Kinetik: Game Technology, Information System, Computer Network, Computing, Electronics, and Control
Journal homepage: http://kinetik.umm.ac.id
ISSN: 2503-2267
Vol. 7, No. 1, February, Pp. 23-34

Design and simulation of low power and voltage micro photovoltaic cell for smartphones

Ikbal Rullah*[1], Robby Kurniawan Harahap[2], Eri Prasetyo Wibowo[3], Antonius Irianto Sukowati[4], Dyah Nur'ainingsih[5], Widyastuti[6]
Magister of Electrical Engineering, Gunadarma University, Indonesia[1]
Department of Electrical Engineering, Gunadarma University, Indonesia[2,5,6]
Department of Informatics Engineering, Gunadarma University, Indonesia[3]
Department of Informatics Engineering, Cendekia Abditama University, Indonesia[4]

Article Info
Keywords:
CMOS, Micro Solar Cell, Photovolaic, Low Power, Low Voltage

Article history:
Received: November 08, 2021
Accepted: January 15, 2022
Published: February 28, 2022

Cite:
I. Rullah, R. K. Harahap, E. P. Wibowo, A. I. Sukowati, D. Nur'ainingsih, and W. Widyastuti, "Design and Simulation of Low Power and Voltage Micro Photovoltaic Cell for Mobile Devices ", *KINETIK*, vol. 7, no. 1, pp. 23-34, Feb. 2022.
https://doi.org/10.22219/kinetik.v7i1.1355

*Corresponding author.
Ikbal Rullah
E-mail address:
rullahikbal@gmail.com

Abstract
In this study, designed and simulated a micro photovoltaic cell circuit which is part of smartphone battery charging system sensor. Problem discussed in this paper was that smartphone are still charging battery from PLN through a wall outlet, but smartphone would be better off if it had other charging alternatives, such as being able to charge anywhere or mobile. This paper proposed used photovoltaic cell that can convert sunlight into electricity and it can charge the battery on a smartphone. Photovoltaic cell were integrated with smartphone batteries in photovoltaic IC to form a battery charging system that can charge smartphone. The design of the micro photovoltaic cell sensor section is based on from the references paper. Micro photovoltaic cell was design by modifying the resistor value in the micro photovoltaic cell circuit, so the output low voltage and power be able to charge the smartphone battery. Designed and simulated micro photovoltaic cell circuits will be carried out using LTSpice. The results that achived in this research, when shunt resistance value was configure negative, the voltage value around 200mV, the power value around 1,48µW. When the shunt resistance value was configured positive the voltage value around 199mV, the power value around 1,44µW. Analysis was carried out by comparing voltage values obtained in this study with previous studies. In this study, a smaller voltage value was obtained by modifying the resistor value in the micro photovoltaic cell circuit. The circuit design will later be implemented in 0.35µm CMOS technology.

1. Introduction
Batteries are one of the energy sources used in various modern technologies, such as smartphones. The battery on a smartphone has a relatively small storage capacity because it adjusts to the size of the smartphone produced by the manufacturer. Smartphones have become a human need because they are always operated, as a result smartphones that have a small battery capacity run out quickly. Because of that smartphones need to charge the battery regularly using a direct power supply from PLN through a wall outlet. Charging the smartphone battery using a wall outlet is less effective because to charge the smartphone battery there is still a certain point where there is an outlet, so that if the battery capacity runs out, the smartphone cannot be operate. The problems discussed in this study are the need for alternative technologies that can charge smartphone batteries without using PLN electricity through a wall outlet, so that charging smartphone battery can be carried out on a mobile basis and the technology can be integrated with smartphones.

Research in the field of renewable energy produces various innovations by utilizing natural energy, such as sunlight, wind, and others, which have increased rapidly in recent years. Photovoltaic cell or photovoltaic devices that use solar energy, are one of the innovations in the field of renewable energy. Photovoltaic cell can be used to convert sunlight energy into electrical energy, so that it can charge smartphones. Utilizing sunlight for charging smartphone batteries makes smartphones able to charge mobile batteries anywhere that is exposed to sunlight.

Several studies have been carried out using photovoltaic cell technology in the form of Integrated Circuit (IC) electronic components. In research conducted by Arima and Ehara, designed and developed a on-chip solar battery using 0.35µm CMOS technology, getting a voltage around 600-830mV [1]. In research conducted by Ferri et al., designed and developed an equivalent circuit for a micro photovoltaic cell based on 0.35µm CMOS technology and the resulting voltage was around 494 mV [2][3]. In addition, research conducted by Wang et al., designed and developed a solar cell to charge Li-ion batteries with a capacity of 1,8V used 0.25µm CMOS technology, the resulted voltage was around 650mV [4].

Based on the research that has been discussed previously, it can be used as a reference for solution in this study. The solution is to use photovoltaic cell technology to charge the smartphone battery, which is then integrated with smartphones with CMOS technology. Integration of the smartphone battery and photovoltaic cell is carried out with a photovoltaic IC. This study designed and simulated the sensor part of a photovolaic IC, namely a micro photovoltaic cell to charge the battery on a smartphone. The purpose of this research is to design a micro photovoltaic cell circuit based on the research circuit reference paper by modifying the resistor value, so that the output can reach a power of around 1.5µW and a voltage of around 200mV [2], with the support of reference [1][3][4]. Later, the series of micro photovoltaic cell will be implemented into 0.35µm CMOS technology. Micro photovoltaic cell are designed to provide energy supply for smartphone battery charging systems with low power and low voltage in order to save energy. LTSpice is used to design and simulate micro photovoltaic cell circuits.

2. Research Method

2.1 Photovoltaic Cell Model

A Photovoltaic cell (PV), is a device made of semiconductor material that can convert sunlight into electrical energy so that it can provide electrical energy to load devices. Photovoltaic cell material is made of semiconductor material consisting of p-n junctions. The p-n junction has two forming materials, namely n-type material and p-type material. In photovoltaic cell, n-type material is made using phosphorus material because the material has one free electron, while p-type material is made using boron material because the material lacks one free electron. The phenomenon that occurs in boron material is called a hole [5].

