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Radiated EMI Emission Study on Photovoltaic Module for Radio Astronomy Receiver Front-end

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Abstract—**Photovoltaic (PV) solar module is one of the possible off-grid energy generations considered to power the receiver front-end of the square kilometer array low-frequency aperture array (SKA-low) project. However, PV module must be designed carefully and evaluated thoroughly to ensure that the module would not degrade the sensitivity and performance of the receiver. This paper presents a study on the electromagnetic behaviour of a typical PV panel structure and on the radiated electromagnetic interference (EMI) emission from a typical commercial-off-the-shelf (COTS) solar charger module. The purpose is to give an insight of possible EMI emission from the PV module, in the context of SKA-low receiver evaluation and development at ICRAR/ Curtin, Western Australia.**

Keywords- Electromagnetic interference, photovoltaic systems, circuit noise, solar power generation, DC-DC power converter, radio astronomy, square kilometer array.

INTRODUCTION

The square kilometre array (SKA) is an international radio astronomy project to build the largest and most sensitive radio telescope ever built [1]. The core of the SKA radio receiver will be built in a remote area either in Southern Africa or in Western Australia, far from civilisation, to ensure radio quietness from man-made radio interference. However, the capability of the radio receiver might be limited by the availability and affordability of energy supply to power the instruments at this remote area [2]. The SKA radio receiver would likely use combination of grid-based and stand-alone power solution for energy generation, including renewable energy means.

The SKA project is divided into several phases, and on the first phase, a baseline design approach is adopted, where the radio receiver will be incorporating both dish array with single pixel feeds and a low frequency aperture array [3]. ICRAR/ Curtin is actively participating in the SKA aperture array verification program (AAVP), working on low-frequency sparse aperture array operating at 70 – 450 MHz. In the sparse array configuration, there will be 11,200 antenna elements in a station, spread across an area with diameter of around 180 m.

In order to provide galvanic isolation between each antenna elements, analogue fiber optics link is considered as means to transport radio frequency (RF) signal received by the elements, to the core station for signal processing and digitisation. However, to maintain the advantage of galvanic isolation, it is preferable to generate the energy for powering electronic circuitry at the receiver front-end directly near the antenna, using renewable energy means, as shown in Fig. 1. PV module is an attractive candidate for energy generation.

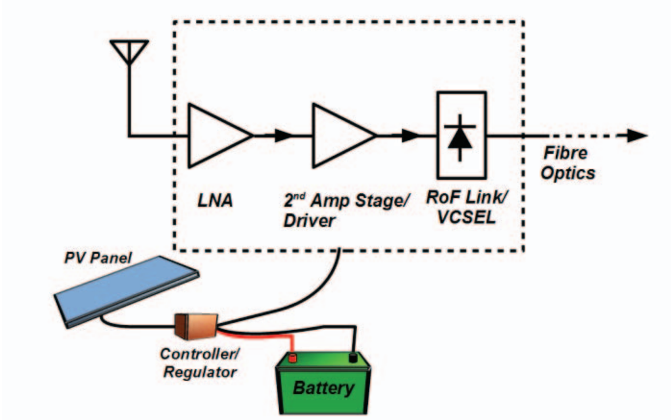

Fig.1 Solar-powered SKA-low receiver front-end [4].

A typical PV module consists of PV panel, solar charger controller, energy storage device and a regulator module. The regulator circuitry provides the voltage required to charge the battery and supplying constant power to the receiver chain (shown inside the dotted box in Fig. 1). However, regulator circuitry, especially the highly efficient switch-mode converter type generates switch noise. This noise could potentially be radiated either from the regulator module, or conducted through the electrical connector/ power cables to the amplifier, which could degrade the performance of the front-end receiver. The PV panel could become an RF antenna emitter as well; therefore there is a possibility of the noise to propagate back into the solar panel and to radiate through the PV panel.

This paper present a study on the PV module to gain insight of possible radiated electromagnetic interference (EMI) of the solar module, when placed near the front-end receiver, in the context of SKA AA-low receiver development at ICRAR/ Curtin, in Western Australia.

SIMULATION OF A TYPICAL PV PANEL

Fig. 2 shows a typical off-the-shelf photovoltaic panel. This panel is used to charge 4x AA size nickel cadmium batteries

(NiCd) connected in parallel. Under direct sunlight (around 50,000 lux), the panel could supply close to 3 V and 200 mA. The panel consists of 5 PV cells connected in series. To facilitate RF measurement, SMA connectors are attached at the panel terminals. The size of the panel is 54 x 85 mm.

