

MEASUREMENT OF MAGNETIC COMPLEX ANTENNA FACTOR OF A DOUBLE-LOADED SHIELDED LOOP ANTENNA BY 3-ANTENNA METHODS

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Abstract - This paper presents two methods for determining the complex antenna factor (CAF) of a shielded loop antenna for HF magnetic field measurements. A circuit model is introduced to apply the field-transferred 3-antenna method to double-loaded shielded loop antennas. In addition, a new 3-antenna method is proposed, where theoretical calculation and circuit measurement are combined. Experiments are made in an anechoic chamber in the frequency range of 50 MHz to 1000 MHz. The magnetic CAF of various shielded loop antennas can be determined by the proposed methods.

Keywords - EMC/EMI, Electromagnetic sensor, Shielded loop antenna, Antenna factor, 3-antenna method

1. INTRODUCTION

It is important to measure electromagnetic fields in the problems related to electromagnetic compatibility (EMC) such as electromagnetic interference (EMI) measurements, radiation from electrostatic discharges (ESD), and electromagnetic biological effects. In the electromagnetic field measurements, the characteristics of a detecting antenna have to be determined. As a characteristic of the antenna, complex antenna factor (CAF) has been proposed to measure transient electromagnetic fields [1]. This paper presents two methods for determining the magnetic CAF of a double-loaded shielded loop antenna. The double-loaded shielded loop antenna is useful for measuring HF magnetic fields, because it has the advantage that the effect of electric field can be reduced [2].

2. ANTENNA AND COMPLEX ANTENNA FACTOR

We consider a double-loaded shielded loop with a $\pi/2$ hybrid circuit as shown in Fig.1. The ideal S-matrix X_{ij} ($i, j = 1, 2, 3$) of the hybrid circuit is expressed as,

$$\begin{bmatrix} X_{11} & X_{12} & X_{13} \\ X_{21} & X_{22} & X_{23} \\ X_{31} & X_{32} & X_{33} \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 0 & 1 & -1 \\ 1 & 0 & 0 \\ -1 & 0 & 0 \end{bmatrix} \quad (1)$$

The S-parameters of an actual component is somewhat different from (1) due to reflection and loss.

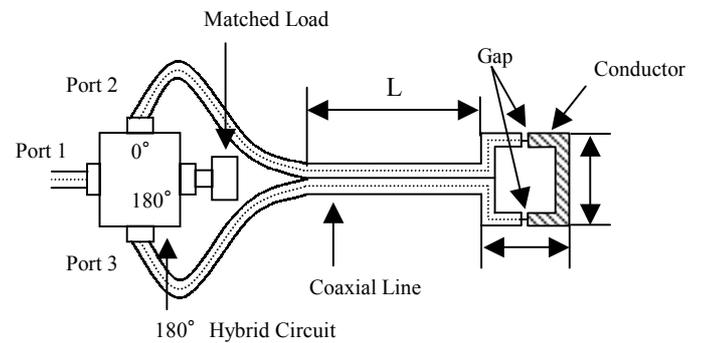


Fig.1 Structure of double-loaded shielded loop antenna

The complex antenna factor (CAF) is usually used in electric field measurements. Here, following magnetic CAF is defined for small loop antennas in magnetic field measurements,

$$F_M(\omega) = \frac{H(\omega)}{I(\omega)} \quad (2)$$

, where $H(\omega)$ and $I(\omega)$ are the magnetic field of an incident plane wave and the current of the load, respectively, as shown in Fig.2. The load shall be matched to the characteristic impedance of the feeder for the use of waveform measurements of transient magnetic fields.

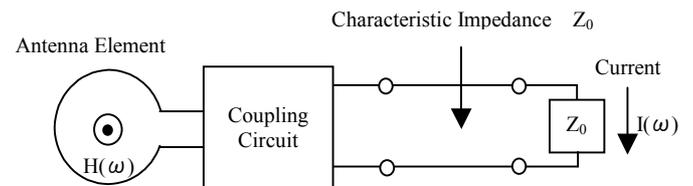


Fig.2 Incident magnetic field and the output current

3. FIELD-TRANSFERRED 3-ANTENNA METHOD

The CAF may be measured by the 3-antenna method in which the transmission S-parameter, S_{21} , between transmitting and receiving antennas is needed. Since CAF is defined for a plane wave incidence, the S_{21} has to be measured under the far field condition.