Measurements on the characteristics of photovoltaic cells are generally carried out analytically, based on mathematical equations from the photovoltaic cell datasheet from the manufacturer which will be used as a reference. Performing mathematical equation modeling analysis on photovoltaic cell, so that the results achieved are more accurate than direct measurements on a photovoltaic cell [6][7]. The requirements that must be possessed in design photovoltaic cell are mandatory to use the STC (Standard Test Condition), where the requirements that must be met are a temperature of 25°C and solar radiation of 1.000 W/m^2 [8].

2.2 Photovoltaic Cell Equivalent Circuit

A photovoltaic cell equivalent circuit is a method needed to design a photovoltaic cell by using a combination of electrical components to create an electrical circuit that has performance characteristics equivalent to those of a photovoltaic cell. The simplest photovoltaic cell equivalent circuit is the ideal photovoltaic cell, a circuit that ignores the internal resistance of the photovoltaic cell device. The components used to design the ideal photovoltaic cell equivalent circuit are current source and diode. Therefore, in an ideal photovoltaic cell equivalent circuit, current flows only through the diode [9][10]. A figure of the equivalent photovoltaic cell circuit can be seen in Figure 1.

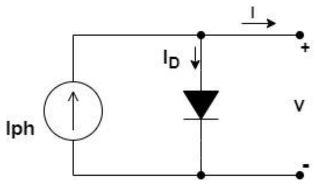


Figure 1. Ideal Photovoltaic Cell Circuit

In the ideal photovoltaic cell equivalent circuit because ignores the internal resistance of the photovoltaic cell, the ideal photovoltaic cell equivalent circuit is rarely used because it is not practical. Therefore, to represent the internal resistance of the photovoltaic cell, series resistance and shunt resistance are used. The solution needed to overcome this problem is to use photovoltaic cell equivalent circuit consisting of one diode and two resistors. This photovoltaic cell equivalent circuit consisting of one diode and two resistors has five parameters known as 1M5P (Single mechanism, five parameters). The equivalent circuit of a 1M5P photovoltaic cell is made by combining a current source component connected in parallel with a diode and two resistors, namely series resistance and shunt resistance [11]. Figure 2 shows the equivalent circuit of a photovoltaic cell with a diode and two resistors.

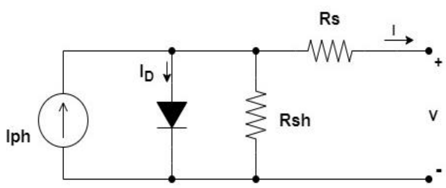


Figure 2. Photovoltaic Cell 1M5P Circuit

© 2022 The Authors. Published by Universitas Muhammadiyah Malang
This is an open access article under the CC BY SA license. (https://creativecommons.org/licenses/by-sa/4.0/)

Figure 3 shows the characteristics of I-V curve, which consists of three important points on this curve, namely current short circuit (Isc), voltage open circuit (Voc) and power maximum point (Pmp). These three points are included in the solar manufacturing datasheet information for photovoltaic cell [12].

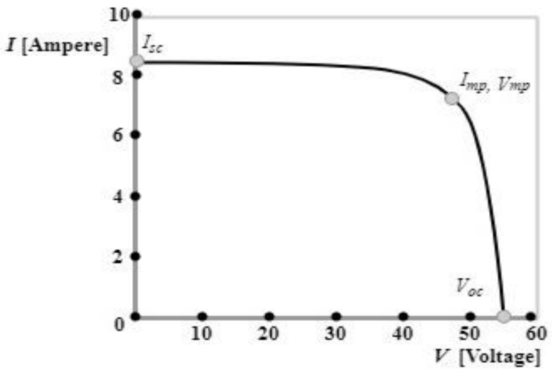


Figure 3. Photovoltaic cell I-V Curve Characteristics

The characteristics of the I-V curve shown in Figure 3 are contained in the equivalent circuit of a solar cell with one diode and two resistors in Figure 2, the Equation 1 can be defined as follows.

$$I = Iph - Io\left(exp\left(\frac{V + IRs}{a\,V_T}\right) - 1\right) - \frac{V + IRs}{Rsh} \quad (1)$$

Where, Thermal Voltage (V_T):

$$V_T = \frac{kT}{q} \quad (2)$$

Based on Equation 1, it can be explained that Iph is a current source that provides the photocurrent to other components, Io is the reverse saturation current found in the diode [13], Rsh (shunt resistance) is a representation of losses that occur due to leakage of electric current through a semiconductor that has a conductivity high at the p-n junction [14], Rs (series resistance) is a representation of losses due to the resistance contained in the semiconductor material [15], α is the ideality factor used in calculating the deviation of the diode based on the Shocley diffusion theory [16][17]. In Equation 2, where the parameter k is the value of the Boltzmann constant, the parameter T is the temperature value in kelvins, and the parameter q is the electron charge [18].

In the reference paper [8], the author state that it is very important to obtain the five parameters of the photovoltaic cell equivalent circuit. There are five parameters owned by the photovoltaic cell equivalent circuit [11]. It is possible to use the following Equation 3, Equation 4, Equation 5, Equation 6, Equation 7, Equation 8, Equation 9, Equation 10, and Equation 11.

- Current Short Circuit (Isc)

$$I_{SC} = Iph - Io\left(exp\left(\frac{Isc\,Rs}{a\,V_T}\right) - 1\right) - \frac{Isc\,Rs}{Rsh} \quad (3)$$

- Voltage Open Circuit (Voc)

$$Voc = \frac{kT}{q}a\,ln\left(\frac{Isc}{Io} + 1\right) \quad (4)$$

- Power Maximum Point (Pmp)

$$Pmp = Vmp\ x\ Imp \quad (5)$$

- Reverse Saturation Current (Io)

$$I_o = \frac{(Rsh + Rs)Isc - Voc}{R_{sh}\, exp(\frac{Voc}{a\, V_T})} \tag{6}$$

- Series Resistance (Rs)
  The series resistance value requires an explicit equation calculation, but even though that can use an implicit equation, there is an easier way to convert it into an explicit equation by using the Lambert W-function [11][14][15].

