

Research Article

Base Transceiver Station (BTS) Antenna Electric Field Influence on the Space Charge Region in a Silicon Solar Cell

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Abstract: In this study, we studied the influence of the electric field emitted by a BTS antenna on the space charge region of a silicon solar cell, placed at a distance r of the antenna. The drift diffusion recombination equation in presence of electric field has been established and the excess minority carries density is deduced. Based on the minority carries density, the space charge region extension, the photocurrent density, the photo voltage and the capacitance have been determined. The objective of his study is to show the effects of the electric field generated by a BTS antenna on the solar cell especially on the space charge region and its associated capacitance.

Keywords: BTS antenna, electric field, solar cell, space charge region capacitance

INTRODUCTION

Photovoltaic solar energy is a very promising solution to meet the requirements in energy for off-grids telecommunication systems (Zéraïa *et al.*, 1999); but it seems that solar panels are sensitive to the electromagnetic field generated by transmission antennas.

According to Zerbo *et al.* (2011) it is the electric component of the electromagnetic wave that have the more influence on solar panels. In this study we then study the effects of the electric field emitted by an antenna on the space charge region of a silicon solar cell.

Based on the continuity equation, we determine the excess minority carrier density in the base of the cell. The photocurrent density, the photo voltage, the space charge region width and its associated capacitance are deduced regarding both the junction recombination velocity and the electric field induced by the antennas.

THEORETICAL STUDY

In the following Fig. 1, we have a Base Transceiver Station (BTS) supplied by a photovoltaic generator. The intensity of the electric field emitted by the antenna is related to the power radiated by the source and the distance r between antenna and solar panels.

The BTS is a whole of emitter/receptor (TRx) controlling one or more cells. In network GSM, each principal cell in the center of which is a perhaps divided basic station, thanks to directional antennas, which use different carrier frequencies (900, 1800 and 1900 MHz, respectively). It is frequent to have tri-sectoral antennas, which cover a little more than 120. These antennas make it possible to carry out the Um connection between the ms and the BTS (Demoulin and Droogenbroeck, 2004; Ndoye *et al.*, 2010).

A GPV or module is a whole of elementary solar cells assembled in series or parallel of a great basic number of cell of the same technology and characteristics identical (Kassmi *et al.*, 2007; Zoungana *et al.*, 2012). We will make a study of a solar cell of our generator.

Excess minority carries density: We have on Fig. 2 the structure of a n-p-p+ solar cell of the type under spectral illumination and external electric field (Zerbo *et al.*, 2011; Zoungana *et al.*, 2012).

Based on the study presented in Zoungana *et al.* (2012), we have:

The continuity equation of the excess minority carriers density in the base of the solar cell under electric field can be written in the form:

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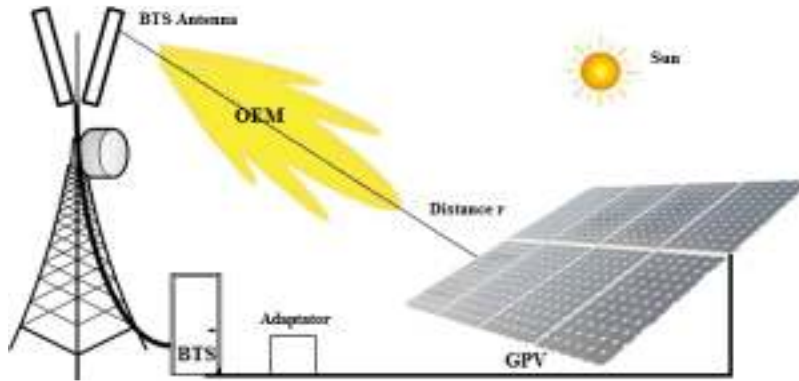


