

## HOME INFORMATION WIRING SYSTEM USING UTP CABLE FOR IEEE1394 AND ETHERNET SYSTEMS

Masahiro Maki<sup>1</sup>, Seiji Hamada<sup>2</sup>, Masamitsu Tokuda<sup>3</sup>, Yoshifumi Shimoshio<sup>4</sup> and Nobuo Kuwabara<sup>2</sup>

<sup>1</sup>Matsushita Electric Industrial Co., Ltd., Fukuoka, Japan

<sup>2</sup>Kyushu Institute of Technology, Fukuoka, Japan

<sup>3</sup>Musashi Institute of Technology, Tokyo, Japan

<sup>4</sup>Kumamoto National College of Technology, Kumamoto, Japan

**Abstract** -- IEEE1394 and Ethernet systems are being extensively adopted for data communications equipment, including audiovisual equipment and personal computers. This paper proposes a wiring system that enables the simultaneous transmission of IEEE1394 signals and Ethernet signals along a single UTP-CAT5 cable consisting of four twisted pairs.

The requirements of this wiring system were determined by taking into account the specifications of both IEEE1394 and Ethernet systems and the actual domestic environment. Home Network adapters were developed to connect IEEE1394 and Ethernet cable to UTP cable. Insertion loss, crosstalk, and eye-diagrams were measured to evaluate the system's performance. The results show that our proposed wiring system is capable of transmitting both the IEEE1394 signal and the Ethernet signal simultaneously at 100 Mbps up to a distance of 100 m along a UTP-CAT5 cable.

### I. INTRODUCTION

There is a growing trend to connect home appliances to "Home Networks." A home network is a domestic network to which both AV (audiovisual) equipment and ITE (information technology equipment) can be connected.

Ethernet LANs (Local Area Networks) [1] using UTP-CAT5 (Unshielded Twisted Pair Category 5) cable are commonly used to link information equipment. The IEEE1394 system [2] is also widely used in networks linking AV equipment. A standard for IEEE1394.b [3] [4] using UTP-CAT5 has been proposed and is being put into actual use. However, no systems as yet exist in which both IEEE1394 and Ethernet signals can be transmitted via a single cable. In the future, since many types of AV equipment and ITE will be used in domestic networks, there is a need for a wiring system that can transmit both IEEE1394 and Ethernet signals.

This paper proposes a new wiring system that actualizes the transmission of IEEE1394 and Ethernet

signals via a single UTP-CAT5 cable consisting of 4 twisted pairs. The specifications of IEEE1394 and Ethernet were first investigated. Actual domestic environments were also studied in determining the requirements of the wiring system. A connection box called a home network adaptor was developed to connect IEEE1394 and Ethernet to UTP-CAT5 cable.

To evaluate the feasibility of the system, measurement of insertion loss and crosstalk and eye-diagrams were used.

### II. NEW WIRING SYSTEM

In this study, PCs and AV equipment are assumed to be included in the home network. We first consider the problems with the network deriving from these and then indicate how to obtain a solution to these problems.

#### A. Present State of Development of Home Networks

The Ethernet system, designed to interconnect ITE, is widely used in households due to the spread of Internet use. Hence, installation of UTP-CAT5 cables for Internet use is increasingly common in new houses.

In addition, an increasing proportion of AV equipment such as DVCs (Digital Video Camcorders) and STBs (Set Top Boxes) come equipped with IEEE1394 terminals. IEEE1394 [2] can transmit digital signals with ease and simplicity. The maximum length of STP (Shielded Twisted Pair) cable that can be used to transmit IEEE1394 signals is 4.5 m. POF (Plastic Optical Fiber) and UTP-CAT5 are being considered to enable longer-distance transmission of IEEE1394.b signals [3]. Optical fibers are expensive and system setup is complicated, ruling out their use for domestic networks. We thus focused our study on a wiring system using UTP-CAT5.