$$Rs = A\,(W_{-1}\,(B\, exp(C)) - (D + C) \tag{7}$$

Where:

$$\begin{aligned} A &= \frac{a\, V_T}{I_{mp}} \\ B &= -\frac{V_{mp}\,(2I_{mp} - I_{sc})}{(V_{mp}\, I_{sc} + V_{oc}\,(I_{mp} - I_{sc})} \\ C &= -\frac{2V_{mp} - V_{oc}}{a\, V_T} + \frac{(V_{mp}\, I_{sc} - V_{oc}\, I_{mp})}{(V_{mp}\, I_{sc} + V_{oc}\,(I_{mp} - I_{sc})} \\ D &= \frac{V_{mp} - V_{oc}}{a\, V_T} \end{aligned} \tag{8}$$

- Shunt Resistance (Rsh)

$$Rsh = \frac{(Vmp - Imp\, Rs)(Vmp - Rs\,(Isc - Imp) - a\, V_T)}{(Vmp - Imp\, Rs)(Isc - Imp) - a\, V_T\, Imp} \tag{9}$$

- Fill Factor (FF)
  The fill factor value is used as a reference for the quality of the photovoltaic cell and if the fill factor value is closer to 1, the greater the power that can be supplied by the photovoltaic cell [19].

$$FF = \frac{Pmp}{Voc\ x\ Isc} \tag{10}$$

- Efficiency
  Efficiency is the ratio of energy output from photovoltaic cell to energy input from sunlight. Efficiency depends on sunlight and temperature in the photovoltaic cell [20].

$$\eta = \frac{Voc\ x\ Isc\ X\ FF}{Pin} \tag{11}$$

2.3 Design Concept

The designed solar cell is part of the sensor of photovoltaic IC as a smartphone battery charging system. In this research on on-chip battery charging systems, the focus will be on designing and simulating micro photovoltaic cell based on references paper [2]. by modifying the resistor value. The designed micro solar cell will later be implemented into 0.35µm CMOS technology [21].

Figure 4 shows the design concept of the on-chip battery charging system on a smartphone. The part of the micro photovoltaic cell system is used as power input by converting sunlight energy into electrical energy, then the electrical energy is channeled to the charge pump system. In the system part, the charge pump is used as a system that accommodates electrical energy supplied by the micro photovoltaic cell system with a voltage of about 200 mV [22]. The micro phovoltaic cell system will cycle supply voltage to the charge pump system so that it reaches a predetermined threshold of around 5V. The charge pump system has accommodated the voltage according to the threshold, then the voltage will be supplied to the smartphone battery. If the charge pump system voltage has not reached the threshold,

© 2022 The Authors. Published by Universitas Muhammadiyah Malang
This is an open access article under the CC BY SA license. (https://creativecommons.org/licenses/by-sa/4.0/)

then the voltage will not be supplied to the smartphone battery [23]. The battery charging process will continue as long as there is sunlight. This research will focus more on the system micro photovoltaic cell.

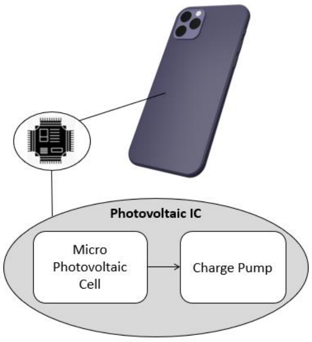


Figure 4. Smartphone Battery Charging System Design On-Chip

2.4 Schematic Design

The first step in design micro photovoltaic cell equivalent circuit is to design an ideal micro photovoltaic cell equivalent circuit. The circuit is needed to measure the Vmp and Imp values that will be needed in the formulation to calculate the series resistance and shunt resistance values.

Figure 5 shows the positioning of the 3 components that make up the ideal micro photovoltaic cell equivalent circuit. In addition, label information is given to components in the LTSpice software [24], labeling important components is done to make it easier to provide parameter values. The components that are labeled based on Figure 5 are the current source labeled "Iph", the diode is labeled "DiodeSC" and the load is labeled "RL". The parameter values assigned to the components using the spice directive command correspond to the values referred to by references and calculations performed in the previous section.

The next step is to measure the value of the Vmp and Imp parameters using the spice directive command. The spice directive command used to calculate the two parameters, namely ".measure Vmp FIND V1 WHEN I(V1)*V1 = Pmp" is used to measure the maximum voltage point value, and ".measure Imp param Pmp/Vmp" is used to measure the current maximum point value. Figure 8 is a schematic of an ideal micro photovoltaic cell after the circuit components are given parameter values and measurement commands with the spice directive.

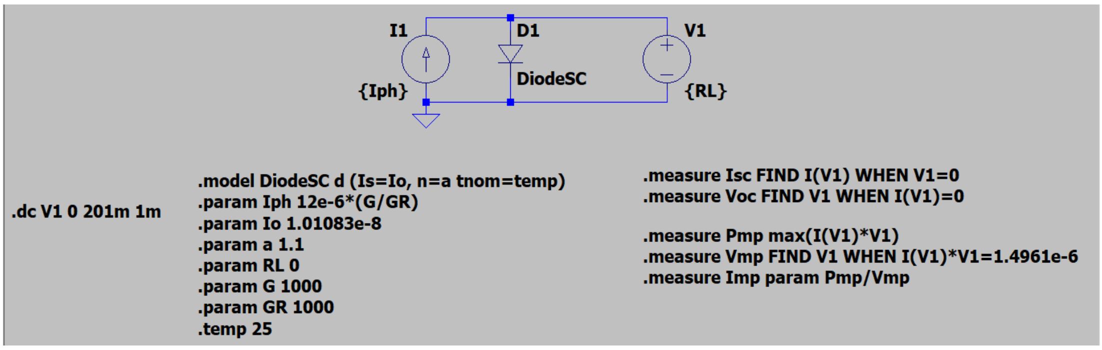


Figure 5. Ideal Micro Photovoltaic Cell Schematic

The ideal micro photovoltaic cell equivalent circuit has a weakness, there is no representation of the losses contained in the physical form of the micro photovoltaic cell. In overcoming the problem of representation of losses, a resistor component is used to represent the losses contained in the physical form of the micro photovoltaic cell. The equivalent circuit of a micro photovoltaic cell consists of a combination of components, namely a current source, a diode and two resistors (series resistance and shunt resistance). The micro photovoltaic cell circuit has five parameters which can be known as 1M5P (Single mechanism, five parameters) [2].