Fig. 1: Photovoltaic generator feeding a BTS relay station

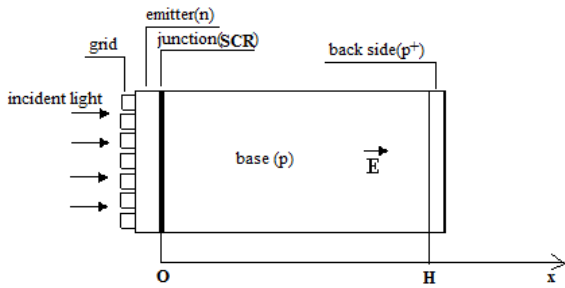


Fig. 2: n-p-p+ silicon solar cell under electric field

$$\frac{\partial^2 \delta(x)}{\partial x^2} + \frac{\mu \cdot E_0}{D_n} \cdot \frac{\partial \delta(x)}{\partial x} - \frac{\delta(x)}{\tau \cdot D_n} + \frac{G(x)}{D_n} = 0 \quad (1)$$

where,

- $\delta(x)$: The excess minority carriers density in the base
- μ : The electron mobility
- τ : The minority carriers lifetime
- D_n : Their diffusion constant (Zoungrana *et al.*, 2012; Mathieu, 2000)
- E_0 : The applied electric of field

$G(x)$ is the minority carriers rate generation for a multispectral illumination on the front surface and is given by Zoungrana *et al.* (2012), Mohammad (1987) and Furlan and Amon (1985):

$$G(x) = \sum_{i=1}^3 a_i \cdot e^{-b_i x} \quad (2)$$

where, the parameters have a_i and b_i are coefficients deduced from solar radiation under AM 1,5 spectrum.

Let us take $Le = \mu \cdot E_0 \cdot \tau$ and introduce electrons diffusion length in this expression, we obtain the following expression:

$$Le = \frac{\mu \cdot E_0 \cdot L_n^2}{D_n} \quad (3)$$

Substituting Eq. (3) in (1), we obtain:

$$\frac{\partial^2 \delta(x)}{\partial x^2} + \frac{Le}{L_n^2} \cdot \frac{\partial \delta(x)}{\partial x} - \frac{\delta(x)}{L_n^2} + \frac{G(x)}{D_n} = 0 \quad (4)$$

The excess minority carriers density $\delta(x)$ can then be written in the form:

$$\delta(x) = e^{\beta x} \cdot [A \cdot ch(\alpha \cdot x) + B \cdot sh(\alpha \cdot x)] + \sum_{i=1}^3 c_i \cdot e^{-b_i x} \quad (5)$$

with

$$\alpha = \frac{(L^2 e + 4 \cdot L_n^2)^{\frac{1}{2}}}{2 \cdot L_n^2}, \quad \beta = \frac{-Le}{2 \cdot L_n^2}$$

and

$$C_i = \frac{a_i \cdot L_n^2}{D_n \cdot [L_n^2 \cdot b_i^2 - Le \cdot b_i - 1]}$$

Coefficients A and B can be determined through the following boundary conditions (Sissoko *et al.*, 1996; Barro *et al.*, 2008; Hamidou *et al.*, 2013):

- At the junction ($x = 0$):

$$\frac{\partial \delta(x)}{\partial x} \Big|_{x=0} = \frac{Sf}{D_n} \delta(0) \quad (6)$$

- And at the back surface ($x = H$):

$$\frac{\partial \delta(x)}{\partial x} \Big|_{x=H} = \frac{-Sb}{D_n} \delta(H) \quad (7)$$

Sf and Sb are, respectively junction and back surface recombination velocities.

