Method of Estimating Calibration Accuracy for Capacitive Voltage Probe

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Abstract— **Capacitive voltage probe (CVP) can measure the common mode disturbance voltages without contact to cables. A common-mode voltage needs to be measured using the calibration unit when a calibration of CVP is carried out. Therefore, the accuracy of calibration should be evaluated, because it is important for an EMC conformity test to confirm validity of a result obtained by CVP. This paper proposes the evaluation method for correction factor of calibration unit using S-parameters. The calibration accuracy was evaluated by the coefficient, α_{asm} that was obtained from S-parameters of the calibration unit. The coefficient was calculated using FDTD method and was measured from 0.1 MHz to 100 MHz to evaluate the proposed method. The results indicated that the deviation between the calculated and measured value is within 0.6 dB from 0.1 to 30MHz. This means that the coefficient, α_{asm}, is effective to evaluate the accuracy. The coefficient, α_{asm}, was also measured using the calibration unit and CVP when a wire radius and a kind of cable were changed. The results indicated that the α_{asm} was within 1 dB from 0.1 MHz to 30 MHz.**
Keywords; uncertainty; CVP; FDTD; S-parameters;

I. INTRODUCTION

CISPR publication 22 [1] describes to use Artificial Asymmetrical Network (AAN) for measuring the disturbance voltage at telecommunication ports. The publication also describes the substitution methods because the AAN is not prepared for all kinds of cables. A Capacitive voltage probe (CVP) [2][4] is used for one of the methods. The CVP can measure the common mode disturbance voltages without contact to cable, however the calibration is needed for the measurement [2].

Therefore, the accuracy of the calibration should be evaluated, when CVP is used for the conformity test. However, the evaluation method has not been presented.

This paper proposes the evaluation method for the accuracy of calibration by using S-parameters of the calibration unit. First, the evaluation method that uses coefficient, α_{asm} obtained from the S-parameters, is proposed. Second, the coefficient is calculated by FDTD method. The result is compared with the measured one to evaluate the proposed method. Finally, the coefficient for the calibration unit and CVP is measured when the wire radius and the kind of the cable are changed.

II. METHOD OF EVALUATING ACCRACY

A. Structure of CVP and equivalent cuircuits

Structure of CVP is shown in Fig.1. The CVP is constructed with the inner electrode and the outer one. The cable is set at the center of the inner electrode. In this figure, V_i is the disturbance voltage source, Z_{in} is the internal impedance of the source, V_c is common mode voltage, and Z_L is load impedance. When the common mode voltage, V_c, is applied between the cable and ground, the voltage, V_m, is induced between the inner and the outer electrode by the electro-static induction. This voltage is proportional to the applied voltage. Thus, the common mode voltage can be obtained by measuring the voltage V_m.

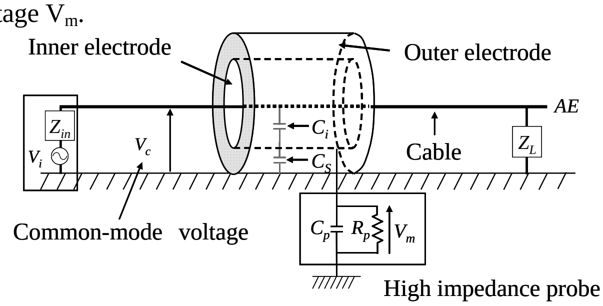

Fig.1 Structure of CVP

The equivalent circuit is shown in Fig.2. In this figure, C_i is the capacitance between the cable and the inner electrode, C_s is the capacitance between inner and outer electrodes, and R_p and C_p are the input resistance and capacitance of the high impedance probe.

