DEVELOPMENT OF TV WAVE ABSORBING PV MODULE BY REARRANGING SOLAR CELLS

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ABSTRACT

A photovoltaic generation is becoming popular as a result that a terrestrial environment problem has been properly understood. The PV modules are installed on a roof of private residence, or on an outer wall of building.

The latter often causes a ghost in the TV picture due to the electromagnetic reflection at the wall. This affect to an ultra high speed wireless communication seriously as well.

This paper proposes a novel PV module absorbing the electromagnetic wave in order to cope with both the PV generation and the reduction of electromagnetic reflection.

The usefulness of our proposed PV module is confirmed experimentally.

INTRODUCTION

The photovoltaic generation is becoming popular, and the PV module is installed on the roofs of many private residences or on the outer walls of buildings in urban area. The latter often causes the ghost in the picture become it arises due to an interference between a direct wave from a broadcasting antenna and the reflected wave from the building as illustrated in Fig.1. This problem can not be resolved even for the digital broadcasting (The terrestrial digital broadcasting has started using the UHF frequency band from 470 to 770MHz in Japan). The problem of reflection by the PV module also affect to the ultra high speed wireless communication seriously.

The purpose of this paper is to develop a novel PV module which absorbs the electromagnetic wave in the UHF band, and maintain the original function. In the half first half of this paper, the new PV module rearranged the solar cells is proposed. In the second half, its effective use is confirmed experimentally.

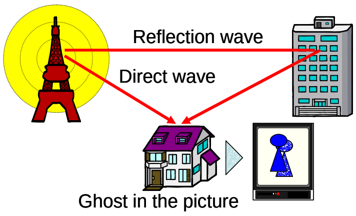


Fig.1. Ghost in the picture

CL MODULE

Basic idea

The absorption of electromagnetic waves is carried out by rearranging the solar cells in PV module. In this paper, a set of rearranged cell constructs a loop antenna which operates as a receiving antenna.

Fig.2 shows an example using the idea; a loop is formed using 8 cells which size of edge is 15cm each. The loop length is 0.6 to 1.8m (15cm*4=0.6m, 15cm*12=1.8m), transforming the length into frequency, that is 166.6 to 500MHz. Therefore, the antenna operates as a receiving antenna targeting VHF band (VHF: Very High Frequency band from 90 to 220MHz in Japan)

Recently, terrestrial digital broadcasting has started by using UHF band in Japan. Therefore, a PV module which absorbs the electromagnetic wave in the frequency band is designed in this study.

Incidentally, the authors call the absorbing PV modules CL module (Cell Loop Module).

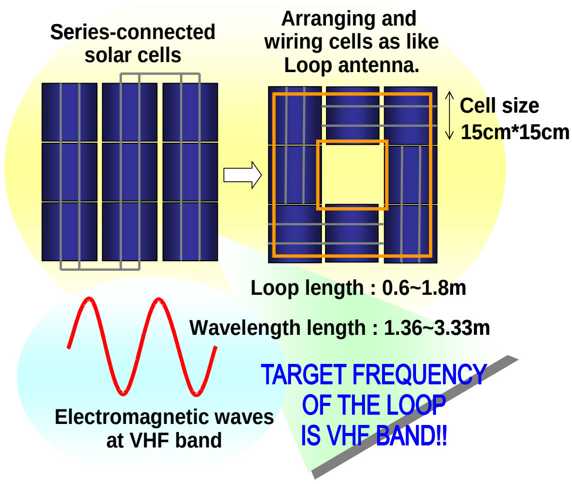


Fig.2. Principle of absorbing electromagnetic waves by PV modules

Design drawing of CL module

Fig.3 shows the design drawing of CL module. UHF band is 470 to 770MHz, so wavelength of the electromagnetic waves is 39.0 to 63.8cm. Therefore, the loop is designed for matching the length with the wavelength by using 7 cells, their edge length is 10cm. In this case, the loop length is set to 40 to 120cm.

Additionally, considering the transmission efficiency of electromagnetic waves, the feeding points of the transmission line should be smaller as coming close to the output port.

