# Building Antennas on Perovskite Solar Cell (PSC) for Hybrid Solar/EM Wireless Energy Harvesting and Transfer

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**Abstract** In this paper, building antennas on Perovskite solar cell (PSC) is advocated for wireless hybrid Solar/EM power harvesting and transfer. PSC is a recently emerged technology that can transfer solar energy into DC power. The anode of PSC is made of Indium tin oxide (ITO), which is a transparent conductive film and can be used as the antenna aperture. This way, PSC can not only absorb energy from optical light but also from RF waves. Due to the structural flexibility of PSC, the antenna is bend into a cylindrical shape to attain omnidirectional radiation pattern for certain applications. The potential and design considerations of building antennas on PSC have been discussed.

**Keyword** Hybrid solar/EM system, Indium Tin Oxide (ITO), Perovskite Solar Cell (PSC), Wireless Power Harvesting and Transfer

## 1. Introduction

Long range wireless power harvesting and transfer is mainly realized by using power beaming of electromagnetic (EM) or solar radiation. At lower frequencies (GHz), antennas combining with rectifier or oscillator are used to transmit and receive the power in EM radiation. At higher frequencies (>THz), power harvesting and transfer are realized by solar cells and ambient light. Solar energy is the most widely used ambient power source since it is clean and free. However, the amount of available energy from ambient light is variable and unpredictable. Therefore, hybrid solar/EM energy harvester is advocated which collects both solar energy using solar cells and EM energy from rectennas [1-3].

For solar/EM hybrid energy harvesters, the integration of solar cells and rectennas is of great importance. The solar cells and antenna can be placed together to attain a compact structure, but the performance of either or both of them can be degraded. Placing transparent antenna atop solar panel is one option [4], which allows light passing through the antenna with minimum degradation, i.e., 5%-10%. However, to achieve transparency, the antenna has to be designed with transparent materials, which introduces more losses [5]. Another option is to property arranging the aperture, making antennas and solar cells geometrically interleaving with each other [6]. It has been shown that it is possible to reduce the effect that the solar cells have on the antenna performance.

Apart from the previously mentioned two integration options, there is a third option, i.e., building antennas on solar cells. In the past few years, Perovskite solar cells (PSC) have been attracting great attention due to their high power conversion efficiency and simple manufacturing process [7]. As shown in Fig. 1, its cathode is indium tin oxide (ITO), a conducting film. Although the conductivity of ITO is not as good as that of traditional metals, ITO has been used to design transparent antennas recently. Therefore, it comes to our mind that why not using the cathode of a PSC as the antenna aperture. This way, the antenna and solar cell can be geometrically overlapped without worrying that the antenna might affect the solar cell's performance. Moreover, the antenna can have a large aperture without introducing defects. Current available solar antennas usually have defected area to host solar cells [3]. Compared to those antennas, PSC-based antenna does not need to have a defect area for solar cells, thus may have a better radiation performance.

This paper presents a primitive attempt to build antennas on PSC for hybrid solar/EM wireless energy harvesting and transfer system. An omnidirectional patch antenna designed on PSC is illustrated as an example. Design considerations and challenges are discussed as a guidance for future work.

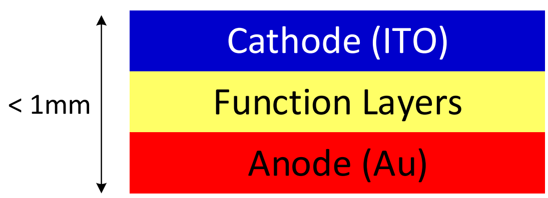



Fig.1. Schematic layer information of a PSC.

## 2. Integrating PSC on Antenna

### 2.1. Configuration A

Compared to conventional silicon-based solar cells, PSC has two noticeable advantages. First, it is very thin and is physically flexible. Second, it is able to absorb room light with low intensity while silicon-based solar cells can only work under strong sun lights illuminations. In this work, to make the best use of these two properties, a cylindrical patch antenna configuration with omnidirectional radiation pattern is selected as shown in Fig. 2. It generally consists of three layers: the reflector layer modelled as PEC, the substrate layer modelled as air, and the patch layer (PSC). Since the thickness of a PSC is very small, i.e., < 1mm, the function layer and the Au layer of the PSC have minor effects on the radiation. Therefore, the PSC layer is modelled as an ITO layer with certain surface resistivity of *Rs*. The patch antenna is fed off-axis by a probe. A more complicated feed network can be designed on a substrate inserted in the reflector's cavity to enhance the impedance matching without affecting the radiation performance [8-9].