If the far field condition is satisfied, the magnetic complex antenna factors F_{Mi} ($i=1,2,3$) of three antennas can be calculated from the following equations,

$$F_{M1} = \sqrt{\frac{Z_0 T_{32} e^{-jkR}}{j\lambda\eta_0 T_{21} T_{13} R}} \quad (3)$$

$$F_{M2} = \sqrt{\frac{Z_0 T_{13} e^{-jkR}}{j\lambda\eta_0 T_{21} T_{32} R}} \quad (4)$$

$$F_{M3} = \sqrt{\frac{Z_0 T_{21} e^{-jkR}}{j\lambda\eta_0 T_{13} T_{32} R}} \quad (5)$$

,where $T_{mn}=(S_{21})_{mn}$ ($m,n=1,2,3$) are transmission S-parameters between antenna m to antenna n . R is the distance between a transmitting antenna to a receiving antenna. Z_0 is the

characteristic impedance of the transmission line in Fig.2. λ , η_0 and k are the wavelength for ω , the wave impedance, and the wave number, respectively, in free space.

The required far field condition can be hardly satisfied in the measurements for small loop antennas, because of too small receiving power and interference of undesired waves. To cope of this problem, the field-transferred 3-antenna method has been developed for monopole antennas and dipole antennas in HF electric fields measurements [3]. In the field-transferred 3-antenna method, the transmission S-parameters are measured in near field and the corresponding far field values are estimated with field transfer factor (FTF). FTF can be obtained by a theoretical calculation using the method of moment (MoM).

In order to calculate FTF for the double-loaded shielded loop antennas, a new circuit model is required, because of the two exciting points as shown in Fig.2. We introduce a circuit model as shown in Fig.3, where $[A]$ and $[B]$ are S-matrices of 3-port hybrid circuits of the transmitting and receiving antennas, respectively, and $[S_e]$ is a 4-port S-matrix of the shielded loop elements.

Using this circuit mode, the transmission S-parameter $S_{50}=[a_5/b_0](b_5=0)$ between the reference planes 0 and 5 can be derived as the following equation (6):

$$S_{50} = [B_{53} \quad B_{54}] \left\{ [M_4] - [S_3] [A_1] [M_1]^{-1} [S_2] [B_1] \right\}^{-1} \left\{ [S_3] \begin{bmatrix} A_{10} \\ A_{21} \end{bmatrix} + [S_3] [A_1] [M_1]^{-1} [S_1] \begin{bmatrix} A_{10} \\ A_{20} \end{bmatrix} \right\} \quad (6)$$

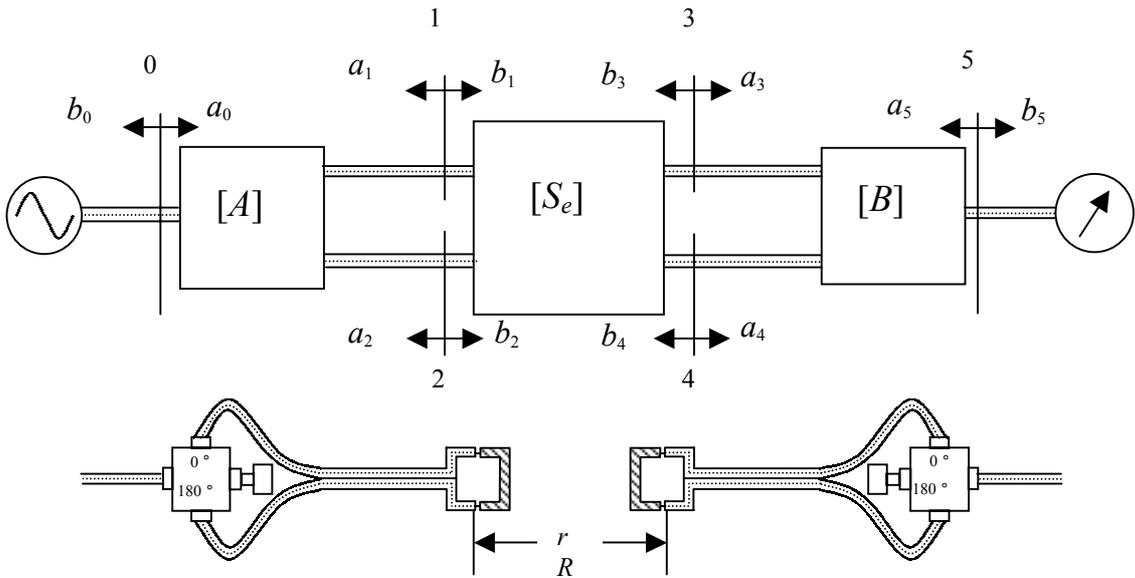


Fig.3 Circuit model of the transmission

, where

$$[S_e] = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix} = \begin{bmatrix} S_1 & S_2 \\ S_3 & S_4 \end{bmatrix}, \quad (7)$$

$$[A] = \begin{bmatrix} A_{00} & A_{01} & A_{02} \\ A_{10} & A_{11} & A_{12} \\ A_{20} & A_{21} & A_{22} \end{bmatrix} = \begin{bmatrix} A_{00} & A_{01} & A_{02} \\ A_{10} & & A_1 \\ A_{20} & & \end{bmatrix}, \quad (8)$$

