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journal or publication title	2003 IEEE Symposium on Electromagnetic Compatibility. Symposium Record
page range	448-453
year	2003-10-14
URL	http://hdl.handle.net/10228/00008542

doi: https://doi.org/10.1109/ISEMC.2003.1236639

Suppression Effect of Radiated Emission from Twisted Pair Wires with Ferrite Core

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Abstract

Telecommunication signal emissions from unshielded twisted pair (UTP) cable should be suppressed to maintain EMC of telecommunication systems. This paper describes the suppression effects of the ferrite cores which are installed on the UTP cable. Twisted pair wire with ferrite core was modeled by 4-port network to evaluate suppression effect. Parameters of the networks which are constructed with UTP cable or ferrite core with wires, were determined from calculation and measurement. Using the networks, the common-mode current distribution on the cable were obtained, and emitted electric field strength was calculated from the distribution. The emission suppression effect were obtained from the result, and the results were almost agree with measured value. The calculation results suggest that 1) the ferrite cores should be arranged side by side, 2) these should be placed near the signal supply end of the cable.

Keywords
EMC, emission, ferrite core, UTP cable

1. INTRODUCTION

Recent progress in telecommunications has created the need of higher speeds telecommunication system such as 100Base-T and 1000Base-T. Unshielded twisted pair (UTP) cable is used as a transmission line, and the possibility of telecommunication signal emission from the cable has been studied [1]-[3].

One method of reducing the emission is installing ferrite cores on the cable. Many study and investigation have been reported to demonstrate the suppression effect of the ferrite core [4], [5]. However, analysis method to evaluate the suppression effect has not been clarified.

This paper describes the method of estimating suppression effect of ferrite cores. A twisted pair wire with ground return and ferrite cores are presented by 4-port networks, and the common-mode current distribution is calculated using the networks. The emission from the cable is calculated form this distribution. The calculation results are compared with measured result to confirm the validity of this model. Using this method, the characteristics of the suppression effect is investigated.

2. ANALYSIS OF SUPPRESSION EFFECT

An emission mechanism of telecommunication signal from UTP cable is illustrated in Fig. 1. Telecommunication signal applied between wires of UTP cable, and differential-mode current appears on the cable. The differential-mode current is converted to common-mode current by the unbalance of UTP cable and telecommunication equipment. Since the common-mode current create a large loop between cable and ground, the telecommunication signal emitted from cable. The differential mode current, of course, causes the emission from cable. However, this does not create significant problem because the area of the loop is sufficiently small compared with that of the common-mode current. So, we consider the emission caused by the common-mode current.

When ferrite cores are inserted on the cable as shown in Fig 1, this suppresses the common-mode current because this increases the impedance of the loop where the common-mode current flows. Consequently, the emission from cable is suppressed.

2.1 Calculation of common mode current

In this paper, we describe how to calculate the emission suppression effect from the cable. Figure 2 shows a model to calculate common-mode current on the cable. Although UTP cable is usually constructed with more than one

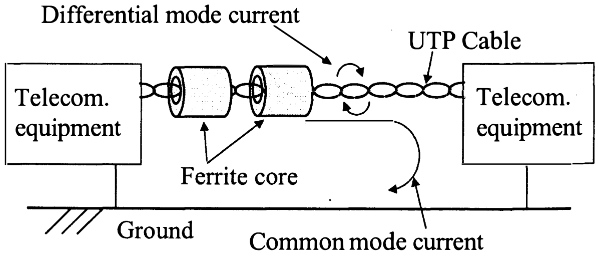

Fig. 1 Emission mechanism of telecommunication signal from UTP cable and effect of ferrite core

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twisted pare, we consider one twisted pare for simplification of calculation. In this model, UTP cable is presented by 4-port networks, F_1, F_2, ... F_T [3]. F_{EUT} and F_{AE} are transmitter and receiver of telecommunication equipment respectively, and these are presented by networks constructed with Z_1, ... Z_6. A pair of current source I_{T1} and I_{T2} present telecommunication signal source. F_n indicate the ferrite core on the cable.

