Experimental study of the relationship between maximum common mode current and maximum magnetic field strength using a simple power distribution line model

Hiroyuki Okumura\(^{(a)}\), Tohlu Matsushima\(^{2}\), Nobuo Kuwabara\(^{2}\), Takeshi Yamamoto\(^{1}\), Toshiyuki Wakisaka\(^{3}\), Yuki Fukumoto\(^{2}\)

\(^{1}\) Product Analysis Center, Panasonic Corporation, 1048, Kadoma, Kadoma-shi, Osaka, 571-8686, Japan
\(^{2}\) Kyushu Institute of Technology, 1-1, Sensuicho, Tobata-ku, Kitakyushu-shi, Fukuoka, 804-8550, Japan
\(^{3}\) Connected Solutions Company, Panasonic Corporation, 62-1-4, Minoshima, Hakata-ku, Fukuoka-shi, Fukuoka, 812-8531, Japan

\(^{(a)}\) okumura.hiroyuki001@jp.panasonic.com

Abstract:

The relation between maximum common mode current and maximum radiated magnetic field strength was experimentally studied using a simple power distribution line model. The common mode current was measured along the cable and the radiated magnetic field strength was measured around the model. They were evaluated using the \(S_{21}\) parameter. The frequency characteristic of both the maximum current and the maximum strength showed a closely similar pattern. Our evaluation of their correlation indicated that the relation between the maximum common mode current and the maximum radiated magnetic field strength could be represented by a straight line, and that 80\% of the measured data was contained within 2dB of the regression line.

Keywords: power line communication, common mode current, radiated magnetic field strength, correlation

Classification: Electromagnetic compatibility (EMC)

References

[1] S. Battermann and H. Garbe, “Influence of modern broadband inhouse PLC transmission on short-wave reception,” 2015 IEEE International Symposium on Electromagnetic Compatibility and EMC Europe, pp.283-288, Dresden, Germany, Sep. 2013.
1 Introduction

The effect of high-speed power line communication (PLC) systems on the electromagnetic environment needs to be evaluated, because the frequency band of the PLC system overlaps that of other radio systems [1], [2], [3]. However, the measurement of magnetic fields is a time-consuming process because the radiated level is weak and the measurement process needs a great deal of space. However, the measurement of common mode current does not require much space or time.

Common mode current is considered the primary source of magnetic fields [4], and the relation between the longitudinal conversion transfer ratios (LCTL) and the radiated magnetic field strength has been studied [5]. One paper [5] suggests that a relationship exists between the electric field strength and the LCTL, and that the LCTL is closely related to the magnitude of the common mode current. Therefore, if the correlation between the common mode current and the magnetic field can be obtained, it will be possible to study the mechanism by which the common mode current generates a radiated magnetic field.

In this paper, we investigate the relationship between the maximum common mode current and the maximum radiated magnetic field strength. The power distribution line was modeled using a simple configuration, and $S_{21}$ between the signal supply point and the output point of the measurement devices was measured. The radiated magnetic field was calculated and a correlation was arrived at based on the measured values.

2 Measurement

2.1 Experimental setup

Figure 1 shows the structure of the experimental setup. Actual power distribution lines have many branches, and line height can vary considerably. However, in this paper, a simple model 2m above ground and 10m long was used...
as a first approximation of a power distribution line as shown in Fig. 1(a). A vinyl-sheathed vinyl-insulated flat (VVF) cable with conductor diameter of 2mm was used as the cable, and a two-wire VVF cable and a three-wire VVF cable were used in the experiment. The cable was placed such that the short side faced the support as shown in Fig. 1(a).

The signal was supplied to the cable via the balun (BH Electronics 040-0092) whose impedance ratio was 1:2. The center tap of the secondary port was terminated to the ground via a 50Ω resistance, and the primary port was connected to the network analyzer via a 20m-long coaxial cable.

When the signal was supplied to the three-wire VVF cable, the upper two wires, represented in Fig. 1(a) in black and white, were used as the transmission line. At the far end, the signal-supplying wires were terminated via a 100Ω resistance, whose value had been selected to be close to the characteristic impedance of the line. The black line in Fig. 1(a) was directly connected to the metallic ground plane to generate a higher common mode current. Both ends of the red wire in the three-wire VVF cable were directly connected to the ground plane to increase the current flowing in the red wire.

A frequency range of 2MHz - 30MHz was selected for the experiment.

---

![Diagram](image-url)

(a) Experimental setup.

![Diagram](image-url)

(b) Measurement points of magnetic field.

**Fig. 1.** Structure of experimental setup.
2.2 Measurement procedure of common mode current

For common mode current measurement, all the wires of the cable were clamped by the current probe, and the output of probe was connected to the vector network analyzer via a 30m-long coaxial cable. The probe was moved in steps of 0.25m with respect to the horizontal part of the model.

The vector network analyzer was calibrated at the coaxial cable ends, and \(|S_{21}|\) from the primary port of the balun to the output of the current probe was measured. The maximum \(|S_{21}|\) of the data at all positions was obtained as the maximum common mode current. Since the factor deviation of the current probe is \(\pm 0.7\)dB in this frequency range, the maximum \(S_{21}\) can be related to the characteristics of the maximum common mode current.

2.3 Measurement procedure for radiated magnetic field

A loop antenna with a diameter of 60cm was used to measure the radiated magnetic field strength. As shown in Fig. 1(b), the antenna was moved at intervals of 1m along the horizontal cable and at intervals of 30˚ through the cable’s vertical area. The distance from the cable was 10- m, and the height from the ground plane was 1.3m.