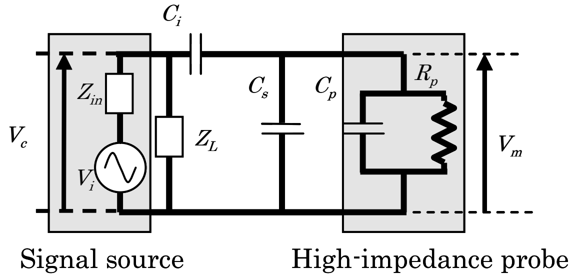

Fig.2 Equivalent circuit of CVP

The relation between the measured value, V_m and the common mode voltage V_c is given by Eq. (1) [4].

$$V_m = \frac{j\omega C_i R_p}{1 + j\omega C_i R_p (C_i + C_s + C_p)} V_c \quad (1)$$

When $\omega R_p (C_i + C_s + C_p) >> 1$, the relation is given by Eq. (2).

$$V_m = \frac{C_i}{C_i + C_s + C_p} V_c = F_a V_c \quad (2)$$

where, F_a is the correction factor of CVP. Eq. (2) shows that the relation between V_m and V_c is independent of the frequency. This correction factor is calculated by the V_m and Vc, which are measured by using the calibration unit [2].

B. *Coefficient Evaluatiing Accuracy*

The 2-port circuit of CVP with the calibration unit is shown in Fig.3. In this figure, the port 1 presents the input side port of calibration kit for signal, and the port 2 presents the output side port of it. Two kinds of the common mode voltage are considered to calculate the factor. One is the voltage at input side of CVP, V_{c1}, and the other is the voltage at output, V_{c2}.

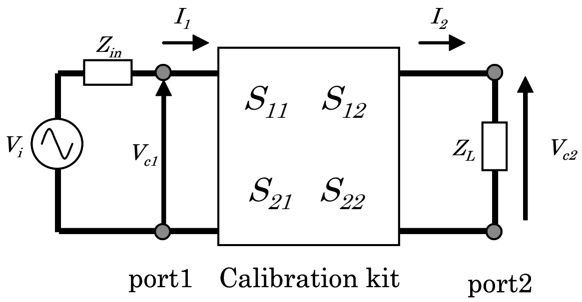

Fig. 3 2-port circuits of calibration kit

The true common mode voltage exists between V_{c1} and V_{c2}. Therefore, we define the coefficient presenting the accuracy of the calibration using Eq. (3).

$$\alpha_{asm} = \left| \frac{F_{a2}}{F_{a1}} \right| \quad (3)$$

Where, F_{a1} is the correction factor by using common mode voltage at input side of CVP, and F_{a2} is the correction factor by using common mode voltage at the output side.

Using circuit theory and the circuit shown in Figs. 2 and 3, the α_{asm} can be presented by S-parameters, and this is given by,

$$\alpha_{asm} = \left| \frac{V_{out}/V_{c2}}{V_{out}/V_{c1}} \right| = \left| \frac{V_{c1}}{V_{c2}} \right| = \left| \frac{1+S_{11}}{S_{21}} \right| \quad (4)$$

S-parameters are usually complex numbers and a network analyzer is necessary to measure the S-parameter, because these are usually complex numbers. Thus, in order to simplify the method, we study how to calculate α_{asm} by only magnitude of S-parameters.

Generally, $|1+S11|$ is smaller than $1+|S11|$. Thus, if we assume that $|S11|<<1$, i.e. input impedance of port 1 is matched for output impedance of signal generator, then eq. (4) can be approximated by Eq. (5).

$$\alpha_{asm} \approx \frac{1}{|S_{21}|} \quad (5)$$

$|S_{21}|$ can be measured by a signal generator and a spectrum analyzer. Therefore, Based on above assumption , α_{asm} can be obtained by using magnitude of S21.

III. Calculatiing and Measuremnt of α_{ASM}

In order to confirm the validity of the method, the α_{asm} was calculated by FDTD and the result was compared with measured one. The CVP whose length was 100 mm, inner diameter was 40 mm, and outer diameter was 70 mm, was used for the investigation. The metallic rod whose diameter is 8 mm and length is 36 cm was used as cable.