The ferrite core, F_n, is also presented by 4-port network. A model of ferrite core with twisted wire can be presented as a two-port network and ground line as shown Fig. 3. From Fig. 3, we can get following relations

$$\begin{cases} V_1(n-1) = V_a + V_1(n) \\ V_2(n-1) = V_b + V_2(n) \\ I_1(n-1) = I_1(n) = I_a \\ I_2(n-1) = I_2(n) = I_b \end{cases} \quad (1)$$

When we consider the ferrite core with UTP as a two-port network as shown in Fig. 3, following relation can be obtained.

$$\begin{bmatrix} V_a \\ V_b \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \end{bmatrix} \quad (2)$$

In this equation, Z_{11}, Z_{12}, Z_{21}, Z_{22} are the impedance matrix parameters of the two-port network.

From Eq. (1) and Eq. (2), we can obtained the expression of the 4-port F-matrix, which is given by

$$\begin{bmatrix} V_1(n-1) \\ V_2(n-1) \\ I_1(n-1) \\ I_2(n-1) \end{bmatrix} = \begin{bmatrix} 1 & 0 & Z_{11} & Z_{12} \\ 0 & 1 & Z_{21} & Z_{22} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} V_1(n) \\ V_2(n) \\ I_1(n) \\ I_2(n) \end{bmatrix} \quad (3)$$

Using model in Fig. 2, the relations between V_i, I_i, V_o, and I_o are given by

$$\begin{bmatrix} V_{i1} \\ V_{i2} \\ I_{i1} \\ I_{i2} \end{bmatrix} = [F_{EUT}][F_1]....[F_n]...[F_T][F_{AE}] \begin{bmatrix} V_{o1} \\ V_{o2} \\ I_{o1} \\ I_{o2} \end{bmatrix} \quad (4)$$

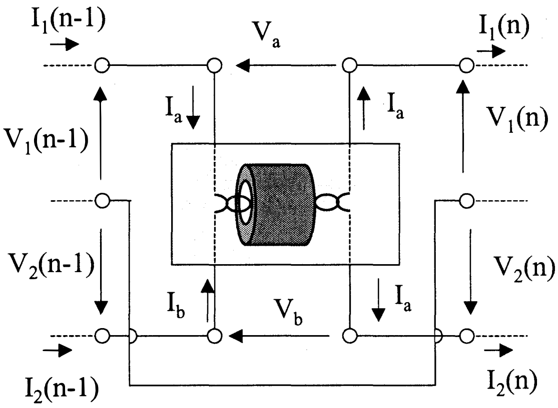

Fig. 3 4 -port network model of UTP cable with ferrite core

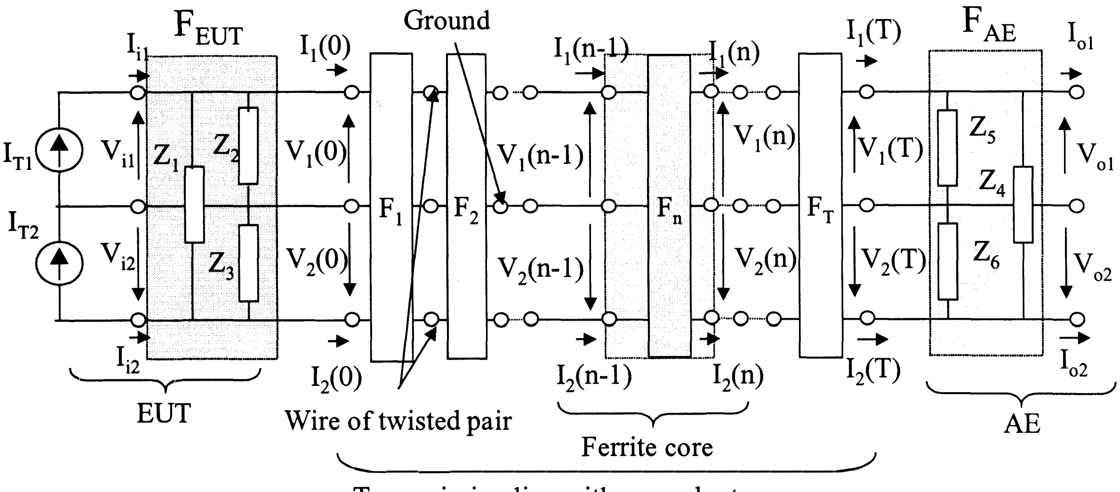

Fig. 2 Analysis model of common-mode current on UTP cable with ferrite core

Then, we can present.