The output of the loop antenna was connected to a vector network analyzer via a 30m-long coaxial cable. \(S_{21}\) from the primary port of the balun to the output of the loop antenna was measured. The loop direction was changed to the y direction, \(S_{21,y}\), and the x direction, \(S_{21,x}\), as shown in Fig. 1(b). The absolute value of \(S_{21}\) was calculated using the following equation.

\[
|S_{21}| = \sqrt{|S_{21,x}|^2 + |S_{21,y}|^2}
\]  

(1)

The maximum \(|S_{21}|\) for all data positions was obtained as the maximum radiated magnetic field strength. Since the deviation of the antenna factor was \(\pm 1.6\)dB from 1MHz to 20MHz and \(\pm 2.6\)dB from 1MHz to 30MHz, the maximum \(|S_{21}|\) can be related to the characteristics of the maximum magnetic field.

2.4 Calculation of radiated magnetic field

The radiated magnetic field was calculated to evaluate the measurement environment. The experimental setup in Fig. 1(a) was modeled using wires [3], [6]. The balun was modeled from the S-parameter measurement results, and the model was included in the wire model. The magnetic field was calculated at the same positions as measured in Fig. 1 using the method of moment, and \(|S_{21}|\) was obtained while taking into account the antenna factor of the loop antenna.

3 Investigation results

3.1 Frequency characteristic

The measurement results of the frequency characteristic are shown in Fig. 2. Figure 2(a) shows the results for the two-wire VVF (2W-VVF) cable, and Fig. 2(b) shows the results for the three-wire VVF (3W-VVF). \(S_{21,C}\) indicates maximum \(|S_{22}|\) from the primary port of the balun to the output of the current probe and \(S_{21,M}\)
indicates maximum $|S_{21}|$ from the primary port of the balun to the output of the loop antenna.

The circles in Fig. 2(a) show the calculation results acquired using the method of moment. The calculation results closely agree with the measurement results. This means that our measurement environment and methods are appropriate for the measurement of the common mode current and the magnetic field strength over this frequency range.

Figure 2 shows that $S_{21,C}$ is greater than $S_{21,M}$ over the frequency range. This means that the influence of $S_{21,C}$ from the surrounding environment is less than the influence of $S_{21,M}$. The peaks of $S_{21,C}$ and $S_{21,M}$ change periodically, and the frequency at which the peak appears is the same. As shown in Fig. 2(b), the frequency characteristic of 3W-VVF is different from the results in Fig. 2(a), but the radiated magnetic field strength of 3W-VVF is close to the results of 2W-VVF. This means that the third wire, to which the signal is not applied, influences the common mode current and the magnetic field strength, but its effects are minor.

3.2 Correlation between common mode current and magnetic field strength

As shown in Fig. 2, the frequency characteristic outlines of $S_{21,C}$ and $S_{21,M}$ are similar, suggesting that the relationship between $S_{21,C}$ and $S_{21,M}$ can be expressed as a straight line for both 2W-VVF and 3W-VVF.

The evaluation results are shown in Fig. 3. In this Figure, the vertical axis indicates the difference between $S_{21,M}$ and $S_{21,C}$ in dB, and the horizontal axis is the frequency. The white circles represent the data for 2W-VVF and the black triangles indicate the data for 3W-VVF. The solid straight line is the regression line for all the data. $F_0$ indicates a linear regression function obtained by the least squares method, and the broken lines indicate the area within 2 dB of the regression line. Both 2W-VVF and 3W-VVF show the same trend. Eighty percent of the data is included in the area.

The relation between the S-parameter and magnetic field strength is described by the following equation.

$$
H_{\text{max}}[\text{dB}(A/m)] - |I_{c,\text{max}}[\text{dB}(A)]
= F_0[\text{dB}(\Omega)] + F_{\text{m}}[\text{dB}(A/m)/V] + \left[ S_{21,M}[\text{dB}] - S_{21,C}[\text{dB}] \right]
$$

(2)
In the above equation, $|H_{\text{max}}|$ is the maximum radiated magnetic field strength, $|I_{c,\text{max}}|$ is the maximum common mode current $F_c$ is the factor transfer impedance of current probe, and $F_{\text{ant}}$ is the loop antenna factor. In Eq. (2), the frequency dependencies of $F_c$ and $F_{\text{ant}}$ are small, as described in subsection 2.2 and 2.3. Therefore, the correlation between $|H_{\text{max}}|$ and $|I_{c,\text{max}}|$ also can be described by the line proportional to the frequency as shown in Fig. 3, and the correlation parameters are related to the radiation characteristics because these factors have only a small influence on the frequency characteristic.

![Graph](image)

**Fig. 3.** Correlation between magnetic fields and common mode current.

If we regard a dipole antenna as a simple radiation model, the maximum radiated magnetic field strength increases in proportion to the frequency at low frequencies and changes periodically at high frequencies. However, the experimental results in Fig. 3 do not support this assumption. Elucidation of this mechanism will be a future focus of research.

### 4 Conclusion

The maximum common mode current and maximum radiated magnetic field strength were measured using a simple power distribution line model. The magnetic field strength of the three-wire VVF cable was close to the result for the two-wire VVF cable. Our evaluation of the correlation between the maximum current and the maximum magnetic field strength suggests that the relationship can be expressed as a straight line. Since the measurement of common mode current is easier than measurement of magnetic fields, this technique is potentially useful for studying the influence of wires that are not carrying a signal.

### Acknowledgments

The authors wish to thank Mr. Y. Igata and Mr. S. Arita for helpful discussions and useful comments on the experimental method and the data analysis.