Faculty Search Committee, 1994-1998, 2002-2004, 2006 (chair), Fall 2007-2009, Chair fall 2009-2012
- Recruitment Committee, Chair 2010-2012
- Strategic Planning Committee, Chair 2010-2012
- Technology Committee, 2010-2012
- Accreditation Advisory Committee, 2007-2009
- Accreditation Coordinating Committee, 2007-2009
- Accreditation Steering Committee, 2007-2009
- SLIS Advisory Group, 2007-2009
- Accreditation Curriculum Standard Committee, Co-chair, 2007-2009
- Accreditation Faculty Standard Committee, Co-chair, 2007-2009
- LSC 551 Information Organization Review Team, Co-chair, 2008-2009, 2015-2016.
- Curriculum Subcommittee on Portfolios, 2009
- LSC 555 Information Systems in Libraries and Information Centers Review Team, contributor, 2008-2009
- Redesign of LSC 730 Use and Users of Libraries and Information. 2009-
- Development of a metadata institute that was taught as LSC 715 Organization of Internet Resources in 2008. The institute is being revised and will be offered in 2010 under a new course title.
- Development of lesson plans, assignments, and evaluation rubrics for LSC 606, Cataloging and Classification, for the School’s NCATE accreditation. 2008
- Howard and Mathilde Rovelstad Scholarship Committee, Chair, 2004-2007
- Assistant Dean Search Committee, Chair, Fall 2007
- Liaison to the Association for Library Collections and Technical Services to bring its preconference program, Cataloging Education and Employer Expectations, to CUA during the 2007 American Library Association Annual Meeting in Washington, D.C.
- Organizer of the colloquium presentation and reception for Tamar Sadeh of Ex Libris on PRIMO June 2007
- Practicum review and design (work with potential supervisors, such as the American Indian Museum internship description revision) 2006-
- Comprehensive examinations (edits, proctoring, and grading), 1990-
- SLIS Web site redesign: Comments and suggestions. Fall 2007
- Conducted surveys of current students and alumni in preparation for the 2005 re-accreditation, 2004-2005
- Student advisement, 1990-
- Technology Committee, 1992-1999 (chair, 1996-1998), 2002-2003 (member)
- Colloquia Committee 1997-1999, 2002-2003.
- Advisor of the CUA Student Chapter of the American Society for Information Science and Technology, 2002-2003
- Visiting Professor Search Committee, 1999, 2000, 2001
- Leader, Participation in the CORC experiment, 1999-2000
- Advisor of the Special Libraries Association Student Chapter, 1993-1999; the group was recognized for outstanding leadership by SLA in 1999.

- COA planning Committee, Task Force on Electronic Presentation of SLIS Reports (team leader) 1997-1998
- COA Planning Committee, Subcommittee on Technology 1996-1998
- NLM practicum coordinator, 1997-1998
- Computer Literacy Workshops: Assisted with the development and evaluation of the workshops, 1996-1998
- Leader, Participation in the InterCat project, 1995-1997

Appendix B

Library of Congress >> MARC >> Understanding MARC

MARC 21 Reference Materials

Part VII:

A Summary of Commonly Used MARC 21 Fields

This is a summary of the MARC 21 tags used most frequently by libraries in entering their own bibliographic records. For full listings of all MARC 21 tags, indicators, and subfield codes, see *MARC 21 Format for Bibliographic Data*.

In the explanations on these pages:

Tags -- The tags (3-digit numbers) are followed by the names of the fields they represent. In this summary, and in the *MARC 21 Format for Bibliographic Data*, if a tag can appear more than once in one bibliographic record, it is labeled repeatable (R). If it can only be used once, it is labeled non-repeatable (NR). For example, a catalog record can have several subjects, so the tags for subject added entries (6XX) are labeled repeatable (R).

Indicators -- The use of indicators is explained in fields where they are used. Indicators are one-digit numbers. Beginning with the 010 field, in every field -- following the tag -- are two character positions, one for Indicator 1 and one for Indicator 2. The indicators are not actually defined in all fields, however. And it is possible that a 2nd indicator will be used, while the 1st indicator remains undefined (or vice versa). When an indicator is undefined, the character position will be represented by the character # (for blank space).

Subfield codes -- All the data in each field (beginning with the 010 field) is divided into subfields, each of which is preceded by a delimiter-subfield code combination. The most common subfield codes used with each tag are shown. Each subfield code is preceded by the character $, signifying a delimiter. The name of the subfield follows the code.