$$\begin{bmatrix} V_{i1} \\ V_{i2} \\ I_{i1} \\ I_{i2} \end{bmatrix} = \left[F_{total} \right] \begin{bmatrix} V_{o1} \\ V_{o2} \\ I_{o1} \\ I_{o2} \end{bmatrix} \quad (5)$$

Converting the F-matrix of F_{total} to impedance matrix of Z_{total}, the relations between V_i, V_o I_i, and I_o are given by

$$\begin{bmatrix} V_{i1} \\ V_{i2} \\ V_{o1} \\ V_{o2} \end{bmatrix} = \left[Z_{total} \right] \begin{bmatrix} I_{i1} \\ I_{i2} \\ I_{o1} \\ I_{o2} \end{bmatrix} \quad (6)$$

From termination condition of $I_{i1}= I_{b1}=-I_{i2}=-I_{b2}$ and $I_{o1}=I_{o2}=0$, V_{i1}, V_{i2}, V_{o1}, and V_{o2} can be obtained from Eq. (6). Then, common-mode current distribution at n-th 4-port network $I_c(n)$ is obtained following equation.

$$I_c(n) = \frac{I_1(n) + I_2(n)}{2} \quad (7)$$

where

$$\begin{bmatrix} V_1(n) \\ V_2(n) \\ I_1(n) \\ I_2(n) \end{bmatrix} = \left[F_{n+1} \right] \cdots \left[F_T \right] \left[F_{AE} \right] \begin{bmatrix} V_{o1} \\ V_{o2} \\ I_{o1} \\ I_{o2} \end{bmatrix} \quad (8)$$

2.2 Calculation of electric field

The model in Fig. 4 is used to calculate the electric field. From electromagnetic theory, the field ***E*** is calculated from vector potential, and which is given by

$$\mathbf{E(r)} = -j\omega \left(\mathbf{A(r)} + \frac{1}{k^2} \nabla \left(\nabla \cdot \mathbf{A(r)} \right) \right) \quad (9)$$

where k is wave number, ***r*** is position vector of observation point, and **A** is vector potential, which is given by

$$\mathbf{A(r)} = \mu \int_v \mathbf{J(r')} \frac{e^{-jk|\mathbf{r}-\mathbf{r'}|}}{4\pi |\mathbf{r}-\mathbf{r'}|} dv'$$
$$\approx \mu \sum_{n=1}^{T} I_c(n) \Delta s \mathbf{u}(n) \frac{e^{-jkR(n)}}{4\pi R(n)} \quad (10)$$

In Eq. (10), **r'** is position vector of excitation point, Δs is length of current segment, **u**(n) is unit vector indicating current direction, $R(n)$ is distance between excitation point and observation point, μ is permeability.

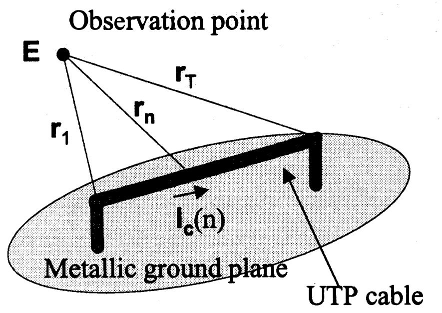

Fig. 4 Calculation model of electric field strength emitted from UTP cable

2.3 Determine of impedance matrix value

The impedance matrix value is determined from measurement. The method of measurement is illustrated in Fig. 5. we measure input impedance Z_{op}, Z_{sh}, Z_R at a-port of the network when another port is open, short and load, respectively. Using these values, we can obtain the 2-port F-matrix parameters, A, B, C, and D, from following equations

$$A = CZ_{op} \quad (11)$$

$$C = \frac{1}{D\left(Z_{op} - Z_{sh}\right)} \quad (12)$$

$$D = \sqrt{R \frac{Z_{op} - Z_R}{\left(Z_R - Z_{sh}\right)\left(Z_{op} - Z_{sh}\right)}} \quad (13).$$

$$B = (1 + AD)/C \quad (14)$$

In Eq. (14), R is load resistance. R of 50 Ω is used in this paper.