A. *FDTD analysis model of CVP*

The α_{asm} is calculated to evaluate the accuracy. The analysis model for calculating the α_{asm} is shown in Fig.4.

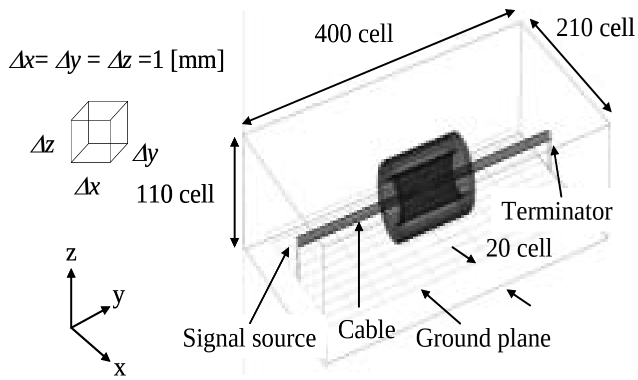

Fig.4 FDTD analysis model of CVP

The FDTD method is used for the calculation. The cell size is 1mm by 1mm by 1mm and the PML constructed with eight cells thickness was arranged after the space of 20 cells from the area in Fig. 4.

In the analysis, the voltage and current at the terminator were calculated when the terminator value was 0.1Ω and 1MΩ by FDTD method. F-matrix parameters were calculated by the results of FDTD, and then, the S-parameter values were obtained from the F-matrix values. Gauss type pulse wave that width is 0.33 ns is used for excitation source because it was effective to calculate the frequency response.

B. *Measurement layout*

To confirm the calculation model, the α_{asm} is measured. The measurement layouts are shown in Figs.5 and 6.

Figure 5 shows the measurement layout of the S-parameters. A network analyzer was connected input and output side of calibration kit. S-parameters were measured from 0.1 MHz to 100 MHz. Figure 6 shows the measurement layout of the correction factor. The ratio of V_{c1} and V_m or V_{c2} and V_m was measured by Gain phase analyzer and a high impedance probe from 0.1 MHz to 100 MHz. The correction factors, Fa1 and Fa2, were obtained from the ratio of Vc1 and Vm or Vc2 and Vm. Then, the α_{asm} was calculated by Eq. (3).

