A New Added Value of Photovoltaic Module
~ Absorption Characteristics of Electromagnetic wave ~

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ABSTRACT: The authors have investigated the reflection and absorption characteristics of the typical Photovoltaic (PV) modules and the special modules designed by ourselves for TV wave length (100~120MHz). The special modules have the characteristics of a Loop-Antenna made by changing the arrangement and wiring of solar cells. As a result, the transmission waves of the PV module was able to be decrease by changing the arrangement of solar cells and a lot of them changed the reflected waves. If the impedance of this module for the TV wave could be matched, the reflected wave would be decreased and the attenuation would be able to be increased. And it is available that the method of using the PV module have different impedance connecting the capacitor. In this method it is possible to attenuate the electromagnetic waves up to 12[dB]. However, It is difficult to attenuate the electromagnetic waves in the method that install the reflector on the surface of the wall.

Keywords: Added Value – 1: Module Manufacturing – 2: PV module – 3:

1. INTRODUCTION

In Japan, PV systems have spread through the roofs of residences and the outer walls of buildings for reason of reflected to design, durability and maintenance. However, there is a problem that PV modules reflect electromagnetic waves. Especially, in the case of TV waves, reflected waves from outer walls of buildings interfere with direct waves from TV stations, and "Picture ghosting" occurs in a certain areas. The costs countermeasures for this phenomenon are very high. In this paper, the authors propose the method of reducing the reflection of electromagnetic waves in order to solve these problems using PV modules or systems. There are two methods of absorbing electromagnetic waves. One method is that the PV module itself absorbs the electromagnetic waves. In fact, the PV module has the characteristics of receiving antenna. In this paper, PV modules that include a Loop-Antenna were designed. The Loop-Antenna is composed eight solar cells. Another method uses two or more reflected waves from PV modules etc., the reflected waves are negated. For example, when PV modules are installed on the surfaces of outer wall, a reflection board is installed between the PV modules and outer walls, and the reflected waves from the reflection board counteract these from the PV modules. In this paper, the adequacy of each method is confirmed using the above methods.

2. Measurement

2.1 Measurement method

The experiment was performed to confirm the characteristics of PV modules. It was performed in the anechoic chamber of Communication Research Laboratory (CRL). In this experiment, eight or four PV modules were used and field intensity was measured every 30cm from PV modules to calculate the reflective coefficient of PV modules and phase of standing wave using spatial standing wave method. This method is shown below. In this paper, the authors confirmed that the electromagnetic characteristics of the typical PV modules and the PV module incorporating the Loop-Antenna. The latter is called "Loop-Antenna PV module" in this paper. The Loop-Antenna PV module is that a Loop-Antenna is made from solar cells changing the arrangement and wiring pattern of solar cell in the PV module..

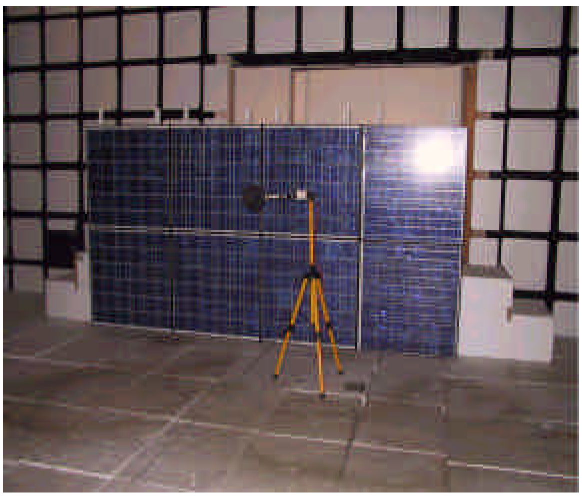

Figure 1: Scenery of measurement experiment

2.2 Spatial standing wave method

Spatial standing wave method is used to investigate electromagnetic wave characteristics of substance. Standing wave ratio (SWR) ? is able to express with the following formula.

$$r = \frac{1+|R|}{1-|R|} = \frac{E_{\max}}{E_{\min}} \quad (1)$$

And the reflection coefficient R and phase ? of the PV modules can also be expressed with the following formula.

$$|R| = \frac{r-1}{r+1} \quad (2)$$

$$q = \frac{4pl_{\max}}{l} = 4p\frac{l_{\min}}{l} - p$$

(3)