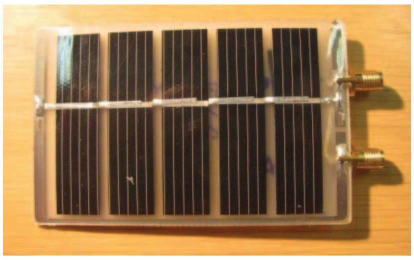

Fig.2 Typical off-the-shelf PV panel

To study the electromagnetic behaviour of the panel, simulation has been performed using HFSS software (Ansoft). To simplify the simulation, the antenna structure was first modelled based only on the main conducting track (copper) that connects all the PV cells and the positive/ negative terminals of the PV panel, as seen in Fig. 3.

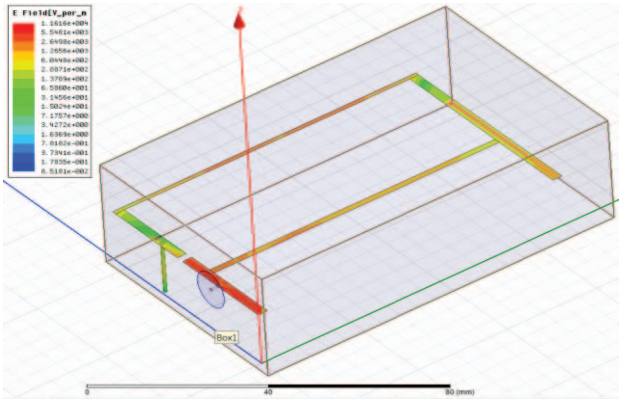

Fig. 3. Simplified structure used to simulate the electrical connection on the PV panel.

To check the effect of the solar cells in the panel simulation, 5 rectangular structures to simulate PV cells were added in the simplified model, as shown in Fig. 4. The comparison of the simulated return loss (S_{11}) between the simplified model and the model with solar cell structure is depicted in Fig.5. In general, the return loss response of both models is about the same, with the exception that the detailed model has some noticeable effects (notches and frequency shift) at frequency lower than 4 GHz. This suggests that the structure that has greater influence on the electromagnetic behaviour of the solar panel is the main electrical tracks.

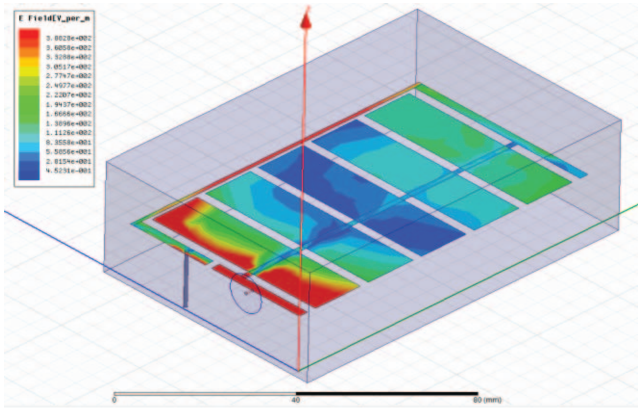

Fig. 4. Model of the PV panel with solar cell structure.

Note that the electrical tracks model in the simulation is also simplified, by having a single piece of continuous transmission line. The actual track on the PV panel is discontinuous, due to the fact that the track is used to connect the p-n junctions of the PV cells. To have a more accurate simulation model, cross sectional cut of the panel, as well as knowing the material and the characteristic of the material used to construct the panel are all required. Note also that the ground plane in the simulation is located 15 mm below the modelled structure.

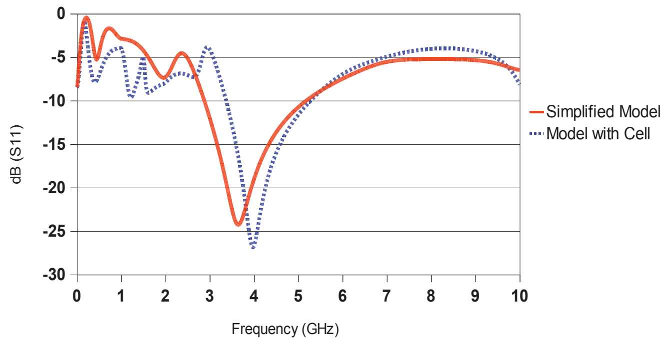

Fig. 5. Simulated return loss plot (S_{11}) of the simplified model and the model with solar cell.

MEASUREMENT RESULTS AND DISCUSSION

A. Measurement of a Typical Solar Panel

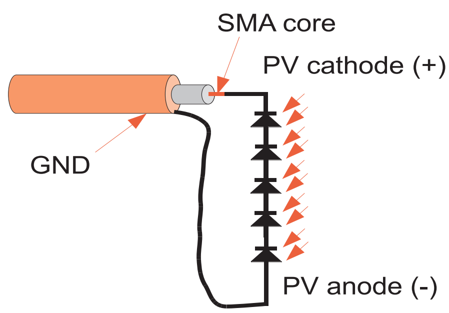

Fig. 6. Electrical connection of the PV panel terminals to SMA connector [4].