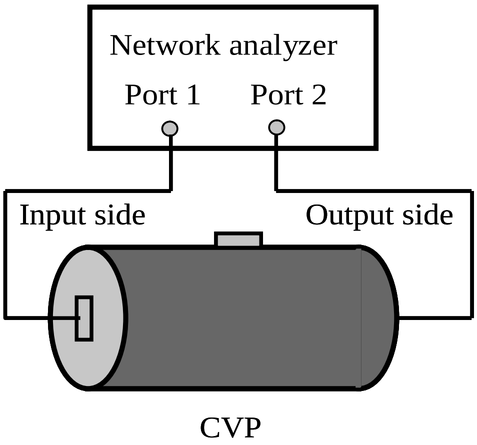

Fig. 5 Measurement layout of α_{asm} by S-parameters

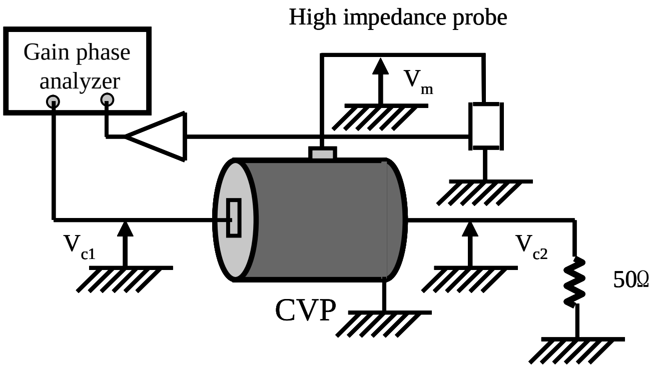

Fig. 6 Measurement layout of α_{asm} by correction factors

C. Investigation results

The deviation between calculated α_{asm} and measurement α_{asm} is shown in Fig. 7. In this figure, the vertical axis is the deviation from the measured value. The dotted line indicates the value when the calculating duration is 3.3 ns and the solid line indicates the value when the calculation duration is 10 ns. The results show that the calculating duration should be more than 10 ns, and the deviation is within 0.6 dB from 0.1 to 30 MHz in case duration of 10ns. This means that α_{asm} can be measured by with sufficient accuracy.

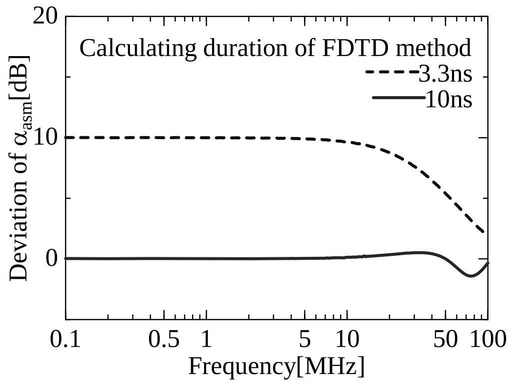

Fig. 7 Calculated and measurement results of α_{asm}

The measurement results of α_{asm} are shown in Fig. 8. In this figure, the black solid line indicates the α_{asm} calculated form the measured correction factors, and the black dotted line is the α_{asm} calculated form the measured S-parameters. This shows that these values well agree with each other in frequency range from 0.1 MHz to 100 MHz. This means that the α_{asm} can be obtained by S-parameters and used to evaluate the calibration accuracy of the calibration unit.

The gray sold line shows the α_{asm} calculated from only magnitude of $|S_{21}|$ using Eq. (5). The deviation is less than 1dB from 0.1 MHz to 100 MHz. The result shows that using only magnitude of S21, we can evaluate the accuracy of the α_{asm} within 1dB deviation.

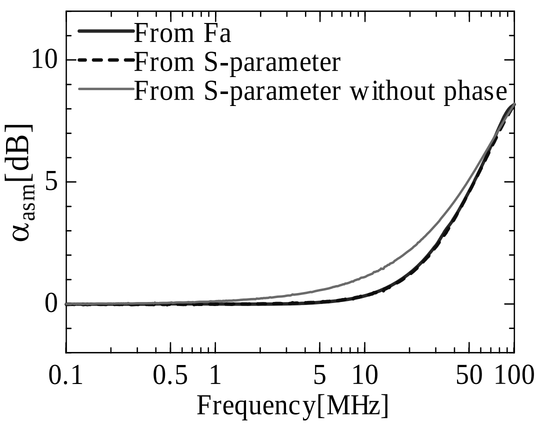

Fig. 8 Measurement results of α_{asm}

IV. MEASUREMENT OF α_{ASM}

The α_{asm} was measured using the calibration unit. The external view of calibration unit and CVP is shown in Fig. 9. The calibration unit is made by aluminum and the CVP is placed inside of the unit. The CVP that length was 100 mm, inner diameter was 30 mm, and outer diameter was 120mm, was used.

The metallic rods and the actual cables were used for the measurement. The diameter of the metallic rod and the kind of cable were changed to evaluate the dependency of them.