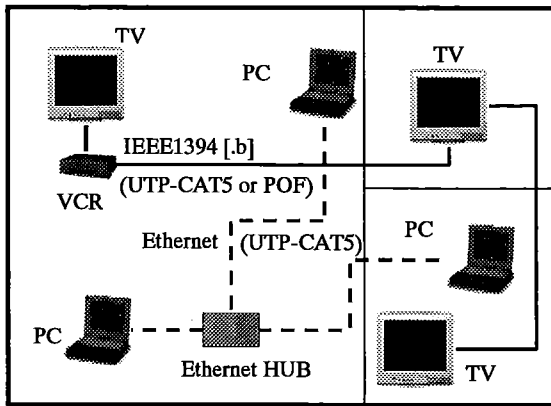


Fig. 1 Examples of networks using different types of wiring

### B. The Home Network Adapter

Wiring costs can be kept low by using UTP-CAT5, a metal cable. However, if separate UTP-CAT5 cables are needed for Ethernet and IEEE1394 as shown in Fig. 1, total costs will rise and domestic wiring will become more complicated.

To solve this problem, we propose the wiring system shown in Fig. 2.

General-use UTP-CAT5 contains four twisted pairs. In Ethernet (100Base-Tx, 10Base-T, etc.) [1] other than Gigabit Ethernet (1000Base-T) [5], only two pairs of twisted pair wires are used. Similarly, IEEE1394.b uses only two twisted pairs.

Only four twisted pairs are thus needed to transmit both Ethernet and IEEE1394 signals. It is thus possible that a single UTP-CAT5 cable, which has four twisted pairs, can be used to transmit both signals.

Fig. 2 shows that only one UTP-CAT5 is needed for basic indoor wiring, simplifying the wiring process and reducing costs. To realize this, a Home Network adapter has been developed that acts as a connector to allow both Ethernet and IEEE1394 signals to be transmitted through a single UTP-CAT5.

The Home Network adapter shown in Fig. 2 has three ports (For Ethernet, IEEE1394.b<sup>1</sup>, and the merged signals). Each port is an RJ-45 connector and can therefore be directly connected to the UTP-CAT5.

In accordance with the Ethernet specification, terminals 1, 2, 3, and 6 of the RJ-45 connector will be used for Ethernet signals. Terminals 1, 2, 7, and 8 are allocated for IEEE1394.b.

<sup>1</sup> Even if it is the resource equipped with IEEE1394, it has not been the IEEE1394.b specification that uses UTP-CAT5. Therefore, these signals need to go via P1394b adapter changed into the signal of IEEE1394.b specification.[2][3]

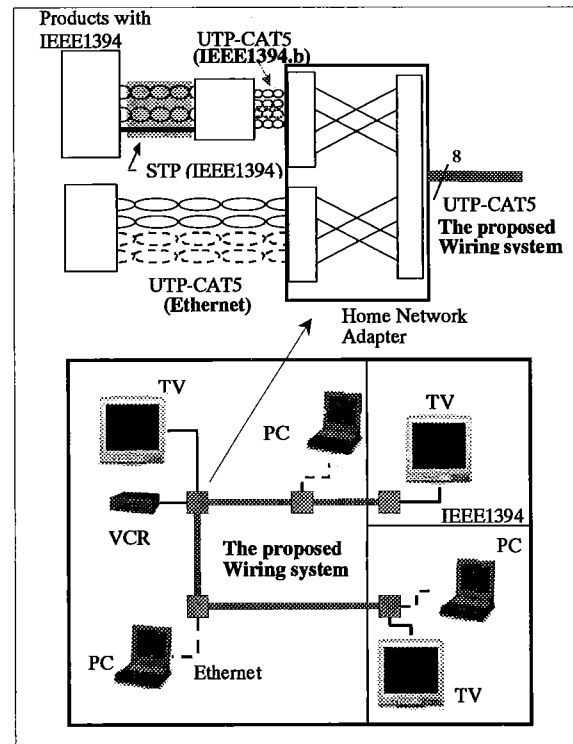


Fig. 2 Proposed wiring system

The Home Network adapter enables both types of signals to be sent through the four twisted pairs by reconfiguring the wiring in the individual Ethernet and IEEE1394.b ports, as shown in Fig. 2.