In order to achieve a broad band antenna, CL Antenna needs to be designed to have a constant impedance in wide frequency range. Furthermore, to use CL antenna as a wave absorber, it should have excellent receiving potential. In consequence, the radiation resistance component of the antenna impedance needs to be so high as possible. Fig.4 shows analytical results of the antenna impedance of CL antenna with FDTD (Finite Difference Time Domain) method. The radiation resistance maintains in the vicinity of 200Ω, and the reactance slightly fluctuates between -34.0 to –32.9Ω. Therefore, fluctuating of the antenna impedance is so small in between 300 to 900MHz that CL antenna has the receiving characteristic of a broad band antenna. Additionally, the value of the radiation resistance is larger than a normal loop antenna, so CL antenna has the distinguished receiving potential. In view of these results and power generation efficiency to ratio of using area, the method of wiring cells was adopted.

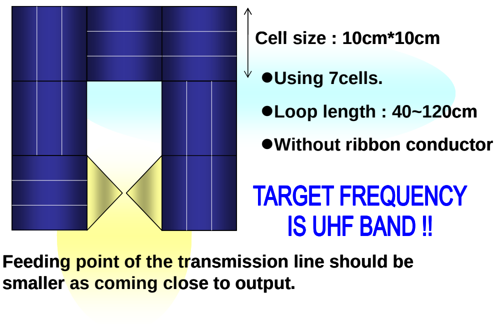


Fig.3. Design drawing of CL antenna for UHF band

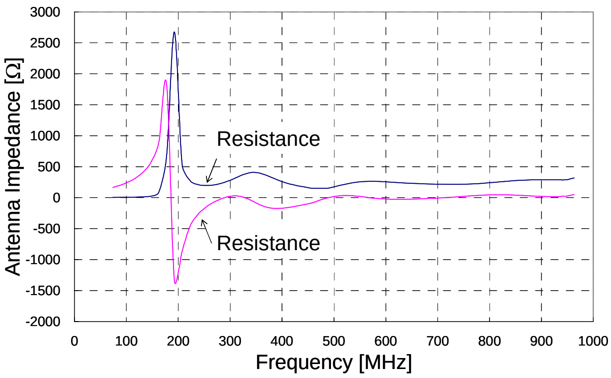


Fig.4. Analytical result of antenna impedance of CL antenna.

Receiving potential of CL module

A test production of a CL module is shown in Fig.5. There are 4 loops in a CL module. Each loop is arranged as far away as possible (about 10cm) to reduce mutual interference among the loops. In addition, I-V curve and P-V curve are shown in Fig.6.

Fig.7 shows the measured characteristics with a network analyzer of the antenna impedance of a CL module composed of one loop. Fluctuating of antenna impedance is extremely small between 300 to 900MHz, so the CL module performs as a broad band antenna with the receiving characteristic. The parallel resonance is generated at 150MHz. It is caused by the EVA (Ethylene-Vinyl-acetate) filling up the cells, the difference of the resonant frequencies between the analytical result shown in Fig.4 and the observed result shown in Fig.7.

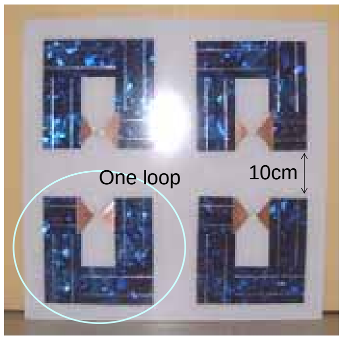


Fig.5. CL module

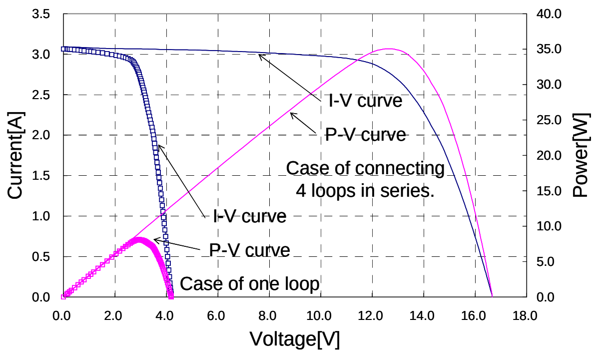


Fig.6. I-V curve and P-V curve of CL module at the case of one loop and connecting 4 loops in series.

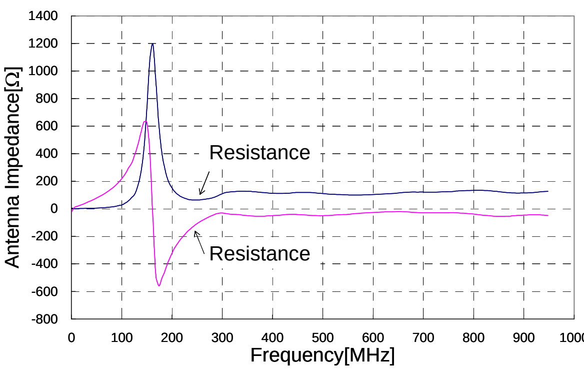


Fig.7. Measured result of the antenna impedance of CL module.

