Radiated Electric Field from a Solar Cell Module Set on the Ground Plane

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***Abstract*— Radiated electric field from a solar cell module set on the ground plane has been studied experimentally and theoretically in order to clarify the antenna effect of the solar cell module. In experimental examination, the radiated electric field characteristic of the thin-film Si solar cell module has measured using the semi-anechoic chamber including the ground plane. In theoretical examination, the solar cell has assumed the conducting wire, which has limited electric conductivity. And the radiated electric field of a solar cell was analyzed by using the method of moment. In both examinations, the maximum value of electric field strength for every frequency was measured or calculated when the solar cell module is rotated by 360 degree. Consequently the calculation value agreed with the measurement one within 10dB at the whole frequency region of 30MHz to 300MHz. As the results, we confirm the availability and the validity of the calculation method using the resistance of the solar cell and the measurement and the calculation methods in the semi-anechoic chamber with the ground plane.**

Key words: antenna effect, method of moment, exchange resistance, radiation electric field

I. INTRODUCTION

In recent years, large amounts of fossil fuels have been consumed by the development of industry and have made green house gases such as NOx and CO_2increase, and we face many kind of problem such as the global warming and acid rain. Therefore, solar cell systems draw attention as a method to cut down on the generation of green house gases. In general, radiated and conducted emission standards for almost all equipment and systems are already specified by CISPR, but standard intended for Photovoltaic(PV) power generation systems does not yet. In order to make emission standards intended for PV power generation systems, it is necessary to build up radiated emission mechanisms, that is, the antenna factor of the solar cell module [1][2]. Our group has found that the antenna factor of the solar cell module can be calculated by modelling the solar cell module by a conducting wire with limited electric conductivity [3]. In our previous paper, we study induction characteristics of solar cell set on the fully anechoic chamber that simulate the free space [4], but the usual PV power generation system is set on the ground plane and the existing emission measurement specified by CISPR below 1GHz is also done on the ground plane.

In this paper, we have measured the characteristics of the radiated electric field from a solar cell using the semi-anechoic chamber that has the ground plane. And we assumed that a solar cell is a conducting wire, which has limited electric conductivity. The theoretical characteristic of the radiated electric field on the solar cell was calculated by the method of moment. As the result, we clarify the validity of the modelling technique of a solar cell by comparing the calculation result with the measurement one.

II. THE MEASUREMENT METHOD OF THE EMISSION ELECTRIC FIELD CHARACTERISTIC

We measured the radiated electric field characteristic of the solar cell module in semi-anechoic chamber, as shown in Fig. 1. The solar cell was placed on the foamed polystyrene with 80 cm high. The receiving antenna was used a biconical antenna, which was set at 3m away from the solar cell. The height of the biconical antenna is set up to the same height as the center of the solar cell module. Since the solar cell module terminal is made by the balanced wire, we have to use a balun (balance-to-unbalance transfer) in order to convert an unbalanced coaxial terminal from the signal generator. The input signal level from a signal generator is 10dBm (about 0.7V), and the measurement frequency range could be 30MHz-300MHz. In measurement of the radiated electric field characteristic, the measurement method of the electric field from PLC (Power line communication) was used as a reference [5]. In the CISPR standard, when measurement conditions are changing, it is ruled that the standard value meets the maximum value of electric field strength. Therefore, the maximum electric field strength for every frequency was measured when the solar cell module is rotated by 360 degree. Moreover, the chassis of balun was grounded to the metal floor surface of the turn table. The Biconical antenna was set up on both the horizontal and the vertical directions.

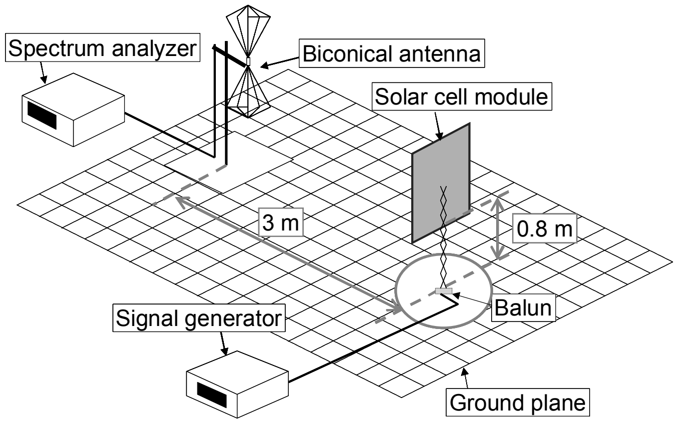
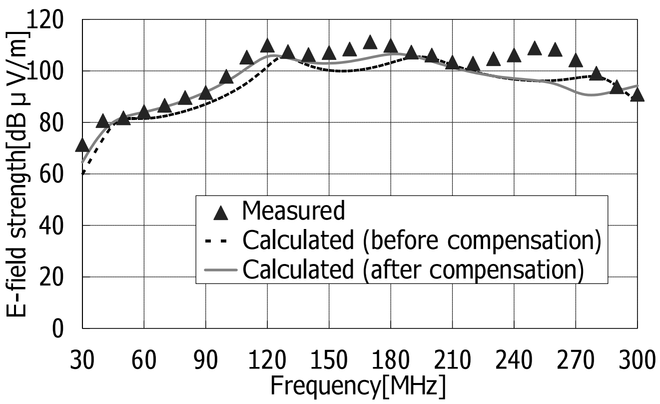