With the installation of only one UTP-CAT5 cable, it is also possible to transmit AV system data using the same cable simultaneously. Hence, this system can also be made compatible with the domestic transmission of digital broadcasting services.

In the realization of future home high-speed networks, this type of system can significantly reduce the quantity of domestic wiring required.

### III. REQUIRED SPECIFICATIONS FOR THE HOME NETWORK ADAPTER

#### A. Target Transmission Specification

As already stated, we aim at integrating ITE and AV equipment networks by transmitting Ethernet and IEEE1394.b simultaneously via the same cable. The specifications needed are shown in Table 1. In addition, the UTP-CAT5 specification is shown in Table 2.

Table 1 Target transmission specification

	IEEE802.3u (100Base-TX, Fast Ethernet)	IEEE1394 [b] (S100)
Transmission rate [Mbps]	100	100
Transmission length [m]	100	100
Transmission media	Two pairs of UTP-CAT5	Two pairs of UTP-CAT5

Table 2 Specification of UTP-CAT5

Frequency [MHz]	Impedance [ $\Omega$ ]	Insertion Loss [dB]	NEXT [dB]	Power Sum NEXT [dB]
1	100 $\pm$ 15	2.0	62	62
4		4.1	53	53
8		5.8	48	48
10		6.5	47	47
16		8.2	44	44
20		9.3	42	42
25		10.4	41	41
31.25		11.7	39	39
62.5		17.0	35	35
100		22.0	32	32

#### B. Requirements for Implementation

To demonstrate the feasibility of this kind of unified home information wiring system, there is a need to first demonstrate that each type of signal (i.e. IEEE1394 signals and Ethernet signals) can be successfully transmitted. Under present standards, the IEEE1394.b standard requires the capability of transmitting the "S100" signal of IEEE1394-95 [2] along more than 100 m of cable. Likewise, the Ethernet standard 100Base-TX (IEEE802.3u) [1] also requires that 100 Mbps signals be transmittable through cable lengths of over 100 m.

To fulfill these requirements, the transmission characteristics of the whole transmission line, including the Home Network adapter, needs to satisfy the UTP-CAT5 specification. The requirements of the proposed wiring system are summarized in Table 3.

Table 3 Requirements of proposed wiring system

Terms	Requirement
Impedance	Satisfy the requirement of UTP-CAT5 within the Home Network adaptor.
Insertion Loss	
NEXT	
Lack of symmetry	Lack of symmetry of the twisted pair does not significantly affect the electromagnetic environment.
Transmission media	UTP-CAT5 with four twisted pairs and Home Network adaptor with three ports.

#### IV. EVALUATION

In this section, we measured the characteristics of the wiring system and investigate whether the proposed wiring system satisfies the requirement in Table 3.

The UTP-CAT5 used in the evaluation consists of four pairs of twisted pair wires with a wire radius of 0.25 mm and a wire-to-wire distance of 1 mm measured from center to center.

##### A. Insertion Loss

Fig. 3 shows the attenuation characteristics of the UTP-CAT5 (100 m and 300 m).

Here, the calculated values of 100 m UTP-CAT5 shown in are derived using the following.

$$InsertionLoss [dB] = -20 \log_{10} F_{(1,1)} \quad (1)$$

where

$$F = \begin{bmatrix} 1 & Z \\ Y & 1 + ZY \end{bmatrix}^{100}$$

$$Z = R_s + j\omega L_s, \quad Y = j\omega C_p$$

$R_s$ : per-unit-length resistance of conductor [ $\Omega/m$ ]

$L_s$ : per-unit-length inductance of conductor [H/m]

$C_p$ : per-unit-length capacitance between conductors [F/m]

The difference between the calculated values and measured values for 100 m UTP-CAT5 is large for frequencies above 100 MHz as shown in Fig. 3. It may cause a reflection due to impedance mismatch at each Home Network adapter. The insertion loss will be improved if the reflection at the adapter can be minimized.