For an isotropic antenna in free space, the radiated power P (W) is related to the electric field E_0 (V/m) through the relation (Freyer, 2009):

$$E_0 = \frac{1}{2 \cdot r} \sqrt{\frac{P \cdot Z_0}{\pi}} \quad (8)$$

Table 1: Electric field values according to the distance r

	Distance r (m)	E_0 (V/m)
a	5	4.899
b	10	2.449
c	40	0.612
d	70	0.350
e	100	0.245
f	200	0.122
g	500	0.049

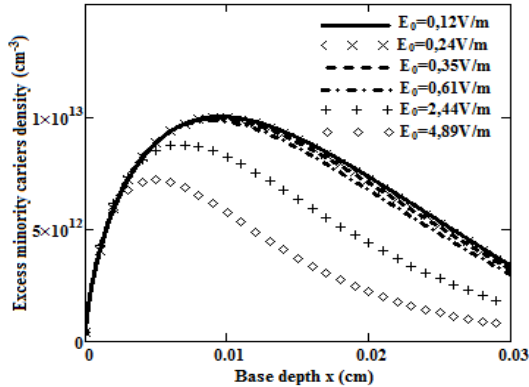


Fig. 3: Carriers density versus base depth for various electric field
 $L = 0.02$ cm; $S_b = 3.10^3$ cm/s; $S_f = 5.10^5$ cm/s;
 $H = 0.03$ cm; $D = 26$ cm²/s; $\mu = 10^3$ cm²/V/s

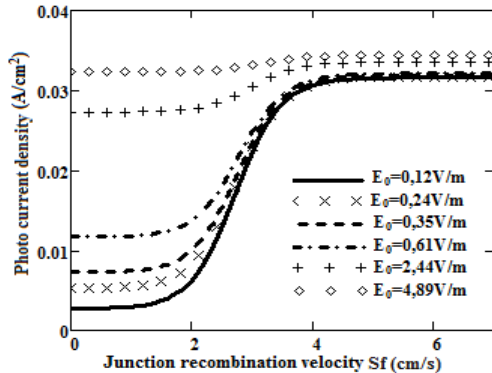


Fig. 4: Photocurrent density versus junction recombination velocity for different values of electric field
 $L = 0.02$ cm; $S_b = 4.10^4$ cm/s; $n = 1$; $H = 0.03$ cm;
 $D = 26$ cm²/s; $\mu = 10^3$ cm²/V/s

r is the distance between the antenna and the solar panels and Z_0 the characteristic impedance in free space ($Z_0 = 120\pi$).

Standard GSM imposes a maximum sensitivity of -104 dBm in GSM 900 and DCS 1800. It also defines the maximum emission power according to the frequency band used (Lagrange *et al.*, 1997).

Table 1 presents the electric field value for a given distance r between antenna and solar panels

Figure 3 shows excess minority carrier density profile versus depth x in the base for various external electric field values.

One can see that excess minority carrier's density increase with base depth until a certain position x_0 in the base; above that position, the excess minority

carriers decrease. Effectively the maximum density is close to the illumination face given the dependence of the absorption coefficient of the silicon to the depth x in the base.

Figure 3 also shows that excess minority carriers decrease for increasing electric field and the maximum density is left shifted. This could be explained by the fact that for increasing electric field, excess carriers in the base are shifted close to the junction so that they can cross the junction; excess carriers density in the bulk of the base decrease correspondingly and the position of the maximum density shifted also to the junction. There is then a reduction of the space charge region with electric field.

Photocurrent density: Due to the presence of an electric field, the photocurrent density has two components: the diffusion current and the drift current. The photocurrent density can then be expressed as follow Zerbo *et al.* (2011) and Mohammad (1987):

$$J_{ph} = q \cdot \left[D_n \cdot \frac{\partial \delta(x)}{\partial x} \Big|_{x=0} + \mu \cdot E_0 \cdot \delta(0) \right] \quad (9)$$

Given the boundary condition at the junction Eq. (8), the photocurrent density can be written as:

$$J_{ph} = q \cdot \delta(0) \cdot (S_f + \mu \cdot E_0) \quad (10)$$

We present on Fig. 4 the photocurrent density versus junction recombination velocity for various electric field values.

One can observe that photocurrent density increases with junction recombination velocity with a maximum value near short circuit. Keeping in mind that junction recombination velocity traduces carrier flow through the junction, the greater the junction recombination is, the greater the photocurrent will be.