$$[B] = \begin{bmatrix} B_{33} & B_{34} & B_{35} \\ B_{43} & B_{44} & B_{45} \\ B_{53} & B_{54} & B_{55} \end{bmatrix} = \begin{bmatrix} & & B_{35} \\ & B_1 & \\ B_{53} & B_{54} & B_{55} \end{bmatrix}, \quad (9)$$

$$[M_1] = [1] - [S_1][A], \quad (10)$$

$$[M_4] = [1] - [S_4][B]. \quad (11)$$

The FTF is defined by

$$q(r, R) = \frac{S_{50}(R)}{S_{50}(r)} \quad (12)$$

, where $S_{50}(R)$ and $S_{50}(r)$ are the transmission S-parameters at the far field distance R and at the near field distance r , respectively. To calculate the FTF by using (12), the S-matrices $[A]$ and $[B]$ of the hybrid circuits have to be known. In order to estimate the FTF without the measurements of $[A]$ and $[B]$, the S-parameters of the hybrid circuits are approximated as follows:

$$[A] = \begin{bmatrix} A_{00} & A_{01} & -A_{01} \\ A_{01} & 0 & 0 \\ -A_{01} & 0 & 0 \end{bmatrix} \quad (13)$$

$$[B] = \begin{bmatrix} B_{33} & B_{34} & -B_{34} \\ B_{34} & 0 & 0 \\ -B_{34} & 0 & 0 \end{bmatrix}. \quad (14)$$

Then, (12) can be expressed as

$$q(r, R) = \frac{S_{31}(R) - S_{32}(R) - S_{41}(R) + S_{42}(R)}{S_{31}(r) - S_{32}(r) - S_{41}(r) + S_{42}(r)} \quad (15)$$

Since this equation is expressed only by the S-parameters of $[S_e]$ of the loop elements at r and R , not including the S-parameters of the hybrid circuits, the FTF $q(r, R)$ can be obtained numerically by the MoM. Once the FTF is calculated, the transmission S-parameters between antenna m to antenna n , $T_{mn}(R) = (S_{50}(R))_{mn}$ satisfying the far field condition, is estimated from $T_{mn}(r) = (S_{50}(r))_{mn}$ measured in a near field as,

$$T_{mn}(R) = q(r, R)T_{mn}(r) \quad (16)$$

The procedure is shown in Fig.4.

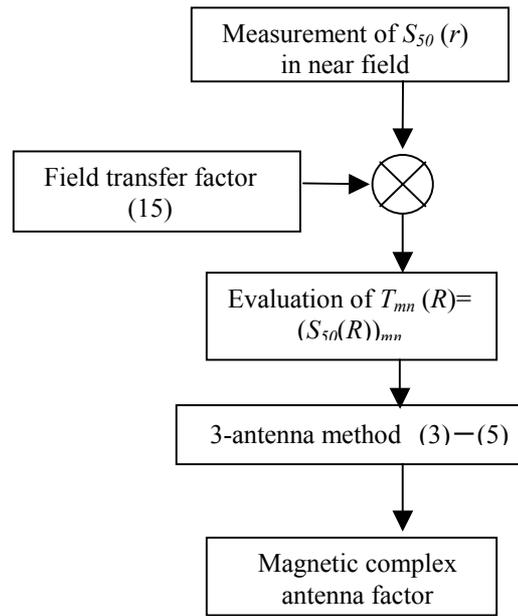


Fig.4 Procedure of the field-transferred 3-antenna method

4. MEASURING HYBRID CIRCUIT METHOD

If the hybrid circuits are detachable from the antenna elements, the S-parameters of $[A]$ and of $[B]$ can be measured by using a vector network analyser. In this case, the far field transmission S-parameters between antenna m to antenna n , $T_{mn}(R) = (S_{50}(R))_{mn}$ satisfying the far field condition are calculated from (6) without the measurements of $T_{mn}(r) = (S_{50}(r))_{mn}$ in the near field. The procedure is shown in Fig.5

5. MEASUREMENT AND COMPARISON

Double-loaded shielded loop antennas in which $L = 10.0$ cm and $a = 1.0$ cm in Fig.2 were constructed using the hybrid circuit with the specifications shown in Table I. The near field measurements were carried out in an anechoic chamber. The frequency range is 50 MHz to 1000 MHz.

Fig.6 and Fig.7 show the magnitude in $\text{dB}_{1/m}$ and the phase in deg of the magnetic CAF determined by the two methods. Here, the near field distance r and the far field

distance R are 2 cm and 100 m, respectively. The two results agree well.