To measure RF characteristic of the PV panel, negative terminal of the PV panel was connected to the ground node of the SMA connector, while the positive terminal was connected to the core of the SMA connector/ cable, as shown in Fig. 6. The PV panel was connected to a vector network analyser (VNA) to measure the characteristic of the panel, as depicted in Fig. 7. Note that there is metallic plate placed 15 mm below the PV panel, acting as a ground plane.

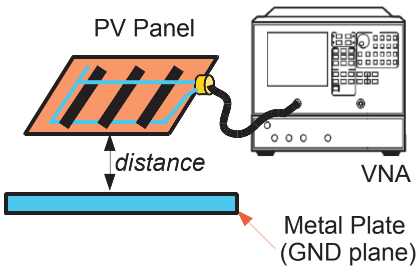

Fig. 7. The set-up for return loss measurement of the PV panel.

Fig. 8 shows the comparison between measured and simulated (HFSS simplified model) of the one-port return loss (S_{11}) plot of the PV panel, showing relatively a good agreement between simulated and measured results. Note that the presence of deep notch measured at around 3.4 GHz can be predicted by the simplified simulation model. Various notches are observed on the measured result, especially at frequency below 4 GHz, which are not predicted in the simulated results. This could be due to the simplification of the HFSS model, as has been discussed in Section II.

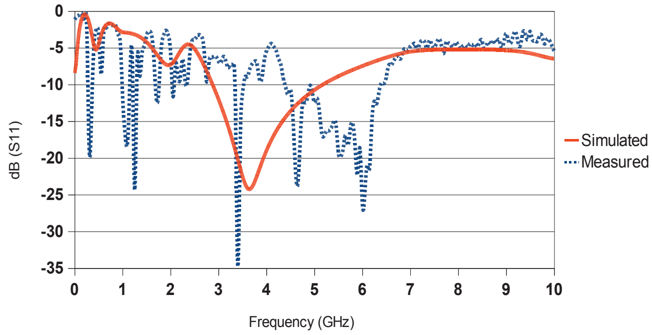

Fig. 8. Comparison between simulated (simplified model) and measured return loss (S_{11}) of the PV panel up to 10 GHz.

It can be seen that the measured response at a higher frequency above 6 GHz is about the same with the simulated results (Fig. 8), however, interesting observation is noted at lower frequency range. Since SKA-low will be operating between 70 – 450 MHz, a return-loss plot from the simulation and measurements results are taken from 10 MHz – 1GHz (Fig. 9). The measured return-loss result (shown in thick dotted line in Fig. 10) of the PV panel shows a relatively low return loss figure at a range of frequency from 250 MHz to 400 MHz, with -20.36 dB S_{11} level at around 300 MHz. This particular PV panel might potentially radiate EMI emission at that frequency if it is connected to a noisy circuit.

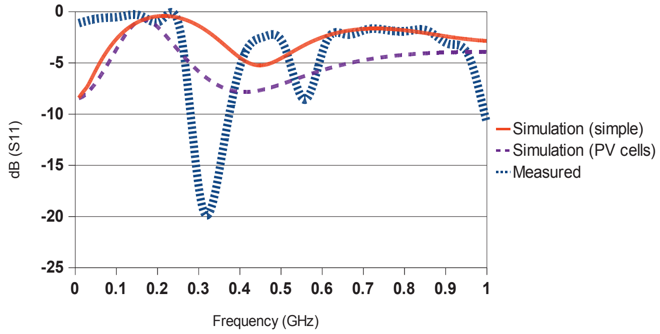

Fig. 9. The simulated results (simplified & model with PV cells) and the measured result of the PV panel, taken from 10 MHz – 1 GHz.

Further evaluation was performed to determine whether PV panel could emit RFI. Fig. 10 shows the experimental set-up, where the panel was connected to an RF signal generator, and placed 15 mm above the ground plane. The signal generator was tuned to produce output of around 300 MHz, with signal power limited to -30 dBm to avoid saturation at the receiving end. The detector antenna was placed relatively near the PV panel at a distance around 50 mm from the PV panel, and was connected to a spectrum analyser.

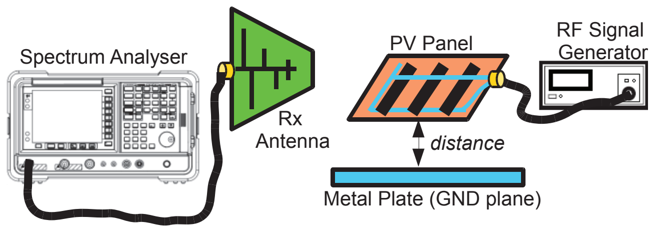

Fig. 10. Measurement set up to check the radiated emission of the PV panel.