Using those formulas, characteristics of PV modules for electromagnetic waves can be confirmed, and impedance Z of PV modules can also be calculated from a formula (4), (5) and (6).

$$Z = \frac{m_0 w}{k_0} \cdot \frac{1+R}{1-R} \quad (4)$$

$$k_0 = w\sqrt{u_0 e_0} \quad (5)$$

$$w = 2pf \quad (6)$$

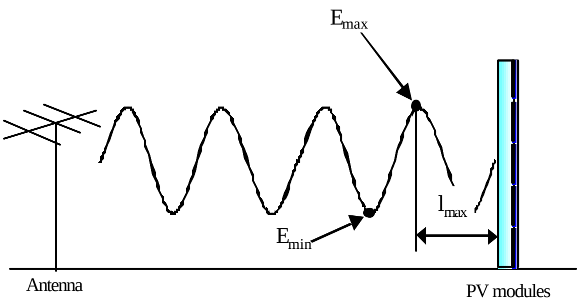

Figure 2: Spatial standing wave method

3. Absorption method of electromagnetic waves

3.1 Loop-Antenna PV module[3]

In order for the PV module itself to absorb electromagnetic waves, PV module should have the characteristics of the receiving antenna. A Loop-Antenna and a microstrip-antenna were thought as an antenna that can be included in the PV module. And the microstrip-antenna is that it is possible to absorb the electromagnetic waves when wavelength and length around metal side are equal. However, it is difficult to include this antenna in the PV module because the capacitors must connect between solar cell and solar cells in the module to regard the two or more cells is one cell for the electromagnetic wave (100~120MHz), and there is no capacitor that have the heat resistance and the low impedance for high-frequency. As opposed to this, the Loop-Antenna is that it is possible to absorb the electromagnetic waves of this wavelength when the wavelength of the TV wave and the length of a loop are equal. However the attenuation of electromagnetic waves must be taken into consideration because the solar cells in the PV module are covered with glass and EVA and the PV modules incorporating the Loop-Antennas had to be designed. The wavelength of Each layer can be calculated by the following formulas (7) and (8).

The velocity of the electromagnetic wave in dielectric v and the wavelength are:

$$v = \frac{1}{\sqrt{m_0 m_r \cdot e_0 e_r}} = c \cdot \frac{1}{\sqrt{m_r e_r}} \quad (7)$$

$$l = \frac{v}{f} \quad (8)$$

When the frequency f is 120[MHz], each wavelength is shown table 1. The feature of these PV modules is that they have four Loop-Antennas by getting out four solar cells. By getting out four solar cells, the power generation performance of these PV modules falls but they have new performance of absorbing the electromagnetic waves. The specific of the Loop-Antenna PV module is shown in table 2 and figure 3. This PV module is made based on the PV module of 100[Wp]. Pmax of Loop-Antenna PV module is lower than one of basic PV module 5[W].

Table 1: wavelength of each frequency and layer

frequency	100MHz	110MHz	120MHz
Glass [m]	0.77	0.70	0.64
EVA [m]	0.97	0.88	0.81
Silicon [m]	0.26	0.23	0.21

Table 2: Specific of Loop-Antenna PV module

	Loop-antenna PV module
Open-circuit voltage	19.164[V]
Shirt-circuit current	7.2211[A]
Pmax	95.198[W]
Pmax voltage	14.367[V]
Pmax current	6.5037[A]