In Figure 6, the LTSpice software shows that there are five forming components used in the equivalent circuit of a micro photovoltaic cell. In addition, label information is given on the components in the LTSpice software, the same as in the ideal micro photovoltaic cell equivalent circuit, but there are additional components, namely series resistance, which is labeled "Rs", and shunt resistance, which is labeled "Rsh". The shunt resistance calculation resulted in a negative value. Since there is no negative resistor value, the value of the shunt resistor will be made positive so that the resistor value will be $1{,}2223 \times 10^6$, this value is used to compare the value of shunt resistance in the formula.

The parameter values given to the micro photovoltaic cell equivalent circuit are based on the values contained in the reference and there are several parameters that are carried out using calculations and to label the parameters on the component using the spice directive command. Figure 6 is a schematic of a micro photovoltaic cell.

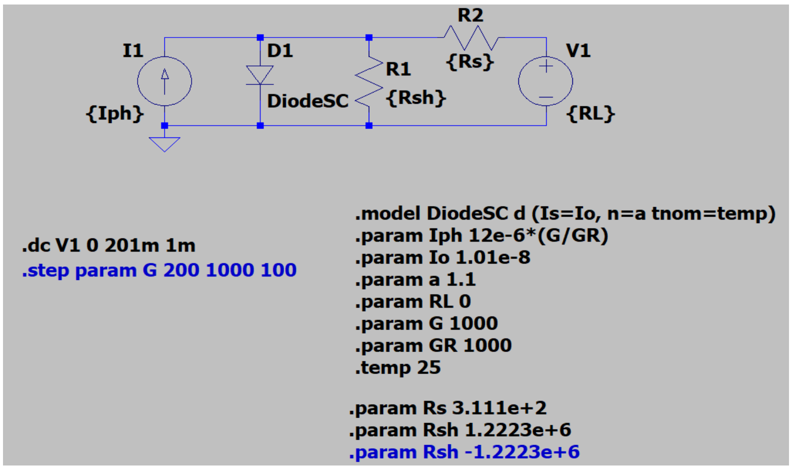


Figure 6. Micro Photovoltaic Cell Schematic

2.5 Simulation Design

The tests will be carried out in a simulation by monitoring the output results in the form of graphs and measuring parameter values in the circuit using the spice directive command. In the output graph, there will be three outputs, namely the value of the open circuit voltage, the value of the current short circuit and the value of the maximum power point. Apart from the output graph results, the output parameter values are obtained using the spice directive command, which is used to measure the parameters needed in the study. In Figure 7 is the spice directive command used to measure the simulation results.

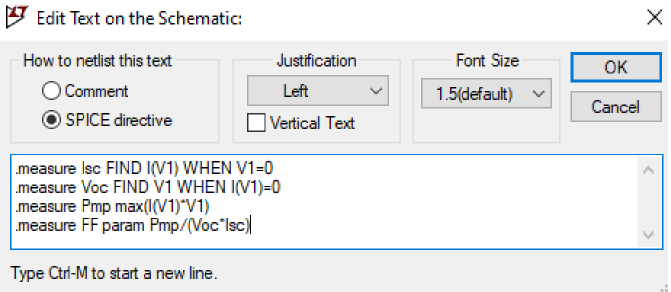


Figure 7. Spice Directive Measuring Output

In the spice directive command "measure Isc FIND I(V1) WHEN V1 = 0" is used to measure the current short circuit value, because the Isc output value is obtained when the micro photovoltaic cell equivalent circuit is in a short-circuit condition or with a value of I = Isc and for the value of V = 0. Measuring the open circuit voltage value, "measure Voc FIND V1 WHEN I(V1)=0" is used because the Voc output value is obtained when the micro photovoltaic cell equivalent circuit is in an open-circuit or with a value of I = 0 for the value of V = Voc. ".measure Vmp FIND V1 WHEN I(V1)*V1 = Pmp" is used to measure the maximum value of the power in the circuit. The spice directive command to measure the fill factor (FF) is used to determine the quality of the micro photovoltaic cell using Equation 10.

In the last stage of testing the micro photovoltaic cell, which is to find the efficiency value of the micro photovoltaic cell. Efficiency testing is done manually using Equation 11. Calculating the efficiency value requires the dimensions of the cell area of the micro photovoltaic cell, to get the cell dimensions area an assumption is used based on references from manufacturers who make chips with CMOS technology [25]. The assumption used for the dimensions of the cell is 1mm^2 with a power input of 10mW.