Attenuation is 25 dB for the 100 m distances at a frequency of 100 MHz as shown in Fig. 3. This value slightly exceeds the value of 22 dB in Table 2. However, since the required bandwidth for 100 Mbps transmission of the Ethernet in actual applications is lower than 100 MHz, as shown in Fig. 4, the 25 dB of attenuation does not pose any obstacle to 100 Mbps transmission. However, if a 300 m cable is used, the frequency at which attenuation is below 22 dB is below 15 MHz. Hence, from transmission characteristics considerations, we can see that a cable length of 100 m is the upper limit for achieving a transmission rate of 100 Mbps without any excess margin.

To satisfy this requirement, the distance should be reduced from 100 m to 80 m. Although the monitoring results shown in Fig. 3 more or less satisfy the specification, a further enhancement in the attenuation characteristics can be achieved if reflection at the adapter can be minimized.

### B. Crosstalk

The NEXT (Near End Crosstalk) characteristics of 100 m UTP-CAT5 are shown in Fig. 5.

The calculation result in Fig. 5 is obtained using formula [6] that is given by

$$\begin{aligned} \text{NEXT}[dB] &= 20 \log_{10} \left| \frac{V_{03} - V_{04}}{V_{01} - V_{02}} \right| \\ &= 20 \log_{10} \left| \frac{B_{11} - B_{12} - B_{21} + B_{22}}{2} \right| \quad (2) \end{aligned}$$

where

$$\mathbf{B} = [\mathbf{A}_{(i+2)j}] \cdot [\mathbf{A}_{ij}]^{-1}, \quad (i, j = 1, 2)$$

$$\mathbf{A} = [\mathbf{F}_{ij}] \cdot [\mathbf{F}_{(i+4)j}]^{-1}, \quad (i, j = 1 \sim 4)$$

$$\mathbf{F} = \mathbf{F}_0 \cdot \begin{bmatrix} \mathbf{1}_4 & \mathbf{R} + j\omega\mathbf{C} \\ j\omega\mathbf{C} & \mathbf{1}_4 \end{bmatrix}^{100} \cdot \mathbf{F}_L$$

(where  $\mathbf{1}_4$  is a 4x4 identity matrix.)

In the calculations for two pairs of twisted pair lines (i.e. four wires),  $\mathbf{R}$ ,  $\mathbf{L}$ , and  $\mathbf{C}$  represent the vector notation of the resistive, inductive and capacitive components of each wire, respectively.  $\mathbf{F}_0$  and  $\mathbf{F}_L$  are the matrices representing the terminal impedance of the cable. The Figure shows a case where a parallel capacitance is inserted as a non-symmetrical component between the lead wire and the ground of the RJ-45 connector in the Home Network adapter.