In general, every field MUST have a subfield 'a' (**$a**). One exception that is often seen is in Field 020 (ISBN), when the ISBN information (subfield **$a**) is unavailable but the price (subfield **$c**) is known. Some subfields are repeatable. In this summary, repeatability is noted for only the more common repeatable subfields.

Examples: Examples follow the explanation for each field. For clarity, one space has been placed between the tag and the first indicator, one space has been placed between the second indicator and the first delimiter- subfield code, and one space has been inserted between the delimiter-subfield code and the subfield data.

010 Library of Congress Control Number -- (LCCN)
(NR, or Not Repeatable

Indicators undefined.
Subfield used most often:
- **$a** -- Library of Congress control number

```
Example:    010 ##  $a ###86000988#
```

020 International Standard Book Number -- (ISBN)
(R, or Repeatable)

Indicators undefined.
Subfields used most often:
- **$a** -- International Standard Book Number
- **$c** -- Terms of availability (often a price)
- **$z** -- Cancelled/invalid ISBN (R)

```
Example:    020 ##  $a 0877547637
```

040 Cataloging source -- (NR)

Indicators undefined.
Subfields used most often:
- **$a** -- Original cataloging agency
- **$c** -- Transcribing agency
- **$d** -- Modifying agency (R)

```
Example:    040 ## $a DLC
                   $c DLC
                   $d gwhs
```

100 Main entry -- Personal name -- (primary author)
(NR; there can be only one main entry)

Indicator 1: Type of personal name entry element
- 0 -- Forename
- 1 -- Surname (this is the most common form)
- 3 -- Family name

Indicator 2 undefined.

Indicator 2 became obsolete in 1990. Older records may display 0 or 1

Subfields used most often:
- **$a** -- Personal name
- **$b** -- Numeration
- **$c** -- Titles and other words associated with a name (R)
- **$q** -- Fuller form of name
- **$d** -- Dates associated with a name (generally, year of birth)

```
Example:    100 1# $a Gregory, Ruth W.
                   $q (Ruth Wilhelme),
                   $d 1910-
```

130 Main entry -- Uniform title -- (NR)

Indicator 1: Nonfiling characters
- 0-9 -- Number of nonfiling characters present (for initial articles, including spaces)

Indicator 2 undefined.

Indicator 2 became obsolete in 1990. (See 100 above.)

Subfields used most often:
- **$a** -- Uniform title
- **$p** -- Name of part/section of a work (R)
- **$l** -- Language of a work
- **$s** -- Version
- **$f** -- Date of a work

```
Example:    130 0# $a Bible.
                   $p O.T.
                   $p Psalms.
```

240 Uniform title (NR)

Indicator 1: Uniform title printed or displayed
- 0 -- Not printed or displayed
- 1 -- Printed or displayed (most common)

Indicator 2: Nonfiling characters

0-9 -- Number of nonfiling characters present (for initial articles, including spaces)

Subfields used most often:

$a -- Uniform title
$l -- Language of a work
$f -- Date of a work

```
Example:    240 10 $a Ile mystérieuse.
                   $l English.
                   $f 1978
```

245 Title Statement (NR)

Indicator 1: Title added entry

(Should the title be indexed as a title added entry?)

0 -- No title added entry

(indicates a title main entry; i.e. no author is given)

1 -- Title added entry

(the proper indicator when an author given in 1XX; the most common situation)

Indicator 2: Nonfiling characters

0-9 -- Number of nonfiling characters present, including spaces; usually set at zero, except when the title begins with an article; e.g., for *The robe*, the second indicator would be set to 4. The letters *T*, *h*, *e*, and the space following them are then ignored in alphabetizing titles. The record will be automatically filed under "*r*" -- for *Robe*.