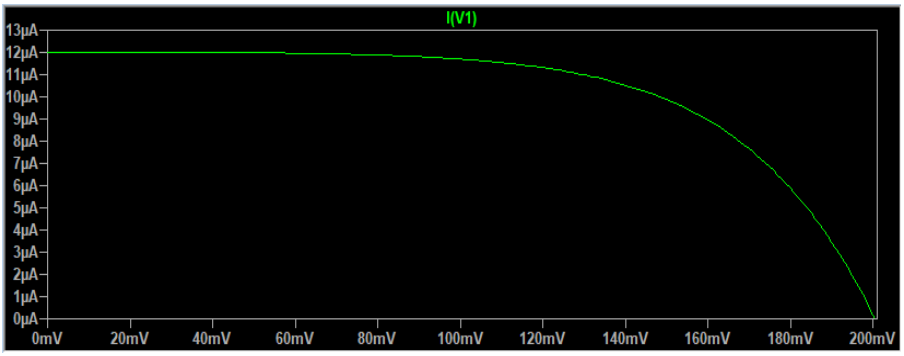
3. Results

3.1 Micro Photovoltaic Cell Curve Simulation

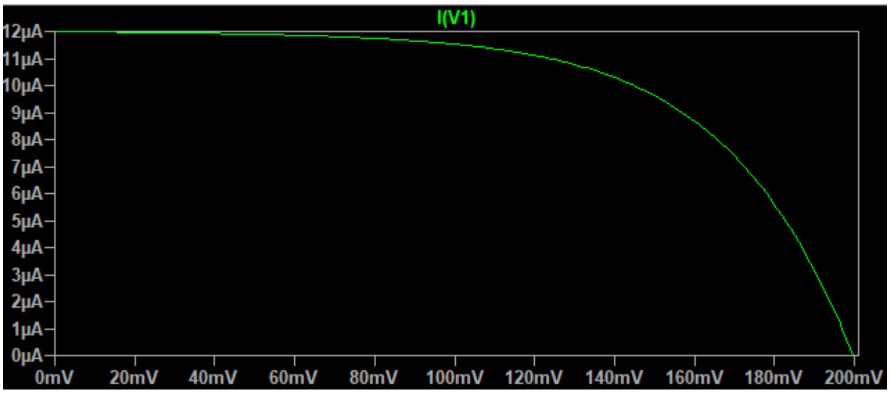
In Figure 8, the graph of micro photovoltaic cell I-V curve is the result obtained when carried out tests in accordance with the Standard Test Condition(STC) where the temperature value used is 25°C and the irradiance value used is 1000 W/m^2 [8]. Based on Figure 8(a) and Figure 8(b), the I-V curve, on the x-axis is the parameter of the open

© 2022 The Authors. Published by Universitas Muhammadiyah Malang
This is an open access article under the CC BY SA license. (https://creativecommons.org/licenses/by-sa/4.0/)

voltage circuit (Voc) with a value range of 0 mV to 200 mV, while the y-axis is the parameter of the current short circuit (Isc) with a value range of 0 µA to 12 µA. Based on Figure 8(a) and Figure 8(b), the output of the I-V curve shows that if the value of the Voc parameter increases, the value of the Isc parameter will decrease, this phenomenon is in accordance with the characteristics of the I-V curve in general.



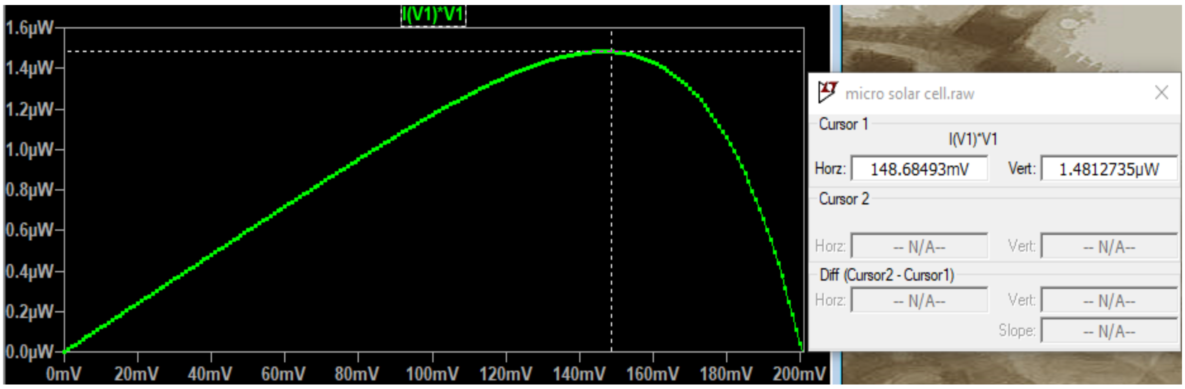
(a)



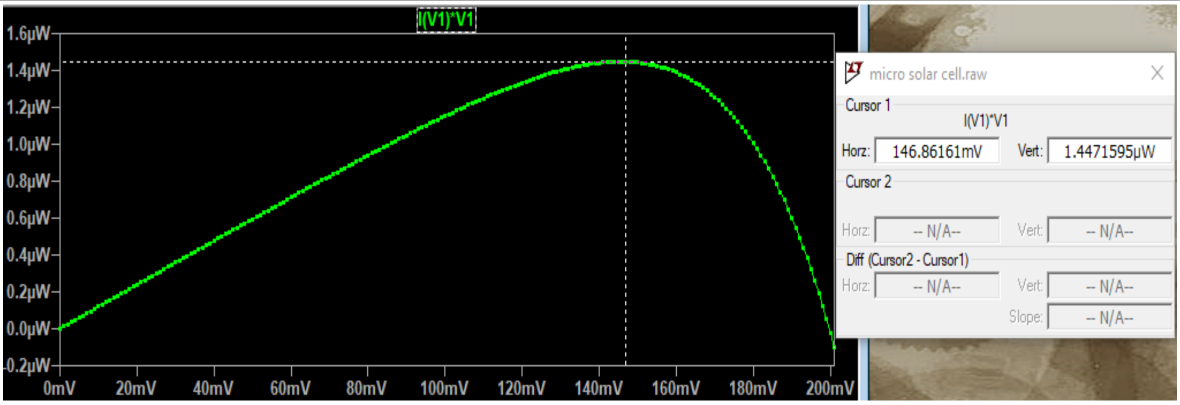
(b)

Figure 8. Micro Photovoltaic Cell I-V Curve. (a) Configure Rsh Value Negative. (b) Configure Rsh Value Positive

Figure 9 is a graph of the P-V curve of a micro photovoltaic cell, the results obtained are based on tests carried out according to the STC where the temperature value is 25°C with an irradiance value of 1000W/m² [8]. Based on Figure 9, the P-V curve, the x-axis is the parameter value of Voc with a value range of 0mV to 200mV, while the y-axis is the parameter value of the power maximum point (Pmp) with a value range of 0µW to 1,6µW. Based on the P-V curve in Figure 9, when the voltage value increases in Figure 9(a), the power value increases as well until the power maximum point (pmp) value is reached, which in this case is 1,48µW with a voltage value of 148 mV, but the power value will decrease after passing the pmp value. The rated power will decrease until it reaches 0µW when the rated voltage is 200mV. The condition P-V curve in Figure 9(b) is the same as the condition P-V curve in Figure 9(a) but the difference is that the pmp value obtained is 1,44µW with a voltage value of 146mV.



