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FitAll

nonlinear regression analysis

Solar Cell Functions Guide

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Contents

Introduction 1

Function Reference 2

Ftn 0501: Dark Current-Voltage: Ideal........3
Ftn 0502: Dark Current-Voltage: Non-Ideal........7
Ftn 0503: Dark Current-Voltage: Sum of Ideal and Non-Ideal:........11
Ftn 0504: Dark I-V: Model 1A: High I-range........15
Ftn 0505: Dark I-V: Model 2A: Mid I-range........18
Ftn 0506: Dark I-V: Model 3A: Low I-range........22
Ftn 0507: Dark I-V: Model 4A: Full I-range........26
Ftn 0508: Dark I-V: Model 4E: Full I-range: 1 non-ideal diode........30
Ftn 0509: Light I-V: Rs = 0 and Rsh = ∞........33
Ftn 0510: Light I-V: Rs <> 0........36
Ftn 0511: Light I-V: Rs = 0........39
Ftn 0512: Dark Current-Voltage: Non-Ideal with Rs........42
Ftn 0513: Dark I-V: Model 1B: High I-range w/ Voltage Offset........46
Ftn 0514: Dark I-V: Model 1C: High I-range: "n" as a Parameter........49
Ftn 0515: Dark I-V: Model 2B: Mid I-range: 2 Non-Ideal Diodes........52
Ftn 0517: Dark I-V: Model 4B: Full I-range: 2 Non-Ideal Diodes........56
Ftn 0522: Dark I-V: Model 4D: Full I-Range: 2 Non-Ideal Diodes with Rs........60
Ftn 0524: Dark I-V: Model 1D: High I-range: w/ Voltage Offset........64
Ftn 0525: Dark I-V: Model 2C: Mid I-range w/ Voltage Offset........67
Ftn 0526: Dark I-V: Model 3B: Low I-range w/ Voltage Offset........71
Ftn 0527: Dark I-V: Model 4C: Full I-range: w/ Voltage Offset........74
Ftn 0528: Dark I-V: Model 4F: Full I-range: 1 non-ideal diode w/ V offset........78

Appendix 81

About Solar Cell-Strings, Modules, Module-Strings & PV Systems........82
Getting Help........87
Adding Functions to FitAll........88

Acknowledgments..89
Index 91

Introduction

This ***FitAll***™ **Solar Cell Functions Guide** describes the functions contained in the **Solar Cell Functions Library** and has an appendix that explains how to get help from ***MTR*** **Software**.

Function Reference 2

Appendix 81

Function Reference Overview

This section describes each of the functions in ***FitAll***'s Solar Cell Functions Library.

In most cases, a graph of the function is shown. These graphs were created using "typical" parameter and constant values.

The actual appearance of a function depends on the parameter and constant values and may look quite different from the illustrations shown.

Equation

Gives the equation and its variations. The variations are listed in order of increasing complexity.

Constants

Lists the constants, K, that are used in the function. The default values for the constants also are given.

Parameters

Lists the parameters, P, that are used in the function.

Multi-Fits

Describes the Multi-Fit functionality of "Multi-Fit enabled" functions.

Sample Applications

Gives examples of some situations in which the function is known to be used.