Subfields used most often:

$a -- Title proper
$h -- Medium (often used for non-book media)
$p -- Name of part/section of a work (R)
$b -- Reminder of title (subtitles, etc.)
$c -- Remainder of title page transcription/Statement of responsibility

```
Example:    245 14 $a The DNA story :
                   $b a documentary history of gene
                      cloning /
                   $c James D. Watson, John Tooze.
```

246 Varying form of title (R)

Indicator 1: Note/title added entry controller
  1 -- Note, title added entry
  3 -- No note, title added entry
Indicator 2: Type of title
  # -- No information provided
  0 -- Portion of title
  1 -- Parallel title
  4 -- Cover title
  8 -- Spine title
Subfield used most often:
  $a -- Title proper

```
Example:    246 3# $a Four corners power review
```

250 Edition statement (NR)

Indicators undefined.
Subfield used most often:
  $a -- Edition statement

```
Example:    250 ## $a 6th ed.
```

260 Publication, distribution, etc. (Imprint) (R)

Indicator 1: Sequence of publishing statements
  # -- No information provided
Indicator 2: Undefined
Subfields used most often:
  $a -- Place of publication, distribution, etc. (R)
  $b -- Name of publisher, distributor, etc. (R)
  $c -- Date of publication, distribution, etc. (R)

```
Example:    260 ## $a New York :
                   $b Chelsea House,
                   $c 1986.
```

300 Physical description (R)

Indicators undefined.
Subfields used most often:
- **$a** -- Extent (number of pages) (R)
- **$b** -- Other physical details (usually illustration information)
- **$c** -- Dimensions (cm.) (R)
- **$e** -- Accompanying material (for example, "teacher's guide" or "manual")

```
Example:    300 ## $a 139 p. :
                   $b ill. ;
                   $c 24 cm.
```

440 Series statement / Added entry--Title

This field was made obsolete in 2008 to simplify the series statement. See 490 and 830.

490 Series statement (No added entry is traced from field) (R)

Indicator 1: Specifies whether series is traced (whether an 8XX tag is also present)
- 0 -- Series not traced
- 1 -- Series traced (8XX is in record)

Indicator 2 undefined.
Subfield used most often:
- **$a** -- Series statement (R)
- **$v** -- Volume number (R)

```
Example:    490 1# $a Colonial American craftsmen
```

500 General note (R)

Indicators undefined.
Subfield used most often:
- **$a** -- General note (Used when no specialized note field has been defined for the information. Examples: Notes regarding the index; the source of the title; variations in title; descriptions of the nature, form, or scope of the item.)

```
Example:    500 ##  $a Includes index.
```

504 Bibliography, etc. note (R)

Indicators undefined.
Subfield used most often:
$a -- Bibliography, etc. note

```
Example:    504 ## $a Includes bibliographical
                      references.
```

505 Formatted contents note (R)

Indicator 1: Type of contents note
0 -- Complete contents
1 -- Incomplete contents (used with multivolume set when some volumes are not yet published)
2 -- Partial contents
Indicator 2: Level of content designation
\# -- Basic
Subfield used most often:
$a -- Formatted contents note

```
Example:    505 0# $a Pride and prejudice -- Emma
                      -- Northanger Abbey.
```

520 Summary, etc. note (R)

Indicator 1: Display constant controller
\# -- Summary
1 -- Review
2 -- Scope and content
3 -- Abstract
Indicator 2 undefined
Subfields used most often
$a -- Summary, abstract, or annotation
$b -- Expansion of summary note

```
Example:    520 ## $a This basic guide to parliamentary
                      procedure tells how to conduct
                      and participate in a meeting
                      properly.
```

600 Subject added entry -- Personal name (R)

Indicator 1: Type of personal name entry element
- 0 -- Forename
- 1 -- Surname (this is the most common form)
- 3 -- Family name

Indicator 2: Subject heading system/thesaurus (identifies the specific list or file which was used)
- 0 -- Library of Congress Subject Headings
- 1 -- LC subject headings for children's literature
- 2 -- Medical Subject Headings
- 3 -- National Agricultural Library subject authority file
- 4 -- Source not specified
- 5 -- Canadian Subject Headings
- 6 -- Répertoire de vedettes-matière
- 7 -- Source specified in subfield $2

(Note regarding Sears subject headings: The MARC 21 format does not provide an assigned indicator for Sears subject headings. Therefore, an indicator of 7 is used, and the MARC defined code "sears" is placed in subfield $2.)