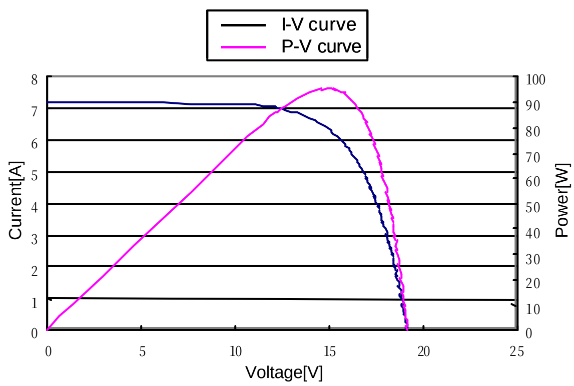

Figure 3: I-V curve of Loop-Antenna PV module

Figure 4: Loop-Antenna PV module

3.2 Method of using reflection board[3]

The electromagnetic waves transmit the PV modules that the back sheet is made of PET (polyethylene terephthalate) because the propagation of them finish with electric conductor. When the PV modules are installed on the outer wall of the building etc., the transmitted electromagnetic waves reflect in the outer wall. The reflection board (reflector) are installed on the surface of the wall and it is possible to change the phase of the reflected waves changing the distance between the PV module and the wall.. Using them from the reflector, the reflected waves from the PV modules are able to be counteracted. The PV module can be regarded as one dielectric using the formula (9) because the reflection coefficient and phase of the PV module have been measured. In fact, it is possible to regard the 2 layer structure of "PV module – air – reflector ".
S is reflection coefficient and d is thickness of the PV module.

$$S=\frac{\sqrt{m_r/e_r}\tanh(j\frac{2pd}{l_0}\sqrt{m_r e_r})-1}{\sqrt{m_r/e_r}\tanh(j\frac{2pd}{l_0}\sqrt{m_r e_r})+1} \tag{9}$$

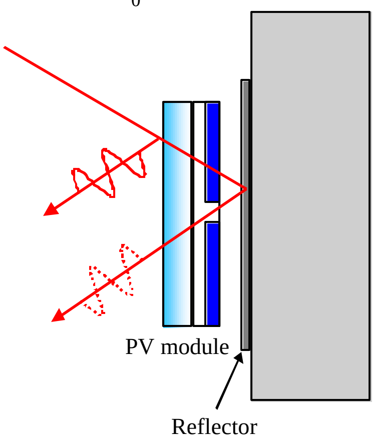

Figure 5: Method of using reflection board

3.3 Method of using different impedance PV modules[3]

Using multiple PV modules that have different impedance, the reflected waves of them can be cancelled each other like figure 4. As a method of changing their impedance, there is that the capacitors and electronic devices were connected with inside or outside of PV module and the disposition pattern of solar cells is changed. In fact, the interference waves are able to completely counteract, if the phase difference of each reflected wave is pi [rad]. However, to keep power generation performance of PV modules the method of connecting electronic devices in parallel is better than the method of changing the disposition of solar cells. In this paper, the simulation was performed using the prevalent PV module and the PV module connected the capacitor, because we want to investigate whether the reflected wave of the latter one counteract reflected wave of the former one.

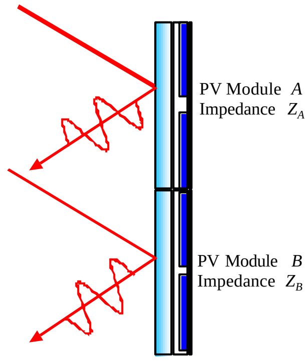

Figure 6: Method of using multiple PV modules

4. Result and discussion

4.1 Loop-Antenna PV module

The experiment was performed to investigate the characteristics of the Loop-Antenna and typical PV modules in the anechoic chamber of CRL. The results of measurement are shown in figure 7, table 3 and 4. The standing wave was identified in figure 7. The reflection coefficient of Loop-Antenna PV module increase in each frequency. Especially, when frequency is 120 MHz, the reflection coefficient of the Loop-Antenna PV module increased more than the typical one. It is thought as this reason that the incident electromagnetic waves do not filter out the Loop-Antenna PV module and the transmission wave changed the reflected wave. In this paper, the impedance of the Loop-Antenna PV module could not be matched for the electromagnetic wave. If the impedance could be matched, it is thought that the reflected waves could be decreased and the absorption of the electromagnetic waves will be able to be increased.

