THE SOLAR CELL EXPERIMENT OF THE FIRST BRAZILIAN COMPLETE SPACE MISSION SATELLITE

N. Veissid, P. Nubile, A. F. Beloto
Instituto de Pesquisas Espaciais, Ph.(123)22-9977, ext. 308,
P.O. Box 515, CEP 12201, São José dos Campos, SP-Brazil
and
A. M. Andrade
Laboratório de Microeletrônica da Escola Politécnica da
Universidade de São Paulo, Ph.(11)815-9322, ext. 256,
P.O. Box 8174, CEP 01051, São Paulo, Brazil

ABSTRACT

The first satellite of the Brazilian Full Space Mission will host a solar cell experiment (SCE). The objective of the SCE is to qualify, in real mission, the solar cells developed at the University of São Paulo. The solar cell array consists of 6 p-n junction single crystal silicon, 10Ω.cm, n-type phosphorus doped subtracts, 2x2cm^2 area cells. The objective of this paper is to describe the development of the Solar Cell Experiment and the mathematical procedures used for the determination of the IxV curve output parameters. This novel method is based in the numerical fit of the voltage versus temperatures curve of the SCE cells as telemetered by the satellite. A laboratory simulation of the electrical behavior of the SCE has shown that analytical method is excellent for the interpretation of the telemetered SCE signal. The parameters obtained from the VxT curves matches satisfactorily the IxV curve parameters obtained by direct measurements. For the first time, it is demonstrated that a low cost experiment which uses passive electric circuits can be used to obtain the complete IxV solar cells curves during the satellite mission lifetime.

INTRODUCTION

The experiments conducted aboard satellites shown the importance of the studies of joint effects of thermal cycles, ionizing radiation damage, ultra-violet light and vacuum in the degradation of the solar cells [1,2]. The main reason is the extreme difficulty in the simulation of all the effects, simultaneously, in laboratory.

The first data collection satellite (SCD1) is a real time repeater of environmental data collected from the ground by data collection platforms. The SCD1 will have a mission life of six months in a circular orbit 750 km high, with a period of 100 minutes, at an inclination of 25°. In this orbit, the satellite will be under the illumination during 80 minutes, the rest of the time being in the shadow cone of the earth. In this cycle, the satellite experiences a temperature change of approximately 150°C. The fig. 1 is a scheme of the SCD1 satellite showing the location of the solar cell experiment array (SCE).

0160-8371/90/0000-1184 © $1.00 1990 IEEE

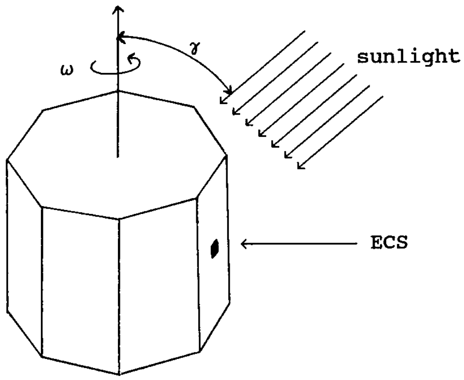

Fig. 1. The SCD1 satellite scheme showing the location of the SCE.

Due to power limitations in the satellite, the experiments had to have a passive electric circuit and a novel method developed for the interpretation of the electric signal data. The method is based in the physical behavior of the device and so, it was necessary to develop a model to describe the IxV characteristic curve dependence with the temperature.

THE SOLAR CELL EXPERIMENT

The SCE experiment structure is shown in fig. 2. A 6-cell series array is held in an aluminum frame fixed in the satellite body. The signal peak detector circuit is shown in fig. 3. It will give the value of the peak of the half-sinusoid shape signal, resulting from the satellite rotation. The circuit was built to assure a better than 3% accuracy signal reading, telemetered every half second.

METHOD FOR THE SOLAR CELLS PARAMETERS EXTRACTION FROM V-T CURVES

The I-V illuminated solar cell curve can be represented by the double-exponential equation [3,4], eqn. 1.