Subfields used most often:
- **$a** -- Personal name (surname and forename)
- **$b** -- Numeration
- **$c** -- Titles and other words associated with a name (R)
- **$q** -- Fuller form of name
- **$d** -- Dates associated with a name (generally, year of birth)
- **$t** -- Title of a work
- **$v** -- Form subdivision (R)
- **$x** -- General subdivision (R)
- **$y** -- Chronological subdivision (R)
- **$z** -- Geographic subdivision (R)
- **$2** -- Source of heading or term (used with 2nd indicator of 7)

```
Example:    600 10 $a Shakespeare, William,
                   $d 1564-1616
                   $x Comedies
                   $x Stage history.
```

```
Example:    600 10 $a Shakespeare, William,
                   $d 1564-1616
                   $x Knowledge
```

```
                  $z Rome
                  $v Congresses.
```

Notice that subfields $v, $x, and $z in the 600 field are repeatable. Subfields $v, $x, $y, and $z do not have to be in alphabetical order. They will be in the order prescribed by the instructions given by the subject heading system.

610 Subject added entry -- Corporate name (R)

*Indicator 1:*Type of corporate name entry element
    0 -- Inverted name (not used with AACR2)
    1 -- Jurisdiction name
    2 -- Name in direct order
Indicator 2: Subject heading system/thesaurus.
    See indicator 2 under 600
Subfields used most often:
    $a -- Corporate name or jurisdiction name as entry element
    $b -- Subordinate unit (R)
    $v -- Form subdivision (R)
    $x -- General subdivision (R)
    $y -- Chronological subdivision (R)
    $z -- Geographic subdivision (R)
    $2 -- Source of heading or term (used with 2nd indicator of 7)

```
  Example:    610 10 $a United States.
                     $b Army Air Forces
                     $v Biography.
```

650 Subject added entry -- Topical term (Most subject headings fit here.) (R)

Indicator 1: Level of subject
    # -- No information provided
Indicator 2: Subject heading system/thesaurus
(identifies the specific list or file which was used)
    0 -- Library of Congress Subject Headings
    1 -- LC subject headings for children's literature
    2 -- Medical Subject Headings
    3 -- National Agricultural Library subject authority file
    4 -- Source not specified
    5 -- Canadian Subject Headings
    6 -- Répertoire de vedettes-matière
    7 -- Source specified in subfield $2

Note regarding Sears subject headings: The MARC 21 format does not provide an assigned indicator for Sears subject headings. Therefore, an indicator of 7 is used, and the MARC defined code "sears" is placed in subfield $2.)

Subfields used most often:

- **$a** -- Topical term
- **$v** -- Form subdivision (R)
- **$x** -- General subdivision (R)
- **$y** -- Chronological subdivision (R)
- **$z** -- Geographic subdivision (R)
- **$2** -- Source of heading or term used with 2nd indicator of 7)

```
Example:    650 #0 $a Theater
                   $z United States
                   $v Biography
                   $v Dictionaries.
```

Notice that subfields $v, $x, and $z in the 650 field are repeatable. Subfields $v, $x, $y, and $z do not have to be in alphabetical order. They will be in the order prescribed by the instructions given by the subject heading system.

651 Subject added entry -- Geographic name (R)

Indicator 1: undefined.
Indicator 2: Subject heading system/thesaurus.
See indicator 2 under 600
Subfields used most often:

- **$a** -- Geographic name
- **$v** -- Form subdivision (R)
- **$x** -- General subdivision (R)
- **$y** -- Chronological subdivision (R)
- **$z** -- Geographic subdivision (R)
- **$2** -- Source of heading or term (used with 2nd indicator of 7)

```
Example:    651 #0 $a United States
                   $x History
                   $v Chronology.
```

Notice that subfields $v, $x, and $z in the 651 field are repeatable. Subfields $v, $x, $y, and $z do not have to be in alphabetical order. They will be in the order prescribed by the instructions given by the subject heading system.

700 Added entry -- Personal name (R)

Indicator 1: Type of personal name entry element
    0 -- Forename
    1 -- Surname (this is the most common form)
    3 -- Family name
Indicator 2: Type of added entry
    # -- No information provided (most common; co-authors, editors, etc.)
    2 -- Analytical entry (The values for Indicator 2 changed in 1994 with Format Integration, and older records may display additional values. An analytical entry involves an author/title of an item contained in a work.)
Subfields used most often:
    $a -- Personal name
    $b -- Numeration
    $c -- Titles and other words associated with a name (R)
    $q -- Fuller form of name
    $d -- Dates associated with a name (generally, year of birth)
    $e -- Relator term (such as ill.) (R)
    $4 -- Relator code (R)

```
Example:    700 1# $a Baldridge, Letitia.
```