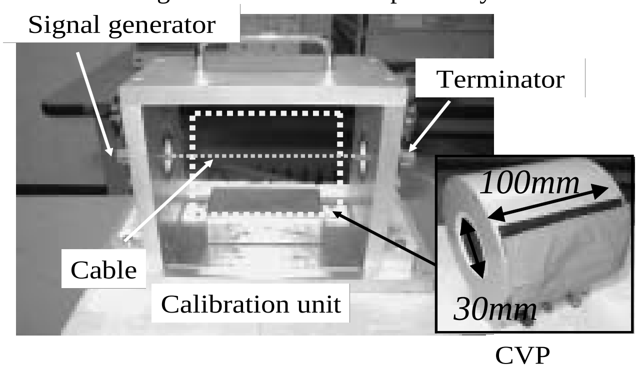

Fig. 9 External view of calibration unit and CVP

Figure 10 shows the measured results of the diameter dependence. The diameter of rods was changed from 26 mm to 1 mm, and the α_{asm} was measured. The result shows that the α_{asm} decreases in proportion to increase of the radius. This dependency of the radius is caused by the inductance of the rod, because the influence of the inductance appears as a transmission loss, i.e. S_{21}, of the calibration kit in high frequency range, especially for above 30 MHz.

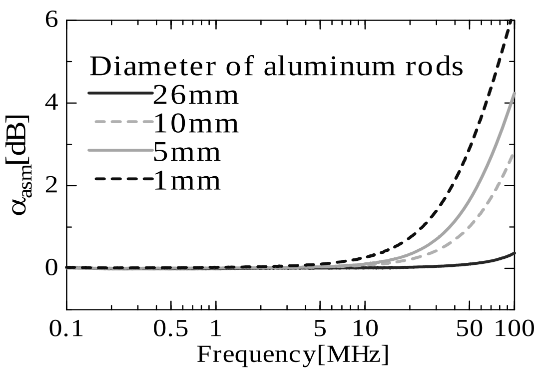

Fig. 10 Measurement results of α_{asm} when diameter of rod is changed.

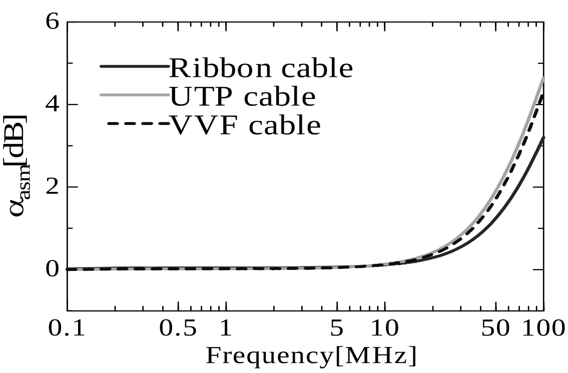

Fig. 11 Measurement results of α_{asm} when kind of cable is changed.

The α_{asm} was measured when the kind of cable was changed. A ribbon cable, an UTP cable, and a VVF cable were used for the experiment. The results are shown in Fig. 11. This result indicates that the α_{asm} is less than 1dB from 0.1 MHz to 30 MHz and the α_{asm} increases when the frequency increases above 30 MHz.

The results as shown in Figs. 10 and 11 indicate that the calibration accuracy of CVP should be evaluated in practical situation, when the measured frequency is above 30MHz.

V. Conclusion

This paper describes the evaluation method of the calibration accuracy for capacitive voltage probe (CVP). The parameter α_{asm} that is defined by the ratio of the correction factors using voltages at input and output side of calibration unit is proposed as the coefficient for evaluating the calibration accuracy.

We obtained the α_{asm} both the calculation using FDTD method and measurement of S-parameter or correlation factors. Comparing these results, following points are clarified.

1) The α_{asm} can be obtained by magnitude of S21 in case $|S11|<<1$.
2) The measured result was well agreed with calculated one in frequency range from 0.1 MHz to 30 MHz.

Therefore, the α_{asm} is effective to evaluate the measurement accuracy.

Moreover, regarding the α_{asm}, dependency of the radius and a kind of cable were evaluated. The results indicated the α_{asm} increased when the rod radius decreased and also varied by the difference of the cable. However, the α_{asm} was within 1dB in the frequency range from 0.1 MHz to 30 MHz. Therefore, measurement accuracy of the CVP should be evaluated above the frequency of 30MHz.

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