From network theory, impedance matrix value is given by

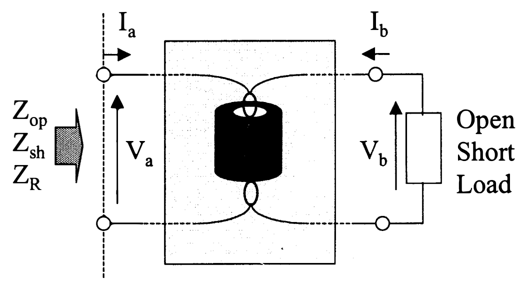

Fig. 5 Measurement method of 4-port network parameter

$$z_{11} = A/C \quad (15)$$

$$z_{12} = z_{21} = 1/C \quad (16)$$

$$z_{22} = D/C \quad (17)$$

3. MEASUREMENT OF SUPPRESSION EFFECT

3.1 Experimental set-up

To confirm the validity of the model, the electric field strength from twisted pair wire was measured using experimental set-up shown in Fig. 6. A twisted wire is used as an UTP cable because convenient UTP cable has twisted pairs. The wire was placed on the ground plane of semi-anechoic chamber, and biconical antenna placed 3 m away from the wire. The twisted wire was terminated by baluns. One of the balun was terminated by 50 Ω, and another balun was connected with output terminal of network analyzer by a coaxial cable. Ferrite cores were inserted near the balun which connected to network analyzer. Gain from balun and output terminal of the antenna was measured using network analyzer from 30 MHz to 150 MHz.

On the calculation, the gain, *Gc*, is calculated following equation,

$$G_c(dB) = 20\log_{10}\frac{|V_{bi}|}{|V_{ao}|} \quad (18)$$

where V_{bi} is input voltage of the balun, V_{ao} is output voltage of the antenna.

3.1 Measurement of suppression effect

Measurement example of gain *Gc* is shown in Fig. 7. In the measurement, the receiving antenna height was moved from 1 m to 4 m. and the maximum gain for horizontal polarization is presented in this figure. The lines indicate the calculation value, and circle and triangle indicate measured value. The solid line and circle indicate the gain when ferrite core was not installed to the wire, and dotted line and triangle indicate the gain when ferrite core was installed at 0.1 m apart from signal input end. Figure 7 indicate that the calculation results almost agree with the measurement results. This means that the electric field strength from the wire installing ferrite cores can be calculated by using the model in Fig. 2 from 30 MHz to 150 MHz.

The suppression effect is obtained from the measurement results shown in Fig. 8. In this paper, the suppression effect *Se* is defined by following equation,

$$S_e(dB) = G_{cr}(dB) - G_{ct}(dB) \quad (19)$$

where G_{cr} is the gain when the cores are not installed on the cable and G_{ct} is the gain when the cores are installed on the cable.

Figure 8(a) is the suppression effect for horizontal polarization and Fig. 8(b) is vertical one. Lines indicate the calculation value and dots indicate the measured value. The ferrite cores were arranged side by side at the 0.1 m apart from signal supplying end.

These figures show that the calculation value is almost agree with the measured value for both horizontal and vertical polarization, and the suppression effect increases in proportion with the increase of ferrite cores. This means that the model in Fig. 2 is effective to evaluate the suppression effect of ferrite cores in frequency range of from 30MHz to 150 MHz.

