Photovoltaic panel with reactance elements for dual-band antenna radome

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Abstract

In this work we present an innovative approach to design a dual-band microwave antenna radome using a photovoltaic panel. A 20-wafers photovoltaic panel is treated as a microwave frequency selective surface on top of a microwave radiator. The transparent and the semi-transparent modes cooperated with different antenna radiating mechanism are utilized for dual-band operation. A layer with reactance elements is attached to the PV panel to modify the transmission response for desired 900MHz/1800MHz bands without degrading the PV efficiency. A proposed prototype, with dimensions 675 mm × 644 mm × 90 mm, achieves remarkable 16 dBi antenna gain at 1750 MHz with single radiator. The very combination of PV cell and antenna exhibits high fill-factor, high-gain, and simple construction characteristics and is potential for various kinds of applications.

1. Introduction

There are two major emerging demands of photovoltaic panel integrated with wireless communication systems. The first is the “off-grid, on-net population” and its market penetration in Southeast Asia and sub Saharan Africa will be reached to 138 million by 2016 according to the global mobile data traffic forecast announced by CISCO [1]. The second is the application of disaster communications. That is to enable an emergency call when the power grid is failed due to natural disaster such as floods, earthquakes and tsunamis.

Several integration approaches have been proposed in the last few years. In those former works, photovoltaic (PV) cells are used as radiation elements [2-3], or are used as radiation ground of a shorted patch antenna [4]. Inspired by the concept of metamaterial Fabry-Pérot resonator [5-6], we treat the PV panel as a periodic structure which having the proper frequency selective characteristic in the operation band. A dual-band PV radome and a dual-band PV-integrated high-gain antenna in a very reasonable, area-saving manner without any major modification of PV cell’s construction are proposed in this work.

2. Dual-band PV-radome design consideration

In our pervious work, we have explained how to model and analyze the transmission response of the periodic PV cell [7]. The PV panel of series connecting cells is classified as a mesh type frequency selective surface and behaves band-pass response. For the similar layer stack-up, the pass-band frequencies are correlated to the cell dimension, cell spacing, and number of connecting electrodes. However, these parameters can’t be selected arbitrarily due to the limitation of cell fabrication and the consideration of efficiency-first cell design.

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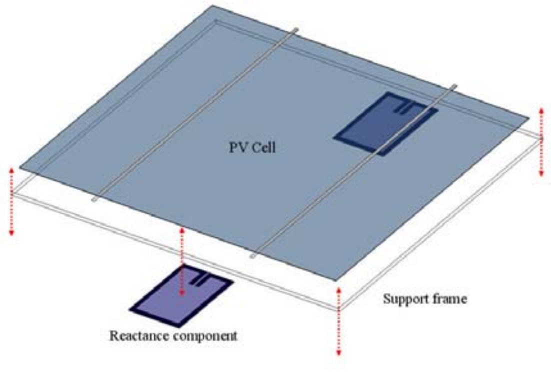
For the frequency of interesting, a standard 156 mm ×156 mm PV wafer is compared to the wavelength. In order to prevent unwanted Floquet modes in periodic structure, we shorten the length of the PV wafer to 126mm in the electrode-connecting direction.

The pass-band frequencies can't meet our 900 / 1800MHz dual-band requirement for all available dimension configurations. The equivalent passive network extracted from the cell's transmission response can help us to turn the frequencies on schematic level. Adding reactance elements on the cell-to-cell connecting path is a reasonable approach to tune the frequency response without modifying the PV cell itself. However, adding reactance elements on the DC current path directly may degrade the PV efficiency and hard to integrate in the commercial fabrication process. Alternatively, we put the reactance elements on an additional dielectric plate and attach it to the back plane of the PV panel. The metal part of the reactance is isolated from the DC current path of the PV cell. We design a C-shaped ring resonator as the reactance element and place it beneath the gap between two PV cells for providing sufficient loading reactance [8]. The transmission response of the 126 mm ×156 mm unit-cell is shifted to our desired level, as shown in Fig. 1.

3. Dual-band PV-integrated antenna design

A GSM 900MHz / DCS 1800 MHZ dual-band, PV-integrated outdoor unit is design as a conceptional prototype. A 675mm × 644mm, 5-by-4 cells' PV panel is used for the dual-band radome. According to our prior unit-cell analysis, the transmission response exhibits multiple pass bands. It's straightforward to select first and second pass band as our dual-band operation frequencies for the radome purpose. To pursue higher antenna gain and considering the finite panel size compared to the wavelength at low frequency, we take different strategies for each band. For 1800MHz band, Fabry-Pérot (FP) cavity mechanism is applied to achieve high antenna gain. The parallelepipedal FP cavity is composed of one semi-transparent surface, one reflective mirror surface and a suitable gap, usually half-wavelength, in-between. We tuned the cell so as the second pass band slightly deviates from the 1800MHz band for appropriate transmission level of the FP's semi-transparent surface. A copper plate, served as reflective mirror, is parallel placed beneath the PV panel with 90 mm (approximate $0.5\lambda_0$ at 1800 MHz) air gap. A central fed microwave power propagates transversely with slow-varying phase to fill the cavity and achieve high gain. At 900 MHz, the panel is too small to apply FP cavity mechanism. We tuned the first pass-band of the unit-cell to 900MHz band to ensure low-loss transmission as a transparent radome at this band. The parallelepipedal structure is not in the state of resonance at this frequency. It becomes a simple antenna with a back-reflector.