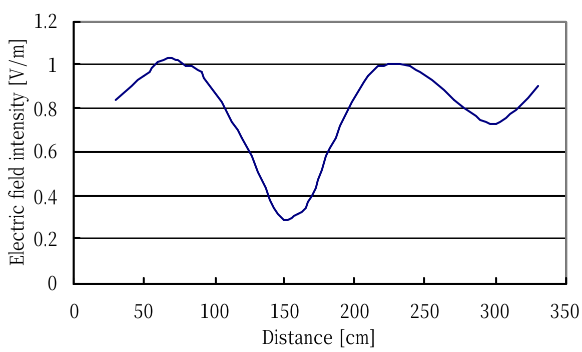

Figure 7: Result of measurement

Table 3: Standing waves ratio, reflection coefficient and phase of the typical PV module

	100MHz	110MHz	120MHz
Stading waves ratio	2.04	1.74	1.61
Reflection coefficient	0.34	0.27	0.23
Phase [rad]	3.77	3.68	3.77

Table 4: Standing waves ratio, reflection coefficient and phase of Loop-Antenna PV module

	100MHz	110MHz	120MHz
Stading waves ratio	3.55	1.88	6.82
Reflection coefficient	0.56	0.3	0.74
Phase [rad]	2.93	2.76	4.52

4.2 Method of using reflector

This method can be used when the back sheet of the PV module is made from PET. The PV module are regarded as one dielectric using the measurement results in 2.2 and the simulation was performed changing the distance between the PV module and reflector. As the results, when distance was 0.073[m], the attenuation was 5.93[dB]at the maximum. However, compared with other method, the attenuation is very small in this method. Because the dielectric of PV modules is very low, it is difficult to change the phase of the reflection waves.

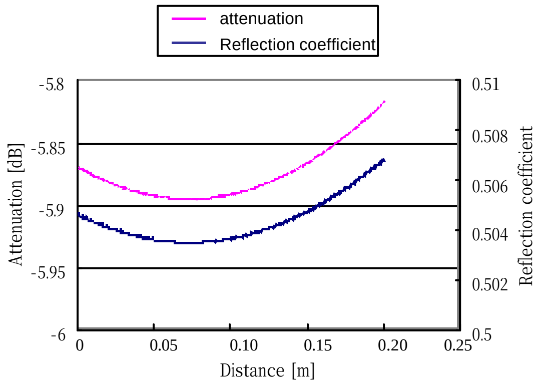

Figure 8: Simulation result

4.3 Method of using multiple PV modules

As the method of changing PV module impedance, a capacitor was connected with outside of the PV module by simulation, and the most suitable value was found by changing capacity. The result is shown in figure 8. It was obtained that the most appropriate capacity is 0.63[pF]. Using the optimum capacitor of figure 8, the simulation was performed for incident angle of electromagnetic waves. This result is shown in figure 9. This method is twice the attenuation of the method using one PV module. However attenuation depends on incident angle in this method. It was conformed that the tilt angle and azimuthal angle of PV modules is important.

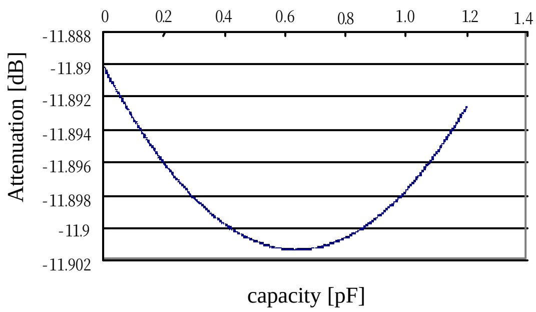

Figure 9: Selection of capacity

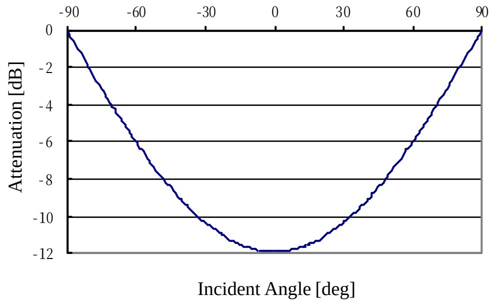

Figure 10: Absorption result

5. Conclusion

In this paper, the authors have suggested the absorption methods of the electromagnetic waves using the PV module. The Loop-antenna PV module have the potentiality absorbed the electromagnetic waves because it can transform the transmission wave into the reflected waves. If the impedance of this module for the TV wave could be matched, the reflected waves will be decreased and the attenuation will be able to be increased. In the method of using the reflector and multiple PV modules, it is difficult to confirm the true absorption performance of this method, because the solar cells change electric conductor from dielectric material when there is solar radiation.

6. Acknowledgement

This work has been supported in part by the Communication Research Laboratory. The authors wish to thank S. Watanabe and T. Arima for their valuable contributions to this work.

7. References

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