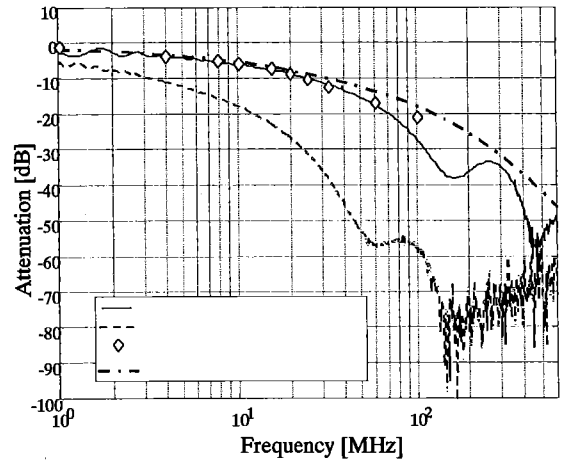


Fig. 3 Attenuation characteristics of the UTP-CAT5

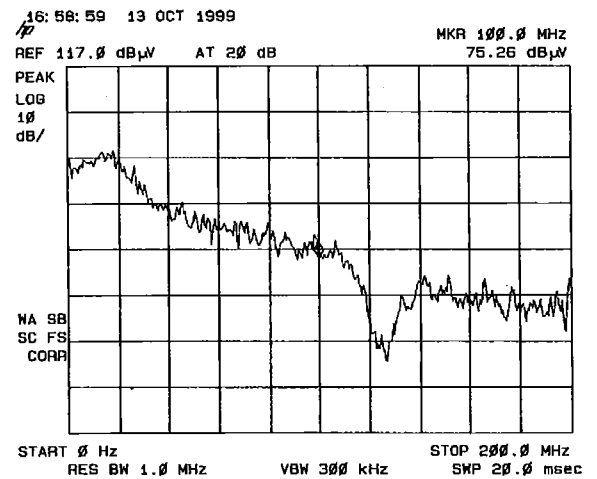


Fig. 4 Spectrum of the 100Base-TX

The result shows that a 20 dB margin is lost when a capacitance of 500 pF is inserted. Although parallel capacitance may be caused by poor connector packaging, there is little likelihood of the parallel capacitance reaching a value as high as 500 pF. Therefore, it is unlikely that the crosstalk margin of a Home Network adapter will be eliminated due to parallel lack of symmetry.

The measured and calculated characteristics of NEXT in Fig. 6 show a 20 dB margin with respect to the specification values in the case of a 100 m cable. This Figure shows that it is within the specification value for 100 m transmissions, and remains so even up to 300 m.

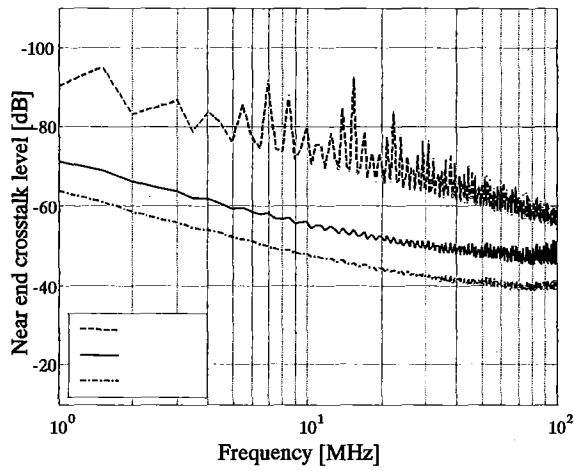


Fig. 5 Calculated NEXT for the UTP-CAT5

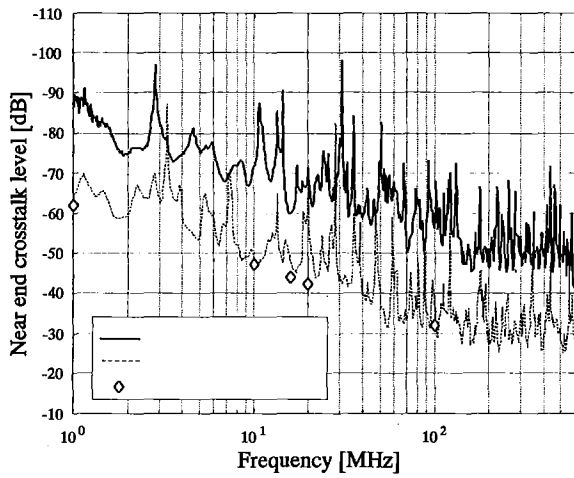


Fig. 6 Crosstalk characteristics of the UTP-CAT5

C. Eye Diagram

An eye diagram was measured for the proposed wiring system using a physically constructed experimental system.

Fig. 7 shows the experimental system used for the measurement. The signal combinations are as follows:

- (a) PN signal (NRZ)
- (b) PN signal (NRZ) + 100Base-TX
- (c) PN signal (NRZ) + IEEE1394.b

Here, a PN signal (NRZ: Non Return to Zero) was chosen as the standard signal. Since NRZ is an on-off baseband signal, it is the most likely to be affected by crosstalk due to its broad bandwidth. Fig. 8 shows the eye diagrams of the NRZ signal at the test point (Out<sub>2</sub> in Fig. 7) for the respective cases (a) to (c).