EXPERIMENT

Measuring method of space standing wave ratio

An absorbing potential of CL module as a wave absorber is evaluated by using a method of measuring standing wave ratio. Standing wave is generated by an incident wave and a reflected wave in front of PV modules. It is possible to comprehend absorbing potential by measuring a situation of the standing wave.

Fig.8 shows the principle of the experiment. Measuring parameters are the maximum electric field strength: *Emax*, the minimum electric field strength: *Emin*, and the distances from the modules to an *Emax* point: *Lmax*. By assigning these parameters to the following equations, standing wave ratio: ρ, reflection coefficient: $|S|$ and its phase: θ are calculated.

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

$$|S| = \frac{E_{max}-E_{min}}{E_{max}+E_{min}} \quad (2)$$

$$\theta = \frac{4\pi l_{max}}{\lambda} = \frac{4\pi l_{min}}{\lambda} - \pi \quad (3)$$

In addition, with taking particular note of the power loss of electromagnetic waves, the following parameters need to be evaluated. Transmission electric power *P* of the electromagnetic waves per unit area can be expressed with the following formula,

$$P = \frac{1}{2} Re\left[\dot{E}_x \dot{H}_y\right], \quad (4)$$

where *Ex* and *Hy* mean horizontal electric field and vertical magnetic field respectively.

In the case of taking notice of electric field, (4) is transformed to

$$P = \frac{|\dot{E}_0|^2}{2Z_0}, \quad (5)$$

where *Eo* and *Zo* mean amplitude electric field and characteristic impedance of vacuum respectively.

Therefore, a ratio of power loss to incident energy can be expressed as

$$Loss = \frac{|\dot{E}_{in}|^2 - |\dot{E}_{re}|^2 - |\dot{E}_{tr}|^2}{|\dot{E}_{in}|^2} * 100 \quad (6)$$

where *Ein* is the incident electrical field, *Ere* is the reflective electric field, *Etr* is the transmitted electric field. Moreover, the ratio of attenuation *Att* can be expressed as

$$Att = \frac{|\dot{E}_{re}|^2 + |\dot{E}_{tr}|^2}{|\dot{E}_{in}|^2} * 100 \quad (7)$$

$$Att[dB] = 10 * log(Att) \quad (8)$$

Measuring system and outline

Fig.9 shows a measuring system of the experiment. High frequency waves are generated by the signal generator and amplified at the RF power amplifier. The waves are transmitted to the antenna, and radiated as electromagnetic waves. Fig10 shows a scene of the experiment. A situation of standing wave is measured, which is generated in front of PV module by incident waves transmitted from the antenna. Additionally, to investigate the transmission coefficient, the transmitted waves are measured.

Evaluated objects were typical PV modules and CL module. The output impedance of each module was conformed to the same value with metal-film resistance. Besides, the transmitted antenna radiated the incident waves of 500, 600, 700MHz.