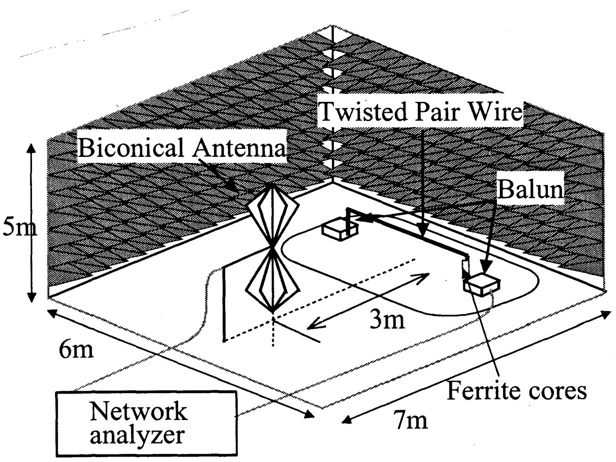

Fig. 6 Experimental set-up for measuring electric field strength

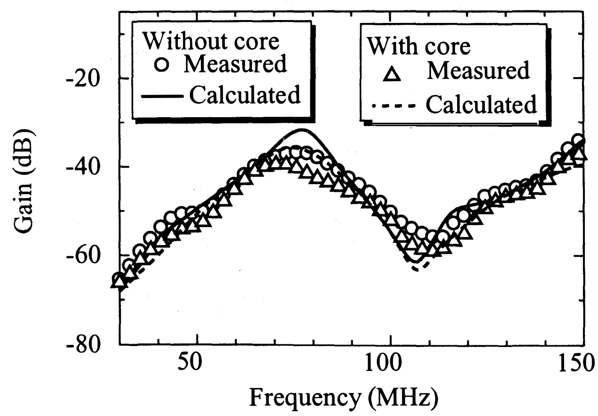

Fig. 7 Measurement example of gain between input terminal of cable and output terminal of receiving antenna for horizontal polarization

4. CHARACTERISTICS OF SUPPRESSION EFFECT

Former chapter indicate that the suppression effect can be calculated by the method described in Chapter 2. In this chapter, we describe the suppression effect dependence on the number of ferrite cores, the cable length, and the core position.

4.1 Number of ferrite cores

Figure 9 shows the calculation results of the suppression effect. On the calculation, the interval of the ferrite core position changed from 0 m to 1 m, and the minimum suppression effect from 30 MHz to 150 MHz is presented in the figure. The result indicates that the suppression effect increases in proportion with the number of ferrite cores when the interval is 0 m. However, the results also show that the effect does not increase monotonously when the interval is not 0 m. This suggests that the ferrite cores should be arranged side by side if you want to achieve a effective suppression effect.

4.2 Cable length

Figure 10 shows the calculation results of the suppression effect when the cable length changes. On the calculation, one ferrite core placed at 0.1 m apart from signal supply end, and the cable length changed 4 m and 10 m. The figure shows that the suppression effect does not significantly change when the cable length changes. This suggests that we need not increase the number of ferrite cores when the cable length increase.

4.3 Ferrite core position

Figure 11 shows the calculation results of the suppres-

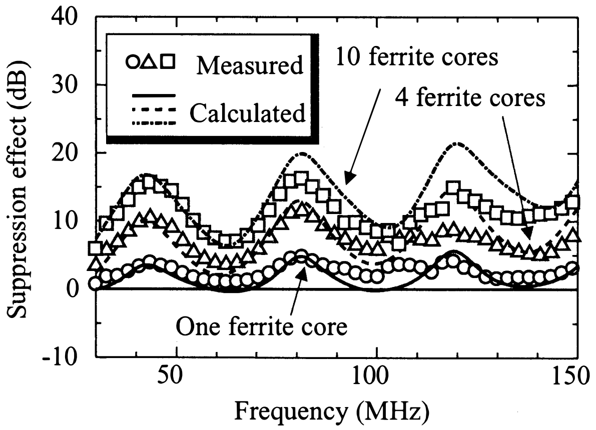

Fig. 8(a) Measuring and calculating results of emission suppression effect for horizontal polarization

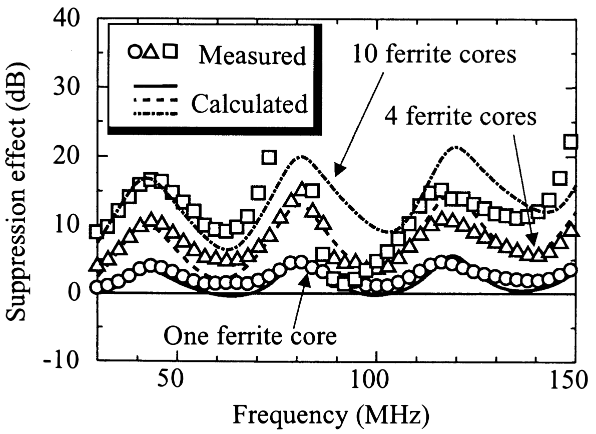

Fig. 8(b) Measuring and calculating results of mission suppression effect for vertical polarization