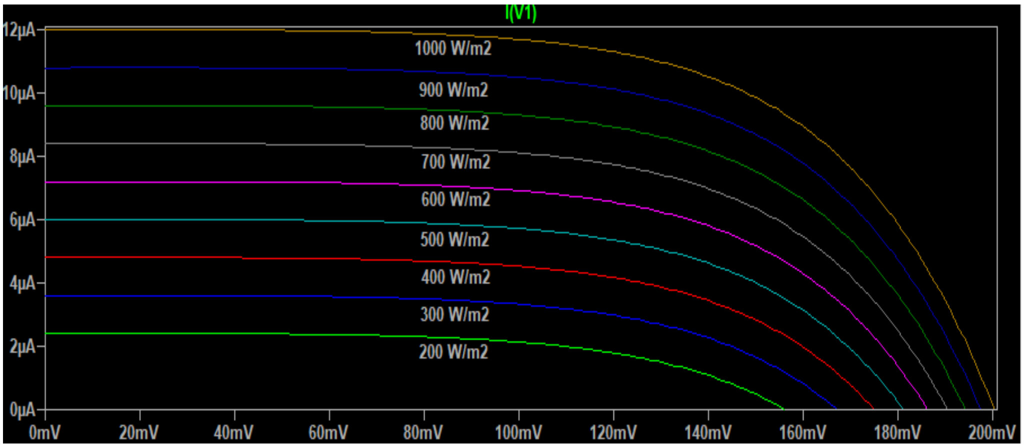
(a)



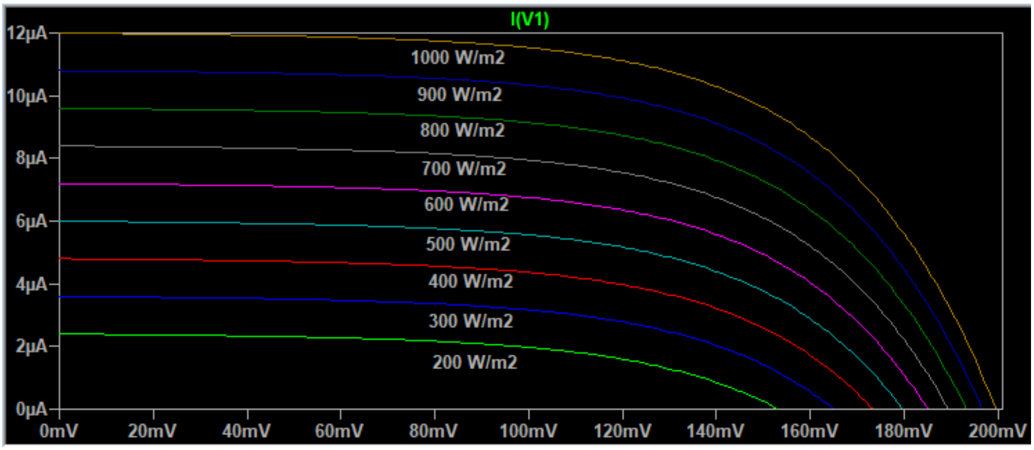
(b)

Figure 9. Micro Photovoltaic Cell P-V Curve. (a) Configure Rsh Value Negative. (b) Configure Rsh Value Positive

Based on the I-V curves in Figures 10(a) and Figure 10(b), which show the same phenomenon caused by changes in irradiance level, which affect the output voltage and current values. Figure 10(a) depicts the effect of changes in irradiance levels on output voltage and current values, where the lowest irradiance value is 200W/m^2, the output voltage is around 156mV, and the current is around 2,4µA, while the highest irradiance is 1000W/m^2, the voltage is around 200mV, and the current is around 12µA.In Figure 10(b) the effect caused by changes in the irradiance level is the same as in Figure 10(a), but the difference is in the value with the lowest irradiance level of 200W/m^2, the output voltage obtained is around 153mV and the current obtained is around 2,3µA, whereas with the highest irradiance level of 1000W/m^2, the output voltage obtained is around 199mV and current obtained is around 11,9µA.



(a)



(b)

Figure 10. Irradiance at Various Levels. (a) Configure Rsh Value Negative. (b) Configure Rsh Value Positive

© 2022 The Authors. Published by Universitas Muhammadiyah Malang
This is an open access article under the CC BY SA license. (https://creativecommons.org/licenses/by-sa/4.0/)

3.2 Parameter Value Test

Parameter value test that uses the spice directive command suitable for measuring parameters, namely Voc, Isc, Pmp and FF. Based on Figure 11(a) and Figure 11 (b), the output parameter measurement results, measurements on the Isc parameter are carried out on the label "i(v1)" which is to measure the current in the v1 component of the micro photovoltaic cell schematic, where the v1 component is the load. Voc measurements are carried out on the label "v1" which is measuring the voltage on the v1 component on the micro photovoltaic cell schematic where the v1 component is the load.

Pmp measurement uses the label "max(i(v1)*v1)", namely by measuring the power in the v1 component, which is the load. The calculation of the FF parameter is done by dividing the value of the Pmp parameter by the value of the product of the Voc parameter and the Isc parameter. Table 1 is the result of parameter measurement when the Rsh value is negative and Table 2 is the result of parameter measurement when the Rsh value is positive.

```
isc: i(v1)=1.20016e-005 at 0
voc: v1=0.200501 at 0.200501
pmp: MAX(i(v1)*v1)=1.48241e-006 FROM 0 TO 0.201
ff: pmp/(voc*isc)=0.616042
```

(a)

```
isc: i(v1)=1.19955e-005 at 0
voc: v1=0.199731 at 0.199731
pmp: MAX(i(v1)*v1)=1.44751e-006 FROM 0 TO 0.201
ff: pmp/(voc*isc)=0.604167
```

(b)

Figure 11. Output of Measurement Parameter. (a) Configure Rsh Value Negative. (b) Configure Rsh Value Positive

Table 1. Parameters Measurement Output when Configure Rsh Value Negative

Parameter	Value	Unit
Voltage Open Circuit (Voc)	200,501	mV
Current Short Circuit (Isc)	12,00016	µA
Power Maximum Point (Pmp)	1,48241	µW
Fill Factor (FF)	0,616042	