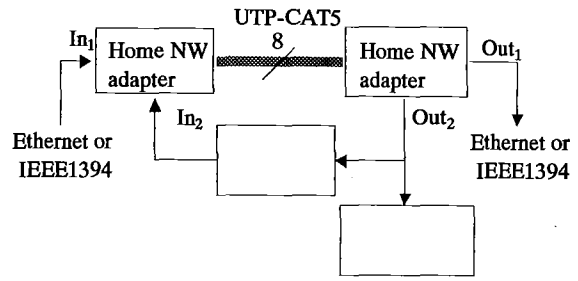
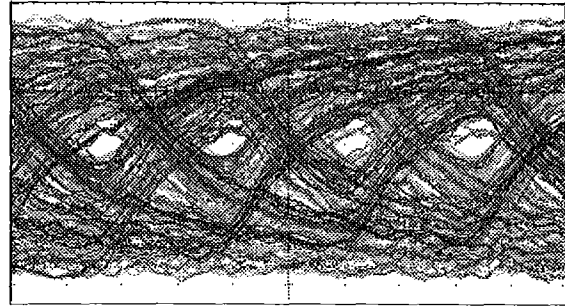
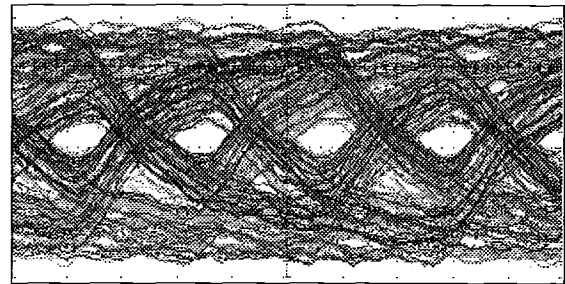


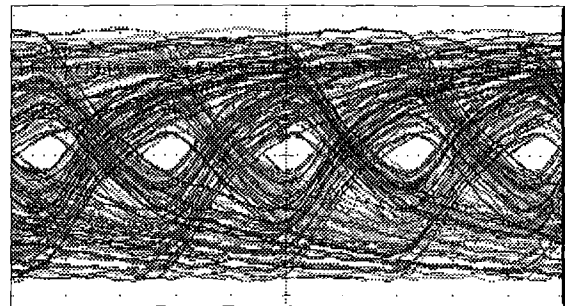
Fig. 7 Measurement conditions for the eye diagram



(a) In<sub>1</sub>: None



(b) In<sub>1</sub>: Ethernet signal



(c) In<sub>1</sub>: IEEE1394.b

Fig. 8 Eye diagram for the NRZ signal

The applied NRZ signal from the pulse generator is given amplitude of 1Vp-p, the same as IEEE1394.b. Furthermore, the transmission rate was set to 100 Mbps, the speed where the eye opening can still be observed during transmission over 100 m. The signals are applied between terminals 4-5 of the Home Network adapter, as shown in Fig. 2. In cases (b) and (c), the 100Base-TX or the IEEE1394.b signals are applied between the pairs labeled 1-2 and 3-6 through the adapter. The length of the UTP-CAT5 cable is set to 100 m.

The results in Fig. 8 indicate that the eye-opening rate is around 10%. Hence, it can be seen that when a cable longer than 100 m is used, there is a high probability of errors appearing in the transmitted signal. However, it can also be seen that the eye opening rate of the two other cases (b) and (c) showed no change compared to when only NRZ was applied. This suggests that reliable communication can be achieved by means of our proposed information wiring system, based on the fact that the NRZ signal is not affected by crosstalk.

#### D. Generation of Electromagnetic Noise

Communications signals are converted to common mode signals by the unbalance with the adaptor and cable. The common mode signal is radiated into space and causes electromagnetic interference.

To estimate the influence caused by terminal lack of symmetry, radiated electromagnetic fields were calculated under the conditions shown in Fig. 9. At this time, a capacitance as a non-symmetrical component was added between the ground and a lead wire at the end of the cable.

The calculation results are shown in Fig. 10. The calculated values were obtained under three conditions: (1) no non-symmetrical capacitance is added, (2) a 5 pF capacitance is inserted, and (3) a 10 pF capacitance is inserted, respectively.

The results indicate that a slight increase in capacitance leads to a significant increase in intensity of emission. With a 10 pF increase in capacitance, the radiated electric field exceeds the level specified in CISPR22 [7], which is the limit for ITE.