710 Added entry -- Corporate name (R)

Indicator 1: Type of corporate name entry element
    0 -- Inverted name (not used with AACR2)
    1 -- Jurisdiction name
    2 -- Name in direct order
Indicator 2: Type of added entry.
    See Indicator 2 under 700
    # -- No information provided
    2 -- Analytical entry
Subfields used most often:
    $a -- Corporate name or jurisdiction name as entry element
    $b -- Subordinate unit (R)

```
Example:    710 2# $a Sunburst Communications (Firm)
```

740 Added entry -- Uncontrolled related/analytical title (R)

Indicator 1: Nonfiling characters

0-9 -- Number of nonfiling characters present (for initial articles, including spaces)

*Indicator 2:*Type of added entry. See Indicator 2 under 700

-- No information provided

2 -- Analytical entry

(This field was redefined in 1994 with Format Integration. Prior to 1994, the field was also used for variant titles, such as a different wording on a spine title. In records created since Format Integration, those variant tiles appear in a 246 field.)

Subfield used most often:

$a -- Title

```
Example:    740 02 $a Uncle Vanya.
```

800 Series added entry -- Personal name (R)

Indicator 1: Type of personal name entry element

0 -- Forename

1 -- Surname

3 -- Family name

Indicator 2 undefined.

Subfields used most often:

$a -- Personal name

$b -- Numeration

$c -- Titles and other words associated with a name (R)

$q -- Fuller form of name

$d -- Dates associated with a name (generally, year of birth)

$t -- Title of a work (the series)

$v -- Volume number

```
Example:    800 1# $a Fisher, Leonard Everett.
                   $t Colonial American craftsmen.
```

830 Series added entry -- Uniform title (R)

Indicator 1 undefined.

Indicator 2: Nonfiling characters

0-9 -- Number of nonfiling characters present (for initial articles, including spaces)

Subfield used most often:

$a -- Uniform title

$v -- Volume number

```
Example:    830 #0 $a Railroads of America (Macmillan)
```

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Part VIII:

A List of Other Fields Often Seen in MARC Records

001	Control number
003	Control number identifier
005	Date and time of latest transaction
006	Fixed-length data elements -- additional material characteristics
007	Physical description fixed field
008	Fixed length data elements (See Part X)
022	International Standard Serial Number (ISSN)
037	Source of acquisition
041	Language code
043	Geographic area code
050	Library of Congress call number
060	National Library of Medicine call number
082	Dewey Decimal classification number (the one recommended by the Library of Congress; locally-assigned call numbers may appear elsewhere)
110	Main entry -- Corporate name (less frequent under AACR2 rules)
256	Computer file characteristics
263	Projected publication date (indicates a CIP -- Cataloging in Publication -- record)
306	Playing time
508	Creation/production credits note
510	Citation/references note (review sources)
511	Participant or performer note
521	Target audience note (first indicator: 0 = reading grade level, 1 = interest age level, 2 = interest grade level, 3 = special audience characteristics, 4 = motivation interest level)
530	Additional physical form available note
538	System details note
586	Awards note
656	Index term -- Occupation
730	Added entry -- Uniform title
852	Location

856	Electronic location and access
9XX	Reserved for local use. (They are used by vendors, systems, or individual libraries to exchange additional data)

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Part IX:

The Leader

There are 24 positions in the Leader, numbered from 00 to 23. For fuller explanation, see the *MARC 21 Format for Bibliographic Data*.

00-04 Record length (calculated by the computer for each record)

05 Record status
- a = increase in encoding level
- c = corrected or revised
- d = deleted
- n = new
- p = increase in encoding from prepublication (previous CIP)

06 Type of record
- a = language material
- c = printed music
- d = manuscript music
- e = cartographic material
- f = manuscript cartographic material
- g = projected medium
- i = nonmusical sound recording
- j = musical sound recording
- k = 2-dimensional nonprojectable graphic
- m = computer file
- o = kit
- p = mixed materials
- r = 3-dimensional artifact or naturally occurring object
- t = manuscript language material

07 Bibliographic level
- a = monographic component part
- b = serial component part
- c = collection
- d = subunit
- i = integrating resource
- m = monograph/item
- s = serial