For increasing electric value, the photocurrent density also increases but this effect is more marked near open circuit.

Effectively, near open circuit, carriers are stored in the base but due to the electric field most of them are drifted and can cross the junction, thus increasing the photocurrent density.

Photovoltage: The photovoltage across the junction expression is given by the Boltzmann relation:

$$V_{ph} = V_T \cdot \ln \left[\frac{\delta(0)}{n_0} + 1 \right] \quad (11)$$

where,

V_T = The thermal voltage

n_0 = The electrons density at thermodynamic equilibrium

Figure 5 shows photovoltage variation versus junction recombination velocity Sf for various electric fields.

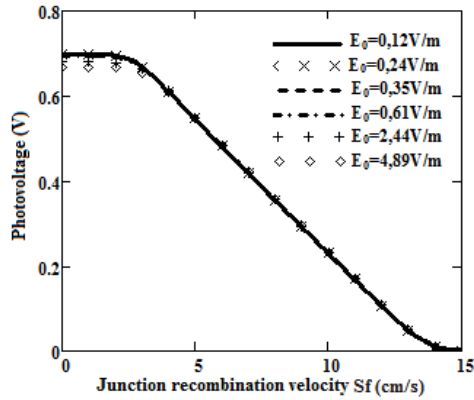


Fig. 5: Photovoltage versus junction recombination velocity for various electric field
 L = 0.02 cm; Sb = 4.10⁴ cm/s; n = 1; H = 0.03 cm;
 D = 26 cm²/s; μ = 10³ cm²/V/s

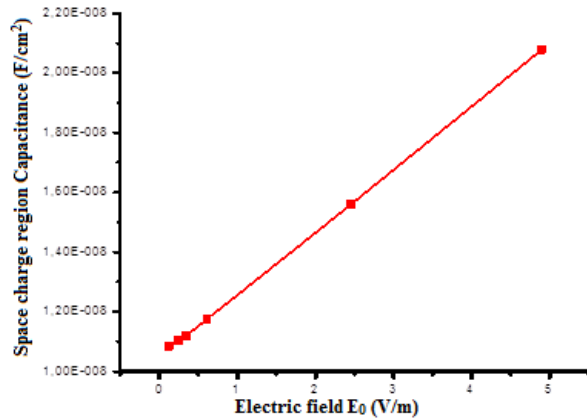


Fig. 6: Space charge region capacitance versus electric field E₀

Figure 5 shows that the photovoltage across the junction decreases as junction recombination velocity increases; this is due essentially to the fact that when junction recombination velocity increases, more and more carriers flow through the junction so that stored carriers density decrease leading to a decrease of the photovoltage.

We can also observe that the photo voltage decreases slightly with the electric field near open circuit.

Space charge region: The collection region of the solar cell also called space charge region extension can be assumed to be a plane capacitor (Sissoko *et al.*, 1998). Its associated capacitance can then be written as:

$$C = \frac{\epsilon \cdot S}{x_0} \tag{12}$$

where,
 ε = The silicon permittivity

S = The junction cross section

x₀ = The collector region width, x₀ can be expressed as:

$$x_0 = x_d + x_{el} \tag{13}$$

x_d = The intrinsic space charge region width

x_{el} = A term that depend on electric field and operating conditions

We consider now six electric field values and for each value we determined the position x₀ of the maximum density profile; the associated capacitance of the space charge region is deduced from Eq. (12) and the profile of this capacitance is showed versus electric field (Fig. 6).

This figure shows that the collection region capacitance depends linearly on the electric field as previously determined by Sissoko *et al.* (1998).

CONCLUSION

We presented in this study a theoretical study of a BTS antenna Electric field influence on the space charge region of a silicon solar cell.

Excess minority carriers, photocurrent density, photo voltage and carriers collection region width have been determined for various electric fields: we showed that collection region width decrease as electric field increase.

Assuming the collection region to be a plane capacitor, we showed a linear dependence of the associated capacitance with the electric field.

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