Due to the sufficient margin that remains, there seems to be no problem in terms of crosstalk even when a 500 pF parallel capacitance was inserted. However, in terms of electromagnetic noise, a mere 10 pF increase in capacitance is sufficient to cause problems. Therefore, when developing a Home Network adapter, special caution must be taken in to avoid lack of symmetry in the transmission line.

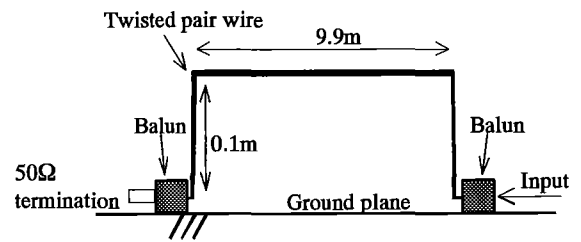


Fig. 9 Conditions assumed for the calculation

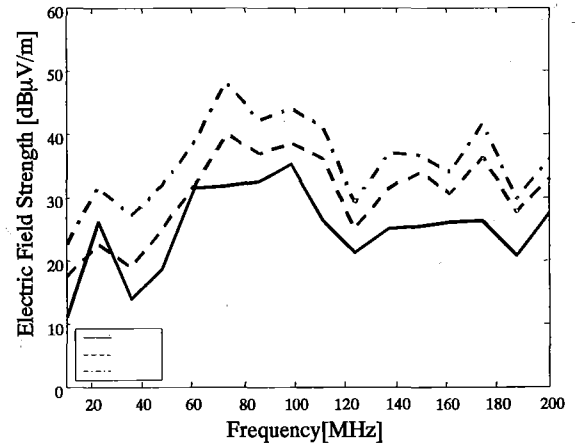


Fig. 10 Emissions from UTP-CAT5 (calculated)

#### V. CONCLUSIONS

An information wiring system is proposed that allows simultaneous transmission of two different types of signals: IEEE1394.b and Ethernet signals.

To investigate the feasibility of transmitting two types of signals simultaneously along a single cable, we carried out an evaluation of the crosstalk and attenuation characteristics of the cable. It was found that for a 100 m UTP-CAT5 cable, there still exists a crosstalk margin of around 20 dB or more. Hence, it was concluded this type of transmission is possible for a cable length not exceeding 100 m.

In addition, a theoretical examination was performed that took into account the non-symmetrical ingredient of a Home Network adapter. The crosstalk was formed satisfactory as far as a capacitance of 500 pF or more was not inserted. Moreover, emissions exceed the minimum value if a capacitance of 10 pF is inserted. These results show that it is important to be especially cautious of lack of symmetry of a transmission line when developing a Home Network adapter.

## ACKNOWLEDGEMENTS

The authors would like to thank Mr. Y. Higashi, Director of Matsushita Electric Industrial's Kyushu Multimedia Systems Research Laboratory, and Mr. K. Hontani, Group Manager of AVC Company, Matsushita Electric Industrial, for their support for this development.

## REFERENCES

- [1] IEEE Std.802.3 2000Ed., "Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications," ISO/IEC 8802-3, 2000
- [2] "IEEE Std.1394-1995 IEEE Standard for a High Performance Serial Bus", IEEE, 1995
- [3] "P1394b Draft Standard for a High Performance Serial Bus (Supplement)", IEEE, 2000
- [4] M. Inada, "Admission IEEE1394 specification", Gijutsu Hyôronsha, 1998 (In Japanese)
- [5] IEEE Std.802.3 2000Ed., "Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications," ISO/IEC 8802-3, pp. 1078-1214, 2000
- [6] N. Yamamoto, Y. Shimoshio, H. Koga and M. Tokuda, "Electromagnetic Noise Characteristics between Two Unshielded Twisted-Wire Pairs in relation to Number of Twists", Tech. Rep. of IEICE, EMCJ2000-10, 2000 (In Japanese)
- [7] "CISPR22 Ed.3.0, Information technology equipment - Radio disturbance characteristics - Limits and methods of measurement", IEC, 1997