Fig.1 measurement method for Radiation electric field

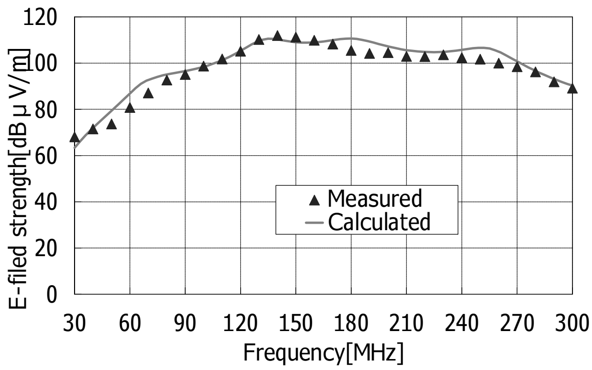
III. ANALYSIS OF DIPOLE ANTENNA BY OUR OWN MAKING

Here, the validity of a measurement method and a calculation model was examined by analyzing the radiated electric field of a dipole antenna by our own making. The dipole antenna with antenna element length of 0.75m was made by using the wire with the radius of 0.6mm, and the antenna was pasted in the polystyrene foam board to fix it. We measured the electric field strength by using two different connecting methods between the balun and the dipole antenna. The first method was connected through a parallel lines and the second one was connected through a twisted pair line. We also calculated the electric field strength by using the method of moment coded by NEC2 (Numerical Electromagnetic Code version -2) as a electromagnetic field analytical techniques.

The measurement result of the radiation characteristics was compared with calculation one by using these models as shown in Fig.2. The radiation characteristic was measured by using biconical antenna within the frequency range of 30 to 300MHz.The parallel lines model come under the influence of the permittivity of the vinyl line used here, and so the calculation values are shifted to high frequency direction. Therefore, their compensations are done beforehand in the calculation. As the result, when the balun is grounded and the antenna is connected through the parallel line, the tendency of the calculation frequency characteristic after the compensation is corresponding to the measurement one in the frequency range from about 30 to 210 MHz, but those are different in the frequency range around 250MHz as shown in Fig.2 (a). On the other hand, when the balun is grounded and the antenna is connected through the twisted pair line, measurements agree with a calculation value in the whole frequency. But those are little bit different in several frequencies and it is thought that unbalance of the twisted pair line cause the difference. However, it can be said that the connecting method between the balun and the antenna as shown in Fig.2 (b) is the best method. From this result, the radiation disturbance wave from the solar cell module is measured by using the twist pair line.



(a) Balun grounded and the antenna connected through the parallel line



(b)Balun grounded and the antenna connected through the twisted pair line

Fig 2 Radiated electric field characteristic of a dipole antenna

IV. METHOD OF ANALYZING RADIATION ELECTRIC FIELD FROM SOLAR CELL MODULE

A photograph of the thin-film Si solar cell module is shown in Fig 3.Constitution of the thin-film Si solar cell module is shown in Fig 4. This module consists of the upper part and the lower part. It contains 50 horizontally long cells, which are connected in series and vertically. The upper and the lower parts are connected in parallel, and the current on the surface of one part is opposite to the other. A lot of pn junction is arranged to the solar cell module pound and pound. However, the pn junction is considered to short-circuit in the measurement frequency range (30MHz to 300MHz). Therefore a solar cell module can be assumed as a conducting wire, which has limited conductivity, as shown in fig 5, and the calculation model was made. In this figure, there are six wires, and resistance Rs of one wire can be set up from equation (1). For instance, six wires are connected in parallel; the resistance of six wires is Rs /6. And the six wires are connected in parallel, resistance Rc of the whole resistance is Rs /12. In this model, it is considered that the measured resistance R_M is equal to the whole of calculated resistance Rc. Therefore, the electric conductivity σ using the calculated model can be calculated. In this calculation example, we consider the case that six wires are connected in parallel. But, even if the wires in the solar cell module assume to connect arbitrary pattern, we can calculate the electric conductivity σ by using the method mentioned above.