08 Type of control
- # = no specified type
- a = archival

- 09 Character coding scheme
  - # = MARC-8
  - a = UCS/Unicode
- 10 Indicator count (always "2")
- 11 Subfield code count (always "2")
- 12-16 Base address of data (calculated by the computer for each record)
- 17 Encoding level
  - # = full level
  - 1 = full level, material not examined
  - 2 = less-than-full level, material not examined
  - 3 = abbreviated level
  - 4 = core level
  - 5 = partial (preliminary) level
  - 7 = minimal level
  - 8 = prepublication level (CIP)
  - u = unknown
  - z = not applicable
- 18 Descriptive cataloging form
  - # = non-ISBD
  - a = AACR2
  - i = ISBD
  - u = unknown
- 19 Multipart resource record level
  - # = Not specified or not applicable
  - a = Set
  - b = Part with independent title
  - c = Part with dependent title
- 20 Length of the length-of-field portion (always "4")
- 21 Length of the starting-character-position portion (always "5")
- 22 Length of the implementation-defined portion (always "0")
- 23 Undefined (always "0")

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Part X:

Field 008 for Books

Field 008 is used for Fixed Length Data Elements ("Fixed Field Codes"). There are 40 character positions in field 008, numbered from 00-39. Undefined positions must contain either a blank (#) or a fill character (|). Positions 00-17 and 35-39 are defined the same way for all media.

The information shown here for positions 18-34 applies only to books. For explanation of all the positions below and for positions 18-34 for other media, see the *MARC 21 Format* *for Bibliographic Data*.

Note that field 008 has no indicators or subfield codes.

00-05 Date entered on file (YYMMDD),
where Y=year, M=month, and D=day
06 Type of date/publication status:
b = no dates given; B.C. date involved
e = detailed date
s = single known date/probable date
m = multiple dates
r = reprint/reissue date (Date 1) and original date (Date 2)
n = dates unknown
q = questionable date
t = publication date and copyright date
| = no attempt to code
07-10 Date 1/beginning date of publication
11-14 Date 2/ending date of publication

Date fields contain the year(s) of publication. The type of date(s) in these elements are specified in fixed field element 06: Type of date/publication status. (For further details, see the field 008 description in the *MARC 21 Format for Bibliographic Data*.)

15-17 Place of publication, production, or execution
For example:
pk# = Pakistan
cau = California (US)

(For a full list of codes used in these positions, see the *MARC Code List for Countries*.)

18-21 Illustrations (up to 4 codes):
# = no illustrations
a = illustrations
b = maps
c = portraits
d = charts
e = plans
f = plates
g = music
h = facsimiles
i = coats of arms
j = genealogical tables
k = forms
l = samples
m = phonodisc, phonowire, etc.
o = photographs
p = illuminations
| = no attempt to code

22 Target audience:
# = unknown or not specified
a = preschool
b = primary
c = pre-adolescent
d = adolescent
e = adult
f = specialized
g = general
j = juvenile
| = no attempt to code
23 Form of item:
# = none of the following
a = microfilm
b = microfiche
c = microopaque
d = large print
f = braille
r = regular print reproduction
s = electronic
| = no attempt to code
24-27 Nature of contents (up to 4):
# = no specified nature of contents
a = abstracts/summaries
b = bibliographies (is one or contains one)
c = catalogs
d = dictionaries
e = encyclopedias
f = handbooks
g = legal articles
i = indexes
j = patent document
k = discographies
l = legislation
m = theses
n = surveys of literature
o = reviews
p = programmed texts
q = filmographies
r = directories
s = statistics
t = technical reports
u = standards/specifications
v = legal cases and notes
w = law reports and digests
z = treaties
| = no attempt to code

28 Government publication:

- # = not a government publication
- i = international intergovernmental
- f = federal/national
- a = autonomous or semi-autonomous component
- s = state, provincial, territorial, dependent, etc.
- m = multistate
- c = multilocal
- l = local
- z = other type of government publication
- o = government publication -- level undetermined
- u = unknown if item is government publication
- | = no attempt to code

29 Conference publication:

- 0 = not a conference publication
- 1 = conference publication
- | = no attempt to code

30 Festschrift:

- 0 = not a festschrift
- 1 = festschrift
- | = no attempt to code

31 Index:

- 0 = no index
- 1 = index present
- | = no attempt to code

32 Undefined (since 1990) (Earlier records may contain the values 0 or 1)

- # = Undefined
- | = no attempt to code

33 Literary form:

- 0 = not fiction (not further specified)
- 1 = fiction (not further specified)
- c = comic strips
- d = dramas
- e = essays
- f = novels
- h = humor, satires, etc.
- i = letters
- j = short stories
- m = mixed forms
- p = poetry
- s = speeches
- u = unknown
- | = no attempt to code

34 Biography:

- # = no biographical material
- a = autobiography
- b = individual biography

c = collective biography
d = contains biographical information
| = no attempt to code

35-37 Language:
A three-letter code. For example: eng fre ger spa rus ita

(For a full list of codes used in these positions, see the *MARC Code List for Languages*.)