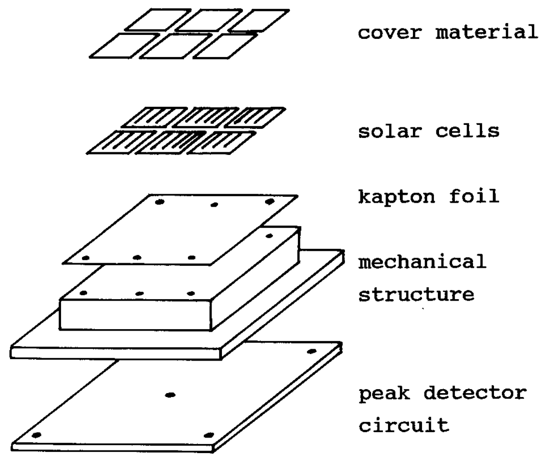

Fig. 2. Mechanical structure of the SCE.

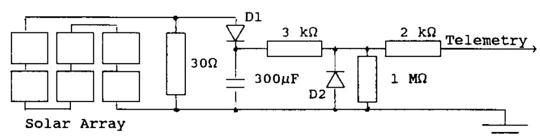

Fig. 3. SCE signal conditioning circuit.

The efficiency conversion is defined by eqn. 2.

$$I = I_L - I_{01}.\left\{ \exp\left[\frac{q}{K.T}(V+I.R_s)\right] - 1 \right\} - I_{02}.\left\{ \exp\left[\frac{q}{A.K.T}(V+I.R_s)\right] - 1 \right\} - \frac{V + I.R_s}{R_p} \quad (1)$$

$$\eta = P_{max}/P_{inc} = FF.I_{SC}.V_{OC}/P_{inc} \quad (2)$$

where the terms in eqns. 1 and 2 have their usual meanings. The dependence of the saturation currents I_{01} and I_{02} with temperature is found in the work of Wolf et al. [5], which are shown in eqns. 3 and 4.

$$I_{01} = C_{01}.T^3.\exp\left(- \frac{E_g}{K.T} \right) \quad (3)$$

$$I_{02} = C_{02}.T^{3/2}.\exp\left(- \frac{E_g}{2.k.T} \right) \quad (4)$$

Where C_{01} and C_{02} are saturation constants and E_g is the silicon gap energy.

In this work it is assumed that the parameters I_L, A, R_S and the neperian logarithm of R_P varies linearly with temperature, which are shown in eqns. 5-8.

$$I_L[T] = I_L[300K].[\ 1 + CI_L.(T-300K)\ ] \quad (5)$$

$$A[T] = A[300K].[\ 1 - CA.(T-300K)\ ] \quad (6)$$

$$R_S[T] = R_S[300K].[\ 1 + CR_S.(T-300K)\ ] \quad (7)$$

$$\ln(R_P[T]) = \ln(R_P[300K]).[\ 1 - CR_P(T-300K)\ ] \quad (8)$$

Where CI_L, CA, CR_S and CR_P are proporcionality constants.

The 6-cell array is connected to a load resistor (R_L). The electrical signal, as function of the temperature of the cells, is given by eqn. 9.

$$V[T] = \left\{ I_L[T] - I_{01}[T].\left\{\exp\left[\frac{q.V[T]}{k.T}\left(1 + \frac{6.R_S[T]}{R_L} \right)\right] - 1 \right\} - I_{02}[T].\left\{ \exp\left[\frac{q.V[T]}{A[T].k.T}.\left(1 + \frac{6.R_S[T]}{R_L}\right)\right] - 1 \right\} - \left(\frac{V[T]}{R_p[T]} \right).\left(1 + \frac{6.R_s[T]}{R_p[T]} \right) \right\}.(\ R_L/6\ ) \quad (9)$$

With the use eqn. 9, from a numerical iterative fit of the V-T solar cell curve, is possible to obtain the values of the parameters which defines the I-V curve. Utilizing the co-sine law for the value of the photocurrent, one can obtain the I_L value in a perpendicular AM0 illumination condition. In this work, an attenuation factor is used for the co-sine law as suggested by Heinamaki and Guekos [6].

EXPERIMENTAL RESULTS

A laboratory simulation of solar cell experiment was performed in a thermo-vacuum chamber. The solar cell array was illuminated through a window at an intensity of 85 mW/cm^2. The voltage output as a function of the temperature, in the range of $-40^{\circ}C$ to $70^{\circ}C$ was recorded. Fig. 4 shows the result of the simulation .