$$R_S = \frac{L_S}{\sigma \pi r_m^2} \quad (1)$$

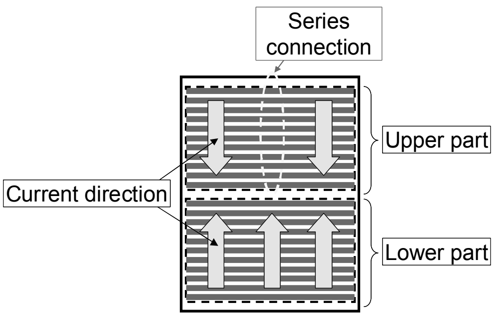
σ : conductivity σ of a wire $[S/m]$

r_m : The radius of the wire $[m]$

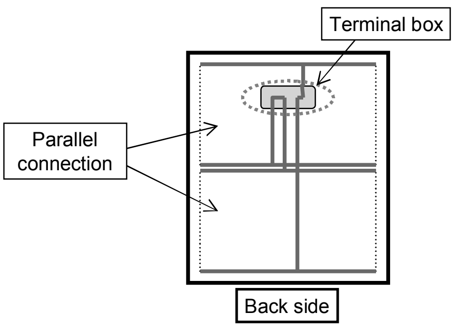
L_S : The length of the wire $[m]$

Impedance Z between the thin-film Si solar cell module terminals was measured with an impedance analyzer (4,194A made by HP),and frequency characteristics (100Hz-1 kHz) of the impedance Z are shown in fig. 6. This figure shows the real (resistance) and the imaginary (reactance) parts of the impedance Z, which depends the conditions whether the solar cell module generate electric power or does not, and so two modes of generating and not generating are measured. When the solar cell module is not generating the electric power, the impedance characteristic is constant at all frequency range. On the other hand, on the generating mode, the impedance characteristic decreases with increasing frequency. In this study, because it is examined in the state that the solar cell module does not generate electric power, we use the resistance value 543Ω of the impedance in 100Hz as the measured resistance R_M. The calculation model of a solar cell is shown in Fig.7. Each part of calculation model consists of 17 wires with the wire length Ls of 0.537m and the wire radius r_m of 0.6mm. These wires are connected in parallel. It is considered that the upper and lower parts are connected in parallel, and the resistance Rc of the whole module is calculated. The wire conductivity σ calculated by putting Rc = R_M is 243[S/m].