Table 2. Parameters Measurement Output when Configure Rsh Value Positive

Parameter	Value	Unit
Voltage Open Circuit (Voc)	199,731	mV
Current Short Circuit (Isc)	11,9955	µA
Power Maximum Point (Pmp)	1,44751	µW
Fill Factor (FF)	0,604167	

Efficiency testing is carried out to see the ratio of the input between the energy output of the micro photovoltaic cell to sunlight. The calculation of the efficiency of the micro photovoltaic cell requires the area dimensions of the cell, because in this paper the research carried out is still at the limit of the simulation stage. Therefore, the value of the cell dimensions will be carried out using assumptions, based on references from chip manufacturers that use CMOS technology. The dimensions of the cell, $1mm^2$ to $5mm^2$, are the values of the cell dimensions area that are used as assumptions [25]. Meanwhile, the power input value used for the cell dimensions area with a size of $1mm^2$ is about 10mW [20]. The following table are the result of the assumption of manual efficiency calculations where Table 3 when shunt resistance is negative and Table 4 when shunt resistance is positive.

Table 3. Efficiency Micro Photovoltaic cell when Configure Rsh Value Negative

Cell Dimension Area (mm^2)	Efficiency (%)
1	1,4784
2	0,7392
3	0,4928
4	0,3696
5	0,2957

Table 4. Efficiency Micro Photovoltaic cell when Configure Rsh Value Positive

Cell Dimension Area (mm^2)	Efficiency (%)
1	1,4414
2	0,7207
3	0,4805
4	0,3603
5	0,2883

Cite: I. Rullah, R. K. Harahap, E. P. Wibowo, A. I. Sukowati, D. Nur'ainingsih, and W. Widyastuti, "Design and Simulation of Low Power and Voltage Micro Photovoltaic Cell for Mobile Devices ", KINETIK, vol. 7, no. 1, pp. 23-34, Feb. 2022. https://doi.org/10.22219/kinetik.v7i1.1355

3.3 Analysis

Comparing the output voltage results in previous studies which were used as a reference with the output voltage results obtained in this study, it is possible to analyze the results of the micro photovoltaic cell circuit design. In a study conducted by Ferri, the micro photovoltaic cell was designed using 0.35µm CMOS technology, the output voltage obtained was around 494mV [2][3]. Research conducted by Arima and Ehara, by designing a on-chip solar battery based on 0.35µm CMOS technology which is integrated so that it becomes a chip, the voltage obtained is 600-830mV [1]. Research conducted by Wang, by designing a solar cell using 0.25µm CMOS technology to charge a Li-ion battery with a capacity of 1,8V, the output voltage obtained is around 650mV [4]. In this study, with the design and simulation of the micro photovoltaic cell circuit, the voltage obtained when the value of shunt resistance negative is around 200mV while when the value of shunt resistance positive is around 199mV.

The analysis was carried out by comparing the output voltage of this study with the references of previous studies. In Table 5, the comparison of the output voltage results obtained in this study is smaller with a micro photovoltaic cell circuit whose resistor value has been modified, which will later be implemented in 0.35µm CMOS technology.

Table 5. Output Voltage Comparison

Research	Value	Unit
Ferri	494	mV
Arima and Ehara	650	mV
Wang	600-830	mV
Ikbal	199-200	mV

4. Conclusion

The equivalent circuit of a micro photovoltaic cell is designed based on a reference paper by modifying the resistor value which will then be implemented later on in 0.35µm CMOS technology. Based on the test results, when the shunt resistance value is configured negative around -1,22MΩ, the output voltage value is around 200mV, the current value is around 12µA and the power value is around 1,48µW. When the shunt resistance value is configured positive around 1,22MΩ, the output voltage value is around 199mV, the current value is around 11,99µA and the power value is around 1,44µW. In the test result of the output irradiance, the lower the level of the irradiance value, the output value of voltage and current decrease as well.

The analysis is obtained by comparing the output voltage value in this study with previous research which is used as a reference. In this study, the micro photovoltaic cell circuit has been modified so that the voltage value obtained is smaller, then the circuit design will later be implemented in 0.35µm CMOS technology.

The problem of charging the smartphone battery from PLN through a wall outlet that is still at a certain point. The technology uses a photovoltaic cell that is integrated with a smartphone via a photovoltaic IC to provide electrical energy supply to the smartphone battery charging system. Based on the research results obtained, a micro photovoltaic cell system can provide low voltage and power. The test output results of the micro photovoltaic cell system according to the input requirements of the charge pump system with a voltage of about 200mV, then the charge pump system will provide the voltage to the smartphone battery.

There are several suggestions for the development research in the field of micro photovoltaic cell, so that the further research can get better results. First add a test section to the micro photovoltaic cell circuit on the I-V curve and P-V curve using different temperature ranges using the polynomial with least square method in reference paper. Second develop micro photovoltaic cell research into materials for making micro photovoltaic cell physical forms and lastly make micro photovoltaic cell layouts.

Acknowledgement

The author would like to thank to Gunadarma University and the Ministry of Education and Culture, Research and Technology of the Republic of Indonesia (KEMENDIKBUD DIKTI) for supporting.

References

[1] Y. Arimata and M. Ehara, “On-chip solar battery structure for CMOS LSI,” *IEICE Electron. Express*, vol. 3, no. 13, pp. 287-293, 2006. https://doi.org/10.1587/ELEX.3.287
[2] M. Ferri, D. Pinna, E. Dallago and P. Malcovati, "A 0.35µm CMOS Solar energy scavenger with power storage management system," *2009 Ph.D. Research in Microelectronics and Electronics*, 2009, pp. 88-91. https://doi.org/10.1109/RME.2009.5201369
[3] M. Ferri, D. Pinna, M. Grassi, E. Dallago and P. Malcovati, "Model of integrated micro photovoltaic cell structures for harvesting supplied microsystems in 0.35-µm CMOS technology," *SENSORS, 2010 IEEE*, 2010, pp. 232-235. https://doi.org/10.1109/ICSENS.2010.5690466
[4] T. Wang, C. C. Huang, and T. J. Wang, “Solar battery charger in CMOS 0.25 um technology,” *International Journal of Automation and Smart Technology*, vol. 4, no. 2, pp. 99–103, 2014. https://doi.org/10.5875/ausmt.v4i2.431
[5] J. S. Kumari and C. S. Babu, ”Mathematical Modeling and Simulation of Photovoltaic Cell using Matlab-Simulink Environment,” *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 2, no. 1, 2011. https://doi.org/10.11591/IJECE.V2I1.117