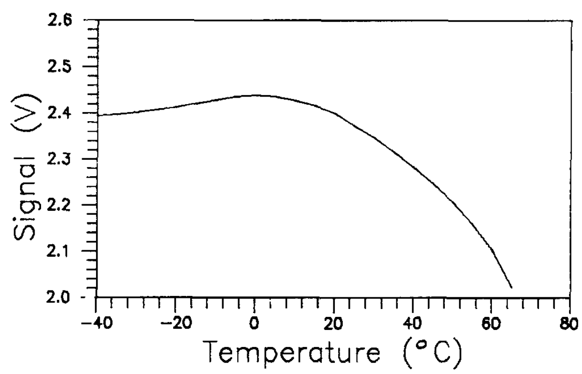

Fig. 4. V-T experimental curve of the solar cell array.

The solar cell parameters are obtained from eqn. 9 after the fit of curve in fig. 4, which are :
$I_L[300K] = 82.7$ mA , $CI_L = 0.055$ %/K , $E_g = 1.125$ eV , $C_{01} = 2.3.10^4$ mA/K^3 , $C_{02} = 2.6$ $mA/K^{3/2}$, A[300K] = 1.954 , CA = 0.126 %/K , $R_S[300K] = 0.0644$ ohm , $CR_S = 0.70$ %/K , $R_P[300K] = 3.3.10^4$ ohm , and $CR_P = 0.13$ %/K .

It is possible, with eqn. 1, correcting I_L for the AM0 value, to determine the values of the output parameters at 27°C (the Heinamaki and Guekos attenuation factor used in this work is 0.92). Table 1 shows the average output parameters values of the solar cells of the experiment.

TABLE 1.

Comparison between the output parameters of the IxV curve obtained by the method and by direct measurements.

Output Parameter	Obtained from VxT curve fit	Obtained from direct measurements
I_{sc}(mA)	144.2	144.7 ± 5.1
V_{oc}(mA)	538.5	555.0 ± 11.4
I_{max}(mA)	131.3	133.4 ± 5.3
V_{max}(mV)	440.3	459.7 ± 11.3
FF	0.744	0.764 ± 0.012
η(%)	10.84	11.51 ± 0.69

CONCLUSIONS

The comparison of the value in table 1 shows that this method, described for the first time, is very convenient to evaluate the performance of the solar cells during the satellite mission life. Discrepancies found in the V_{oc} and V_{max} values are probably originated from the thermistor temperature readings since the thermal inertia in the temperature rise during the VxT curve experimental determination (see fig. 4), was not taken into account. A simulation of the influence of systematic and random errors in the evaluation of the conversion efficiency by the fit of the VxT curve is being done. Also, a criterion for the selection, or the compensation, of the telemetered data susceptible of albedo radiation influence is being studied.

This work shows the feasibility of low cost, highly reliable, solar cells performance experiments during the satellites mission life.

REFERENCES

[1] D. H. Walker and R. L. Statler, A satellite experiment to study the effects of space radiation on solar cell power generation. Solar Cells, 23(1988), p. 245.

[2] C. Huang, Q. Wang and Q. Jiang, Solar cell calibration experiment on chinese scientific satellite. Proc. of the Eighteenth IEEE Phot. Spec. Conf., Las Vegas, 1985, p. 634.

[3] H. J. Hovel, Solar Cell in: R. K. Willardson and A. C. Beer, Semiconductors and Semimetals. Academic Press Inc., New York, Vol. 11, 1976.

[4] H. S. Rauschenbach, Solar cell array design handbook, Van Nostrand Reinhold Company, New York, 1980.

[5] M. Wolf, G. T. Noel and R. J. Stirn, Investigation of the double exponential model in the current-voltage characteristics of silicon solar cell, IEEE Trans. on Electron Devices, Vol. ED-24(4), 1977, p. 419.

[6] A. Heinamaki and G. Guekos, Solar cell short-circuit current dependence on the angle of the incident radiation, Solar Cells, 20 (1977), p. 65.