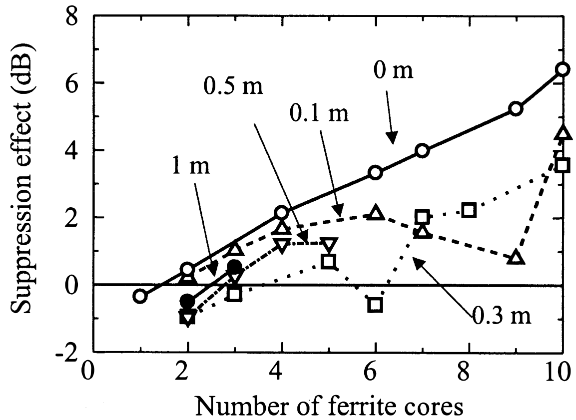

Fig. 9 Relation between the minimum emission suppression effect and number of ferrite cores with the parameter of the ferrite core space

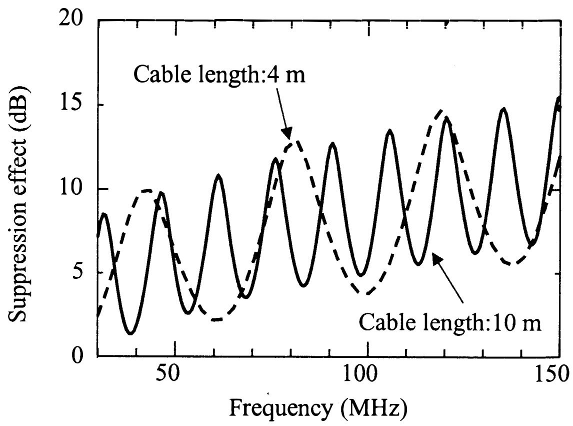

Fig. 10 Cable length dependence of emission suppression effect

sion effect when the position of the ferrite core changes. On the calculation, one ferrite core was inserted on the cable and the position of the core was changes from 0.1 m to 3.7 m. The result indicates that the maximum suppression effect is obtained when the core places at 0.1 m apart from the signal supply end of the cable. This suggests that the ferrite core should be placed at the signal supply end if we want to achieve an effective suppression.

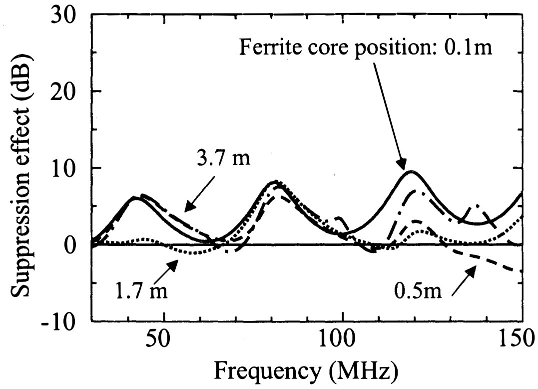

Fig. 11 Relation between emission suppression effect and ferrite core position from signal input port

5. CONCLUSION

The telecommunication signal emission from UTP cable should be suppressed to maintain EMC of telecommunication system. This paper investigate the emission suppression effect from the UTP cable by the ferrite cores. The common-mode current on the cable with ferrite cores was calculated by the network constructed with 4-port F-matrices. The electric field strength was calculated from the distribution of the common-mode current.

The F-matrix parameters was obtained from the measurement results of 2-port F-matrix parameters. The investigation results indicate that the calculated suppression effects were almost agree with the measured one.

The calculation characteristics suggest that 1) the ferrite cores should be arranged side by side, 2) we need not increase the number of ferrite cores when the cable length increases, and 3) the ferrite core should be placed at the signal supply end.

Future problem is the investigation of the suppression effect for further high frequency.

ACKNOWLEDGMENTS

Authors would like to thank Fujio Amemiya and Kusuo Takagi for their useful suggestion.

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