© 2022 The Authors. Published by Universitas Muhammadiyah Malang
This is an open access article under the CC BY SA license. (https://creativecommons.org/licenses/by-sa/4.0/)

[6] R. Chenni, M. Makhlouf, T. Kerbache, and A. Bouzid, “A detailed modeling method for photovoltaic cells,” *Energy*, vol. 32, no. 9, pp. 1724–1730, 2007. https://doi.org/10.1016/J.ENERGY.2006.12.006
[7] E. Saloux, A. Teyssedou, and M. Sorin, “Explicit model of photovoltaic panels to determine voltages and currents at the maximum power point,” *Solar Energy85,* vol. 5, pp. 713–722, 2011. https://doi.org/10.1016/J.SOLENER.2010.12.022
[8] S. A. Afghan, H. Almusawi, and H. Geza,"Simulating the electrical characteristics of a photovoltaic cell based on a single-diode equivalent circuit model." *MATEC Web of Conferences*, vol. 126, 2017. https://doi.org/10.1051/MATECCONF/201712603002
[9] M. Azzouzi, D. Popescu, and M. Bouchahdane, "Modeling of electrical characteristics of photovoltaic cell considering single-diode model, " *Journal of Clean Energy Technologies*, vol. 4, no. 6, pp. 414–420, 2016. https://doi.org/10.18178/JOCET.2016.4.6.323
[10] M. G. Villalva, J.R. Gazoli, and E. R. Filho, "Comprehensive approach to modeling and simulation of photovoltaic arrays." *IEEE Transactions on power electronics*, vol. 24, no. 5, pp. 1198–1208, 2009. https://doi.org/10.1109/TPEL.2009.2013862
[11] J. Cubas, S. Pindado, and C. De. Manuel, “Explicit Expressions for Solar Panel Equivalent Circuit Parameters Based on Analytical Formulation and the Lambert W-Function,” *Energies,* vol. 7, no. *7*, pp. 4098–4115, 2014. . https://doi.org/10.3390/EN7074098
[12] A. Laudani, F. Riganti Fulginei, and A. Salvini, “High performing extraction procedure for the one-diode model of a photovoltaic panel from experimental I-V curves by using reduced forms,” *Solar Energy*, vol. 103, pp. 316–326, 2014. https://doi.org/10.1016/J.SOLENER.2014.02.014
[13] G. Wang, K. Zhao, T. Qiu, X. Yang, Y. Zhang, and Y. Zhao, ” The error analysis of the reverse saturation current of the diode in the modeling of photovoltaic modules,” *Energy*, vol. 115, pp. 478–485, 2016. https://doi.org/10.1016/J.ENERGY.2016.08.098
[14] *Series Resistance | PVEducation*. (n.d.). Retrieved September 16, 2021, from https://www.pveducation.org/pvcdrom/solar-cell-operation/series-resistance
[15] *Shunt Resistance | PVEducation*. (n.d.). Retrieved September 16, 2021, from https://www.pveducation.org/pvcdrom/solar-cell-operation/shunt-resistance
[16] C. Carrero, J. Amador, and S. Arnaltes, “A single procedure for helping PV designers to select silicon PV modules and evaluate the loss resistances,” *Renewable Energy*, vol.32*,* no. 15, pp. 2579–2589, 2007. https://doi.org/10.1016/J.RENENE.2007.01.001
[17] W. Xiao, W. G. Dunford, and A. Capel, “A novel modeling method for photovoltaic cells,” *PESC Record - IEEE Annual Power Electronics Specialists Conference*, vol. 3, pp. 1950–1956, 2004. https://doi.org/10.1109/PESC.2004.1355416
[18] P. M. Cuce and E. Cuce, “A novel model of photovoltaic modules for parameter estimation and thermodynamic assessment,”. *International Journal of Low-Carbon Technologies*, vol. 7, no. 2, pp. 159–165, 2012. https://doi.org/10.1093/IJLCT/CTR034
[19] *Fill Factor | PVEducation*. (n.d.). Retrieved September 16, 2021, from https://www.pveducation.org/pvcdrom/solar-cell-operation/fill-factor
[20] *Solar Cell Efficiency | PVEducation*. (n.d.). Retrieved October 25, 2021, from https://www.pveducation.org/pvcdrom/solar-cell-operation/solar-cell-efficiency
[21] R. Kurniawan and E. Prasetyo, “Konsep dan Metodologi Desain Analog CHIP -Berbasiskan Teknologi disertai Penggunaan Tool,” *TEKNOSAIN*, 2016.
[22] C. Steffan, P. Greiner, B. Deutschmann, C. Kollegger, and G. Holweg, “Energy harvesting with on-chip solar cells and integrated DC/DC converter,” *European Solid-State Device Research Conference*, *2015-November*, 142–145, 2015. https://doi.org/10.1109/ESSDERC.2015.7324733
[23] G. Nagy, D. Arbet, V. Stopjakova, and M. Kovac, “Novel CMOS bulk-driven charge pump for ultra low input voltage,” *Radioengineering*, vol. 25, no. 2, pp. 121–331, 2016. https://doi.org/10.13164/RE.2016.0321.
[24] Zolkefali, M. Z. B., & Ibrahim, M. N. “A simulation of single stage BJT amplifier Using LTSpice,” *e-Academia Journal, UiTM Press*, 2016.
[25] List, M. P. W. P. “From Layout to Chips 2021 MPW Price List,” *https://mycmp.fr*. *January*, 3–4, 2021.

© 2022 The Authors. Published by Universitas Muhammadiyah Malang
This is an open access article under the CC BY SA license. (https://creativecommons.org/licenses/by-sa/4.0/)