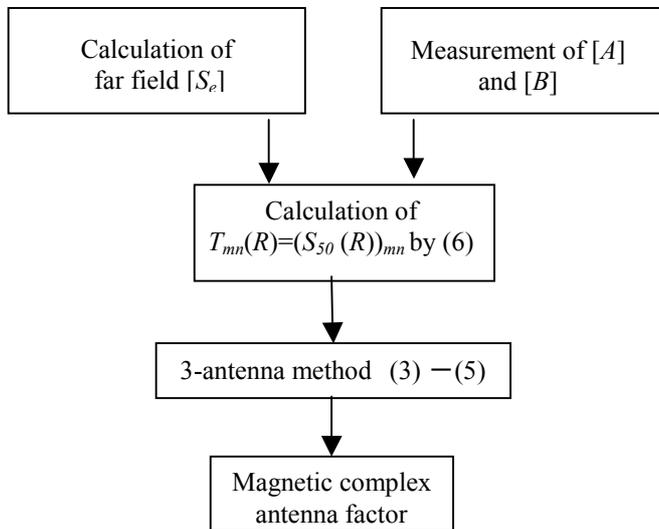


Fig.5 Procedure of the measuring hybrid circuit method

Table I – Specifications of the hybrid circuits.

Frequency band	5MHz - 1 GHz
Insertion loss	4 dB (maximum)
Isolation	22 dB (minimum)
Amplitude balance	0.8 dB (maximum)
Phase balance	5 deg. (maximum)
VSWR	1.6 (typical)

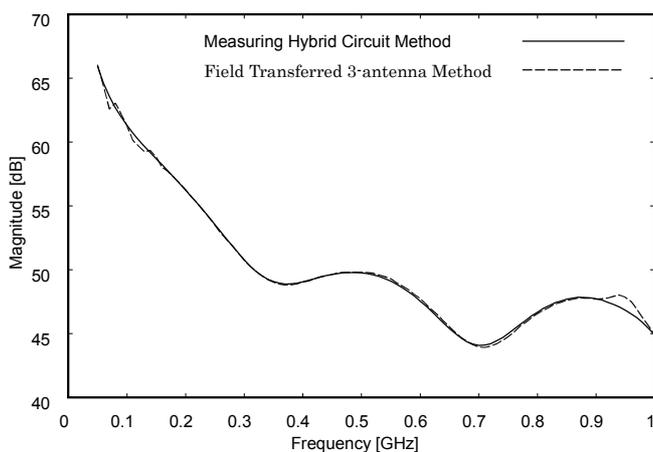


Fig.6 Magnitude of magnetic complex antenna factor

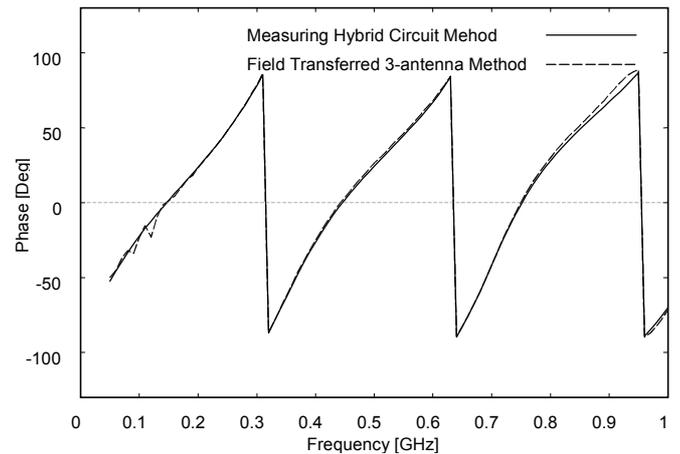


Fig.7 Phase of magnetic complex antenna factor

6. CONCLUSION

The field transferred 3-antenna method can measure the magnetic CAF of the shielded loop antennas without the measurements of the hybrid circuits. On the other hands, the measuring hybrid circuit method can determine the magnetic CAF of the shielded loop antennas without the measurements of the transmission S-parameters T_{mn} . Using the proposed two methods, various shielded loop antennas can be calibrated for measuring HF magnetic fields.

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REFERENCES

- [1] S. Ishigami, R. Gokita, Y. Nishiyama, I. Yokoshima, and T. Iwasaki : Measurements of Fast Transient Fields in the Vicinity of Short Gap Discharges , IEICE Transactions on Communications, Vol.E78-B, No.2, pp.199-206 , 1995.
- [2] J. D. Dyson: Measurement of Near Fields of Antennas and Scatterers, IEEE Trans. Antennas Propag., Vol.AP-21, No.4, pp.446-460, 1973.
- [3] K. Fujii, S. Ishigami, and T. Iwasaki: Evaluation of Complex Antenna Factor of Dipole Antenna by the Near-Field 3-Antenna Method with the Method of Moment, IEICE Transactions, Vol.J79-B-II, No.11, pp.754-763, (1996). (in Japanese) and Electronics and Communications in Japan, Part1, Vol.80, No.11, pp.34-44 , 1997.