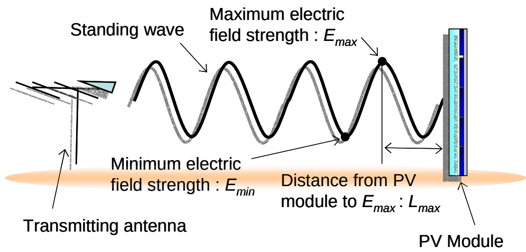


Fig.8. Measuring method of standing wave ratio

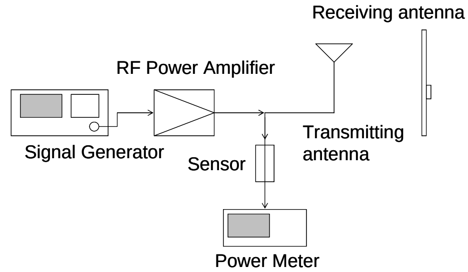


Fig.9. Measuring system

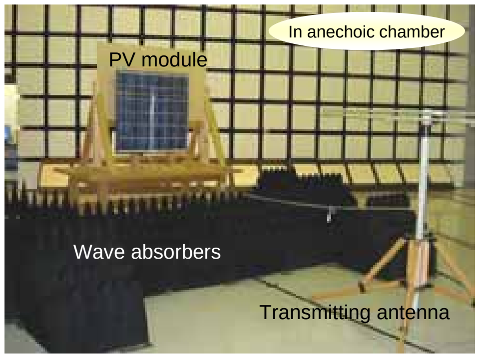
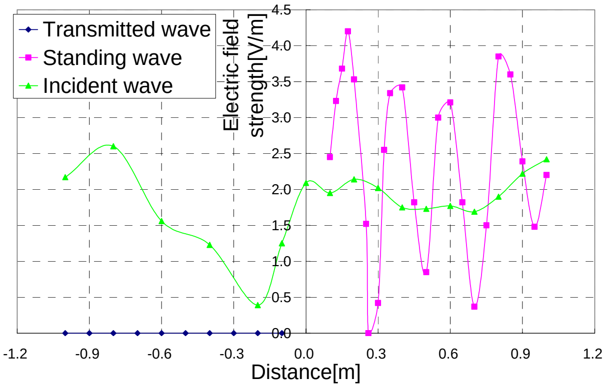


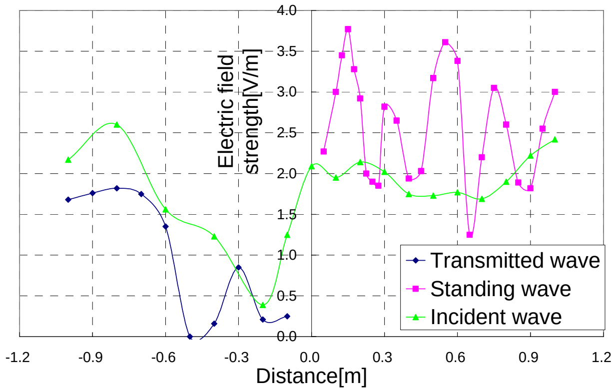
Fig.10. A scene of the experiment

Experimental Results

Fig.11 shows the measured characteristics of typical PV module and CL module at 700MHz. About the typical PV module, the standing wave ratio is remarkably large, and transmitted wave is not generated at all. On the other hand, the CL module shows the different characteristic to the typical PV module. The Standing wave ratio is very small, so absorbing potential of the CL module is confirmed. Table.1 shows the results of the reflection coefficients, phase, loss, and attenuation. Typical PV module reflects electromagnetic waves at UHF band. However, CL module has the absorbing potential stably. In particular at 700MHz, *Loss* is 86.90% and *Att* is 13.10%.



(a) Typical PV module



(b) CL module

Fig.11. Measured results of the 700MHz standing wave condition at the experiment

Table.1. Absorbing or reflection statuses of general PV module and CL module at the case radiated 600, 500, 700MHz waves.

Frequency [MHz]	ρ	|S|	θ [rad]	*Ein* [V/m]	*Ere* [V/m]	*Etr* [V/m]	*Loss* [%]	*Att* [%]	*Att* [dB]
Typical PV Module									
500	6.63	0.74	4.75	2.26	1.67	0.00	45.54	54.46	-2.64
600	---	1.00	5.03	1.46	1.46	0.00	0.00	100.00	0.00
700	---	1.00	5.15	2.09	2.09	0.00	0.00	100.00	0.00
CL Module									
500	3.09	0.51	3.17	2.26	1.15	1.13	48.91	51.09	-2.29
600	2.04	0.34	3.77	1.46	0.50	1.05	36.51	63.49	-1.97
700	2.04	0.34	4.41	2.09	0.71	0.25	86.90	13.10	-8.83

CONCLUSION

The idea of absorbing electromagnetic waves using PV module has been proposed. A CL antenna which operates as a receiving antenna in UHF band has been designed. The analytical results shown that the CL antenna has the receiving potential in not only UHF band but also in broad band.

Additionally, absorbing characteristic of CL module has been confirmed by the method of measuring the standing wave ratio. While typical PV module completely reflects electromagnetic waves, CL module performs as an absorber with maintaining stable loss and attenuation. Especially, the results at 700MHz show the exceptional absorbing characteristic.

A future issue is to design a circuit which has a matching impedance in wide range. Realization of the circuit has a profound effect on the absorbing characteristic of CL module. Moreover, the output port of CL module weaves generated DC component with received AC component. Therefore, it is absolutely essential to design the matching circuit, which separate DC from AC component and consumes only AC component at the resistive elements.

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