38 Modified record:
# = not modified
x = missing characters (because of characters unavailable in MARC character set)
s = shortened
d = "dashed-on" information omitted
r = completely romanized/printed cards in script
o = completely romanized/printed cards romanized
| = no attempt to code

39 Cataloging source:
# = national bibliographic agency
c = cooperative cataloging program
d = other sources
u = unknown
| = no attempt to code

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Library of Congress
Library of Congress Help Desk (10/27/2009)

Appendix C

Revised November 30, 2016

AMENDED ARTICLES OF INCORPORATION OF OCLC Online Computer Library Center, Inc.

FIRST The name of the corporation shall be OCLC Online Computer Library Center, Inc. (the “Corporation”).

SECOND The place in this State where the principal office of the Corporation is to be located is in the City of Dublin, Franklin County, Ohio.

THIRD The purpose or purposes for which the Corporation is formed are to establish, maintain, and operate a computerized library network and to promote the evolution of library use, of libraries themselves, and of librarianship, and to provide processes and products for the benefit of library users and libraries, including such objectives as increasing availability of library resources to individual library patrons and reducing the rate of rise of library per-unit costs, all for the fundamental public purpose of furthering ease of access to and use of the ever-expanding body of worldwide scientific, literary, and educational knowledge and information.

FOURTH The affairs of the Corporation shall be managed by the Board of Trustees. The qualifications of the Trustees, together with their terms of office, manner of election, removal, change of number, filling of vacancies and of newly-created trusteeships, powers, duties and liabilities, shall, except as otherwise provided in these Articles, or by the laws of the State of Ohio, be as prescribed by the Code of Regulations.

FIFTH There shall be two classes of members of the Corporation and they shall be OCLC Members, and Trustee Members. The voting powers of each class of members shall be only as defined in the Code of Regulations or as stated in these Articles.

SIXTH There shall be a Global Council composed of Member Delegates as prescribed in the Code of Regulations.

SEVENTH These Articles may be amended at any business meeting of the Trustee Members called for that purpose provided that notice of the proposed amendment(s) has been sent to the Trustee Members at least ten (10) days prior to said meeting. A two-thirds (2/3) vote of all of the authorized Trustee Members of the Corporation is required for approval.

EIGHTH The duration of the Corporation shall be perpetual.

NINTH No part of the earnings, dues, or receipts of the Corporation shall inure to the benefit of or be distributed to its members, trustees, officers, or other private persons, except only that the Corporation shall be authorized and empowered to pay reasonable compensation for services rendered and expenses incurred and to make payments or distributions in furtherance of the purposes set forth in Article Third hereof. No substantial part of the activities of the Corporation shall be the carrying on of propaganda, or otherwise attempting to influence legislation, and the Corporation shall not participate in, or intervene in (including the publishing or distribution of statements) any political campaign on behalf of, or in opposition to**,** any candidate for public office. Notwithstanding any other provision of these Articles, the Corporation shall not carry on any other activities not permitted to be carried on (a) by a corporation exempt from Federal income tax under Section 501(c)(3) of the Internal Revenue Code of 1986, as amended (or the corresponding provision of any future United States internal revenue law) (the "Code") or (b) by a corporation, contributions to which are deductible under Section 170(c)(2) of the Code.

TENTH Upon the dissolution of the Corporation, the Board of Trustees shall, after paying or making provision for the payment of all of the liabilities of the Corporation, dispose of all of the assets of the Corporation exclusively for the purposes of the Corporation in such manner, or to such organization or organizations as are described in Section 170(c)(1) or (2) of the Code, as the Board of Trustees shall determine. Any of such assets not so disposed of shall be disposed of by the Court of Common Pleas of the county in which the principal office of the Corporation is then located, exclusively for such purposes or to such organization or organizations, as said Court shall determine, which are organized and operated exclusively for such purposes.

ELEVENTH These Articles supersede all prior Articles or Amended Articles.