Fig 3 Photograph of thin-film solar cell module



(a) Arrangement of cell



(b) Wiring for module

Fig 4 Composition of the thin-film solar cell module

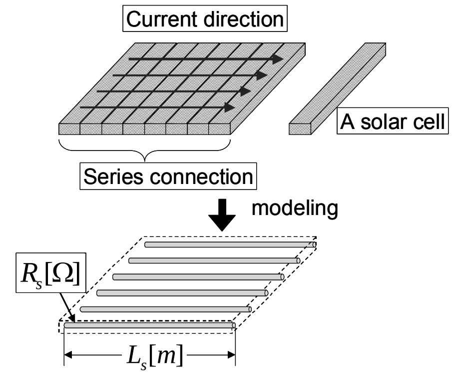


Fig.5 Approximation to the wire of a solar cell module

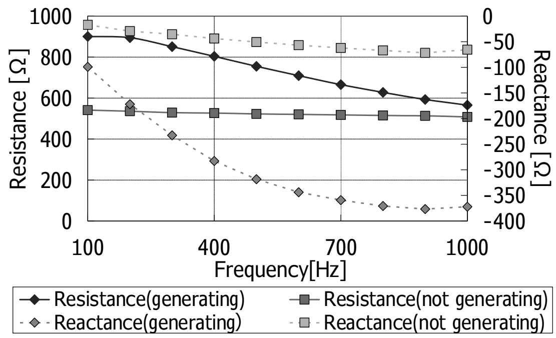


Fig.6 Impedance of a solar cell module

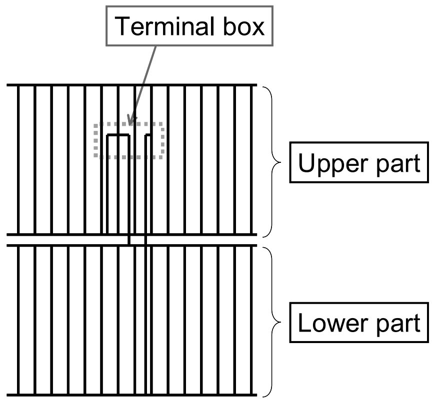


Fig 7 Calculation model of the thin-film solar cell module

V. ELECTRIC FIELD CHARACTERISTIC OF A SOLAR CELL

The angle directivity to the radiation field strength of a thin-film Si solar cell module is shown in Fig. 8. Here, the result of 30MHz and 150MHz is shown. Fig. 9 shows an angle relation on the directivity of the solar cell module as shown in Fig. 8. The radiated electric field intensity from a solar cell module has a difference of 5~10dB to the angle direction. The measured and the calculated frequency characteristics of the radiated electric field from solar cell module is shown in Fig.10. The dashed lines are the measured frequency characteristics for every 15 degrees angle. The maximum of the measured values is shown as rhombic plots, which correspond to the maximum of the dashed line plotted in Fig. 10. In addition, the calculation value is also calculated every angle, and the maximum of the calculation values is shown by an ash solid line. From Fig 10, the dashed lines are scattering result on the high frequency region. It is though that the measured wavelength shortens more than the module size and so the angle distribution became more complicate. And the measurement values of the thin-film Si solar cell module are different from the calculated one about 10dB. Especially, this difference is bigger between 100MHz to 170MHz. The common mode noise was generated from the twisted pair line, which became unbalance because of unbalance of the solar cell module. The twisted pair line makes image line under the metallic ground and so the real and the imaginable lines compose a dipole antenna, which emits the radiated electromagnetic wave. The measurement results may be affected by these mechanisms mentioned above. However, the calculation value accords with the measurement one within 10dB at the whole frequency region of 30MHz - 300MHz. From this, it is confirmed that the measurement method and the calculate model are proper as a method to evaluate the radiated electromagnetic wave from a thin-film Si solar cell module in this study.

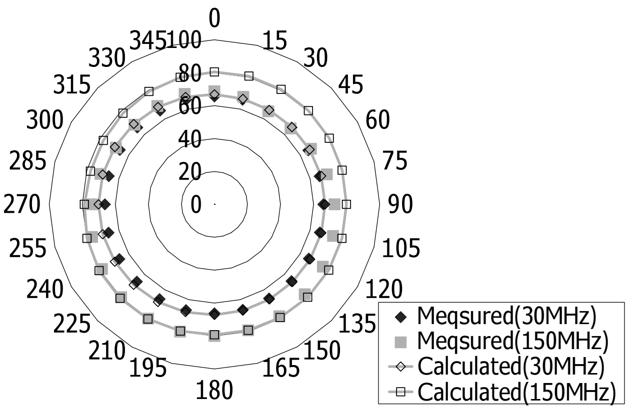


Fig 8 Angle distribution of the radiated electric field strength for the thin-film solar cell module (30MHz, 150MHz)

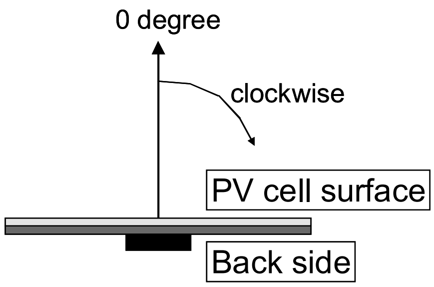


Fig 9 Angle relation on the directivity of the solar cell module

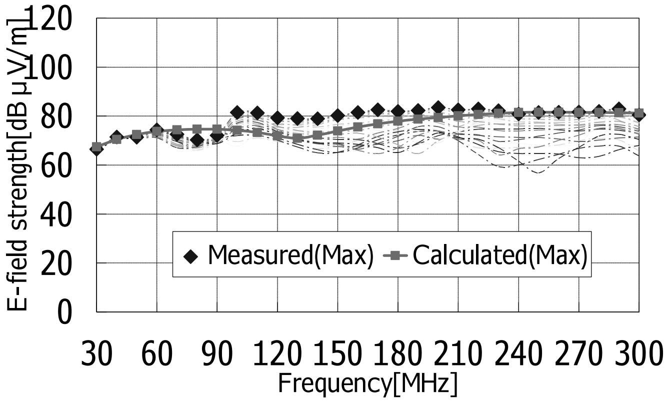


Fig.10 Radiation characteristic of solar battery module

VI. CONCLUSION

In this study, radiated electric field from a solar cell module set on the ground plane has been studied experimentally and theoretically in order to clarify the antenna effect for the solar cell module. For the experimental examination, the radiated electric field characteristic of the thin-film Si solar cell module was measured in a semi-anechoic chamber including the ground plane. In the theoretical examination, the solar cell has assumed the conducting wire, which has limited electric conductivity. And radiated electric field of a solar cell was analyzed by using the method of moment. In both examinations, the maximum value of electric field strength for every frequency was measured or calculated when the solar cell module is rotated by 360 degree. Consequently the calculation value agreed with the measurement one within 10dB at the whole frequency region of 30MHz - 300MHz. As the results, we confirm the availability and the validity of the calculation method using the resistance of the solar cell and the measurement and the calculation methods in the semi-anechoic chamber with the ground plane.

In future, it will be necessary to examine the radiated electric field characteristic of the other modules that size and materials are different, and a characteristic difference when the solar cell module generates electric power.

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