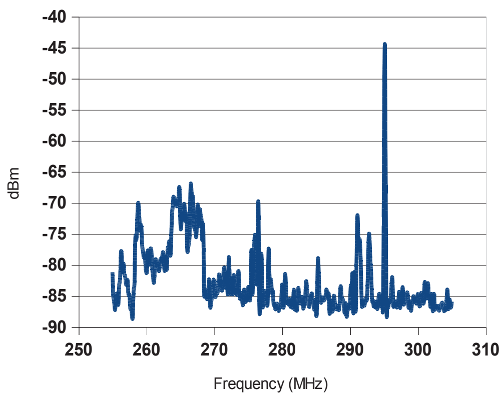

Fig. 11. Radiated RF emission detected from the PV panel.

The detected signal was captured by the spectrum analyser as can be seen in Fig. 11. The peak of the detected signal has a power level of around -45dBm, suggesting that under certain conditions (e.g. depending of the shape, characteristic of the PV panel and the presence of metallic object nearby), the PV panel could potentially radiate EMI emission.

B. Radiated EMI Measurements of a Solar Charger Module

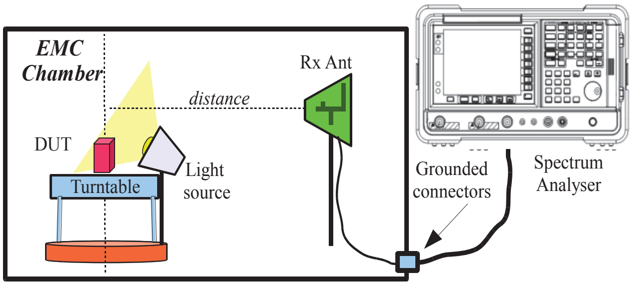

Fig. 12. Measurement set-up in the EMC chamber [4].

The measurement set-up to examine radiated emission from commercial off-the-shelf (COTS) solar charger module can be seen in Fig. 12. In this setting, the device under test (DUT) was placed on the wooden table in the EMC chamber and a suitable light source was employed to facilitate electricity generation of the PV panels. The DUT was connected to a 5 Ω resistive load directly (no extension cable). For a start, the distance between the DUT and the sensing antenna was set at 3m according to MIL STD-461F [5].

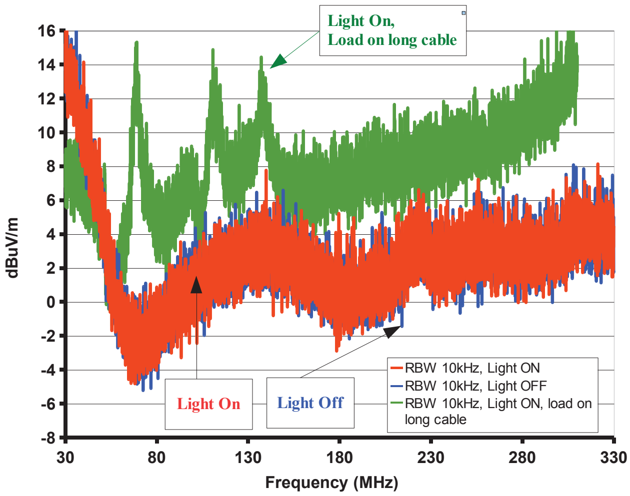

Fig. 13. Measured radiated emission of the solar charger module.

The measurement result of the detected radiated EMI emission from the PV module can be seen in Fig. 13. The results shows that there was no significant difference in detected emission when the PV panel was active (light source is turned on) and when the panel was not producing the energy (light source is turned off). This indicates that the detected noise was generated by the voltage regulator (DC-DC converter). When the resistive load is connected to the DUT via a 1.5m-long cable, the emission was significantly increased, suggesting that the connection between the charger module and the load had a significant impact on the EMI emission of the solar module. The measured emission was well below commercial standard limits (CISPR 11 requirement of - 40dBuV/m up to 230 MHz) [6]. However, the measured emission is about 10dB above MIL-STD limits (24dBuV/m at 100 MHz, then increasing by 20dB per frequency decade) [5].

CONCLUSIONS

This paper presents a study on the potential of radiated EMI emission from the PV module. It has been observed that under certain conditions PV panel could potentially become a radiating structure. The source of the radiated EMI emissions in the PV module mainly could come from the high-efficient circuitry used to regulate the power, which typically use switch-mode operation (pulse width modulation). Switch-mode regulator should be designed carefully to avoid both conducted and radiated RFI leakages. Suitable filtering scheme should be considered to avoid any RF signal being leaked into the PV panel, or any RFI being injected to noise sensitive instrumentation from the power supply connection. Suitable components, EMI shielding material and filter circuitry should be carefully selected and evaluated when designing photovoltaic-based power supply unit for the SKA-low front-end receiver to ensure that the PV module does not generate excessive EMI emission that will impact the sensitivity of the front-end receiver system

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