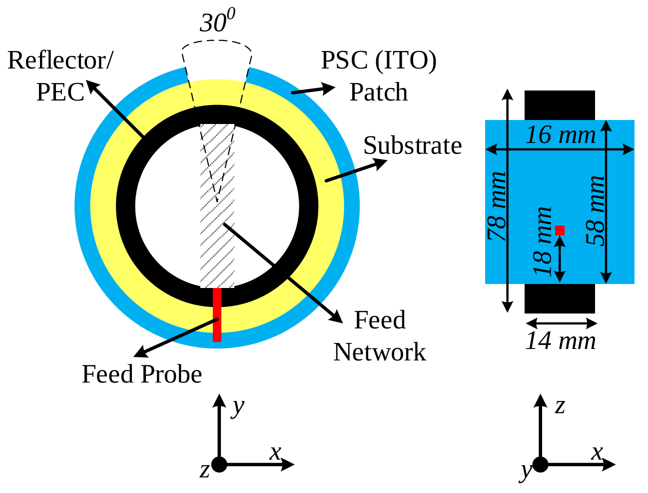
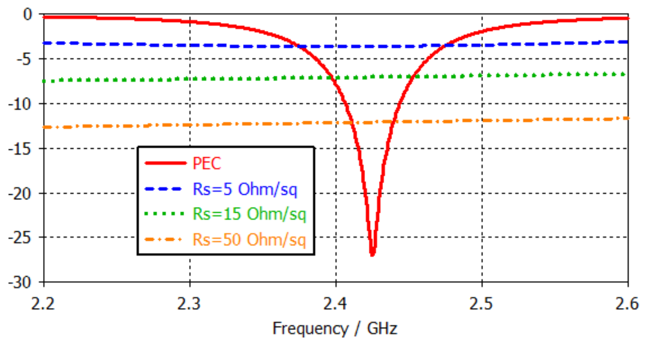
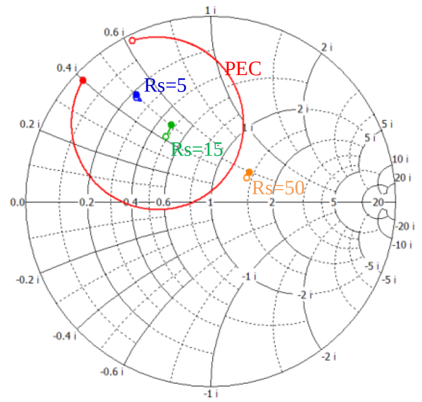



Fig.2. Geometry of a cylindrical patch antenna based on PSC.

This study focuses on the analysis of the performance degradation of the antenna by replacing PEC with ITO as antenna aperture. First the patch aperture was modelled using PEC and the dimensions were adjusted to make the antenna resonates around 2.4 GHz according to the theory reported in [10]. Then the PEC material was replaced by resistive ITO thin film with *Rs* = 5, 15, and 50 Ohm/sq. The obtained reflection coefficients and input impedance in Smith Chart are plotted in Fig. 3(a) and 3(b), respectively. It is noticed that the reflection coefficients and input impedance of the antenna using resistive ITO as radiating aperture can be very different with that of the normal case employing PEC (metal). As shown in Fig. 3(b), the input impedance is dominated by the surface resistivity *Rs* and remains quite stable with frequency changing when ITO is employed as the patch material. The advantage is the fact that since the input impedance is stable, the antenna can be matched across a much wider band by using a simple impedance transforming circuit like the ones proposed in [8-9]. However, the drawback is that the resistive thin film introduces significant loss, which reduces the antenna gain. Figs. 4(a) and 4(b) show the 3D radiation pattern of the patch antenna at 2.4 GHz employing PEC and resistive ITO (Rs = 5 Ohm/sq) as patch material, respectively. Although the shapes of the patterns are similar, the gain difference is significant, i.e., the maximum gains for the two cases are 2.26 dB and -11.04 dB, respectively. Note that here we considers gain rather than realized gain to eliminate the matching performance's effect on the results.

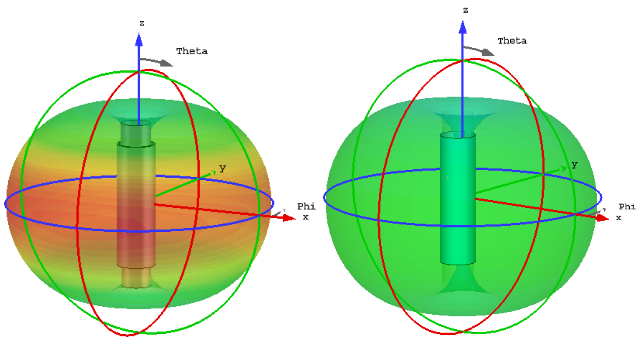



(a)




(b)

Fig.3. (a) Reflection coefficient and (b) input impedance in Smith Chart of the cylindrical patch antenna employing PEC and resistive ITO as patch material across the band from 2.2 to 2.6 GHz.