Full structure is shown in Fig. 2. Full model is simulated by commercial EM software, Ansoft HFSS. Loss of materials and conductivity of PV cells are all taken into consideration. The performance of the proposed dual-band antenna is shown in Fig.3. It performs good matching in targeted two frequency bands and achieves a peak gain of 16 dBi at 1750 MHz and 8 dBi at 920MHz in broadside direction.



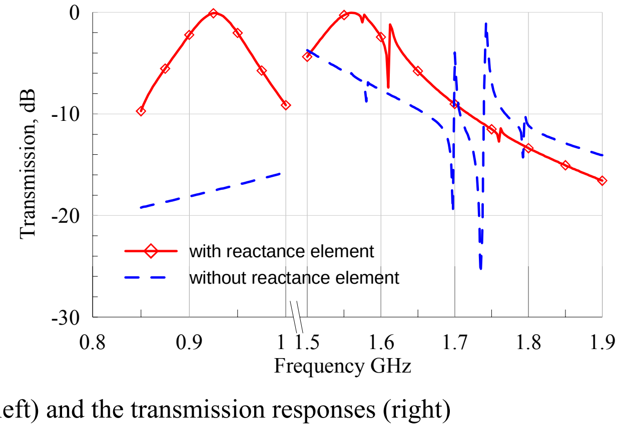


Fig. 1: Unit-cell with reactance load (left) and the transmission responses (right)

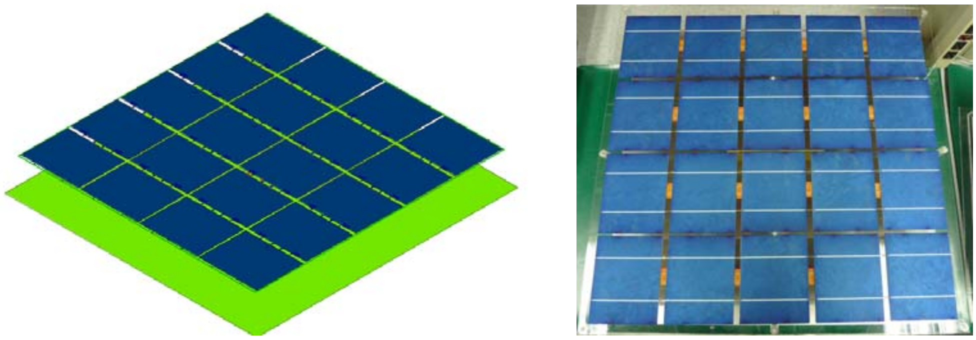


Fig. 2: The proposed dual-band PV-integrated antenna, simulation model (left) and prototype photo (right).

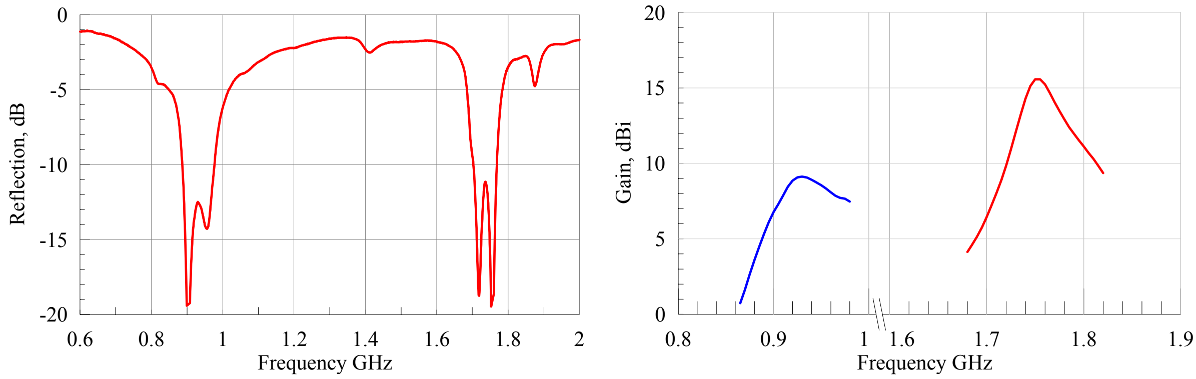


Fig. 3: Reflection response (left) and antenna gain (right) of the proposed dual-band PV-integrated antenna.

4. Conclusion

This work successfully demonstrated a PV solar cell panel into a dual-band antenna radome with very little additional structures and cost. The pass band frequency of the PV radome can be tuned by additional reactance elements without degrading the PV efficiency. The proposed PV-integrated antenna, with reasonable configuration and simple construction, exhibits high antenna gain in second operation band. The PV radome shows very high potential for various kinds of wireless communication applications.

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