(a) (b)

Fig.4. 3D radiation pattern of the patch antenna employing (a) PEC and (b) resistive ITO with *Rs* = 5 Ohm/sq as patch material at 2.4 GHz.

## 2.2. Configuration B

Although the gain reduction of the antenna due to the resistive ITO sheet is expected, it can be a severe problem in many applications. Therefore, a modified model is proposed as shown in Fig. 5, which utilized PSC/ITO as the sleeve of a conventional cylindrical patch antenna. It is like a stacked patch in cylinder version. The additional patch or sleeve is usually employed to enhance the bandwidth.

Similarly, we examined the performance change caused by ITO. Fig. 6 shows the reflection coefficients and input impedance of the sleeved cylindrical patch with the sleeve modelled using PEC and resistive ITO sheet with *Rs* = 5 Ohm/sq. It can be easily concluded that, when ITO is used as the sleeve, it does not change the impedance too much compared to that of the PEC sleeve. Moreover, the gain reduction is minor by replacing PEC sleeve with ITO sleeve, i.e., from 2.08 to 0.86 dB at 2.45 GHz.

In addition, here we remark that the size of the sleeve matters. Generally, to get the maximum power harvest, the solar cell (sleeve) is preferred to be as large as possible. However, if the antenna patch is fully covered by PSC, i.e., *L* > 58 mm, the antenna performance can be further degraded. Although the impedance matching remains similar, as shown in Fig. 6, the gain is further reduced to -7.93 dB.

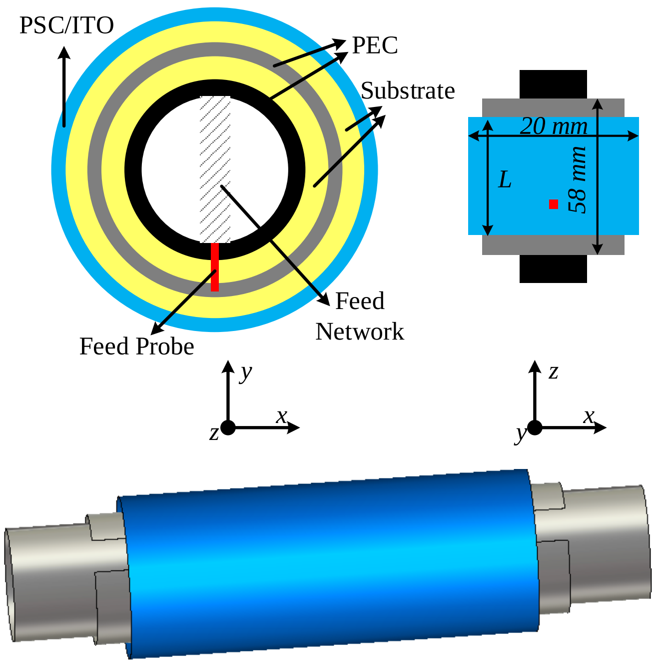
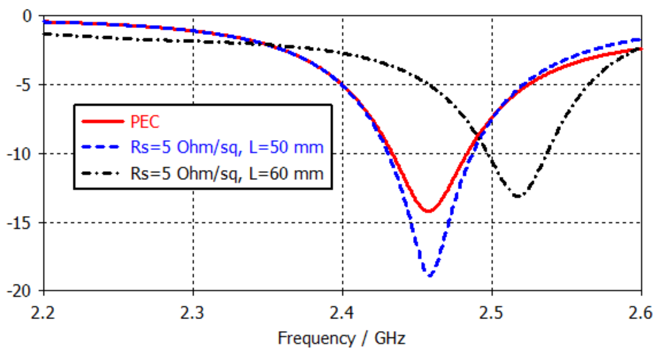
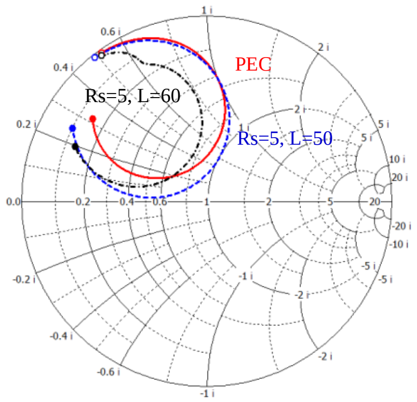



Fig.5. Geometry of a stacked cylindrical patch antenna using PSC as sleeve.




(a)




(b)

Fig.6. (a) Reflection coefficient and (b) input impedance in Smith Chart of the cylindrical patch antenna employing PEC and resistive ITO as additional sleeve.

## 3. Conclusion

This paper presents an idea of employing PSC in cylindrical patch antenna design for hybrid solar/EM power harvesting and transfer. Two methods of integrating PSC and cylindrical patch antenna are proposed. The performance degradation of the antenna due to the employed PSC has been discussed, which can be used as the guidance for future work.

## 4. References

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