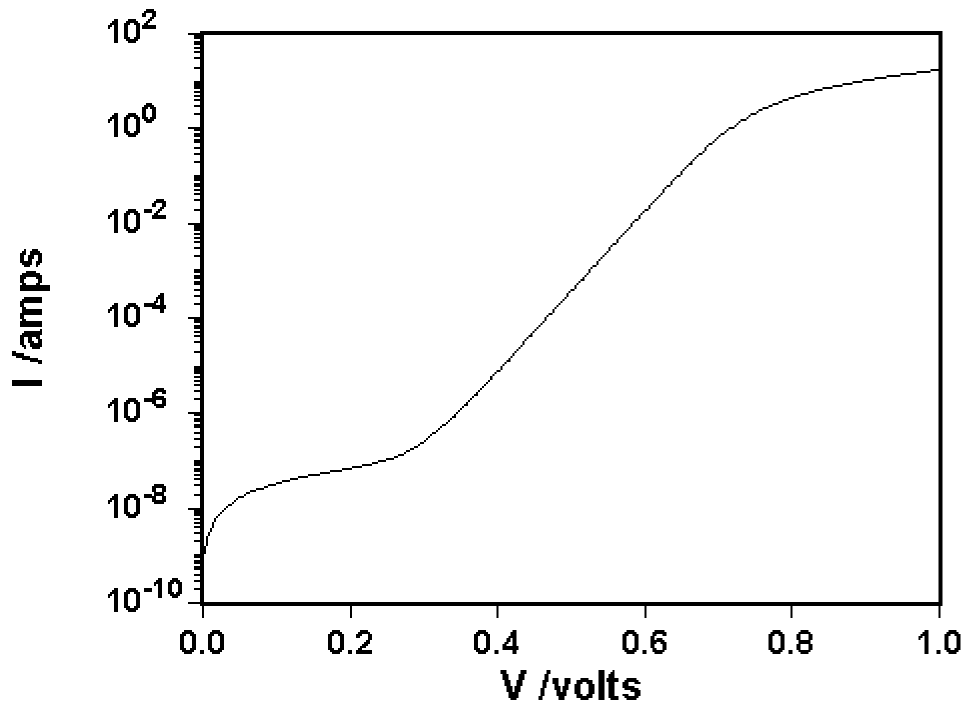
Remarks

Provides general comments and hints, and lists any known limitations or restrictions that should be observed when using the function.

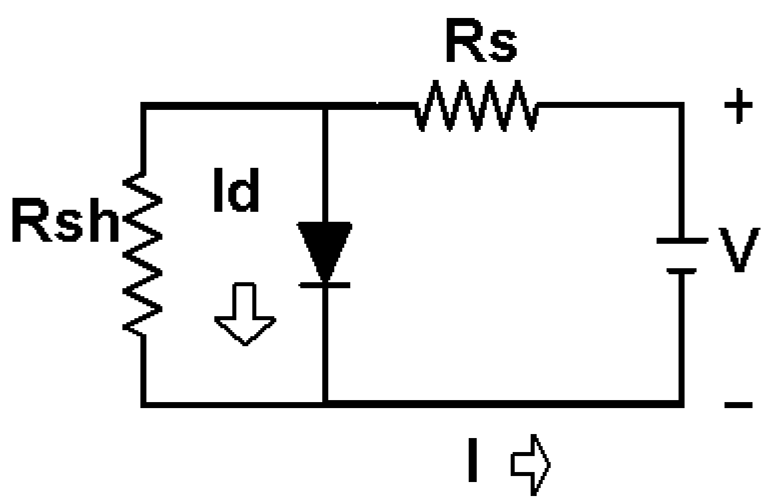
Also see

Provides links or references to other related functions.

Ftn 0501: Dark Current-Voltage: Ideal



Equivalent Circuit



Equation

There are two variations of this function:

- $$Y = K4 * \left(P2 * \left\{ e^{\left[\frac{K1*X}{K3*(273.15+K2)}\right]} - 1 \right\} + \frac{X}{(K3*P1)} \right)$$

- $$Y = K4 * \left(P2 * \left\{ e^{\left[\frac{K1*(X/K3-Y*P3/K4)}{(273.15+K2)}\right]} - 1 \right\} + \frac{(X/K3 - Y*P3/K4)}{P1} \right)$$

in which:

- Y is the measured response, the current in amperes.
- X is the independent variable, the voltage in volts.

NOTE:

It is strongly suggested that you use function 0512 instead of this function.

Function 0512 is the same as this function except that:
(a) The definitions of the dependent and independent variables are switched. That is, the meanings of X and Y are interchanged and
(b) The value of the diode ideality factor is treated as a parameter rather than assuming that it has a value of one.

This difference makes the regression analysis easier.

Constants

Constant	**Name**	**Comments**
K1	q/k	Elementary charge, q = 1.602177E-19 Coulomb, divided by Boltzmann's constant, k = 1.380662E-23 J/^{o}K Default value is 1.160441151E4 C^{o}K/J
K2	t	Temperature in ^{o}C Default value is 25 ^{o}C.
K3	Ns	Number of series connected solar cells in a cell-string or module-string. Default value is 1.
K4	Np	Number of cell-strings connected in parallel in a module or PV System.

Constant	Name	Comments
		Default value is 1.
K5	Max I /amps	The maximum value of the current, I, that ***FitAll*** will use during the regression analysis. By default this is set to 1.5 times the maximum value of I in the current data set when the function is selected. Manually adjusting this to a lower value may help to reduce the occurrence of "numeric overflow" or "invalid floating point operation" errors during the analysis.

Parameters

Parameter	Name	Comments
P1	Rsh	Shunt resistance in ohms, Ω.
P2	Io	Diode saturation current, in amperes, for recombination mechanisms with ideality factor equal to one.
P3	Rs	Series resistance in ohms, Ω. When doing a fit that includes Rs as a parameter, it is often advantageous to limit it to values greater than or equal to zero. These are the only physically meaningful values of Rs.

Sample Applications

- Characterizing the current-voltage behaviour of semiconductor diodes.

- Characterizing the dark current - voltage behaviour of solar cells.

Remarks

Because of the extreme non linearity of the function, ***FitAll*** may arrive at one of several possible solutions. Manual adjustment of the initial estimates will most likely be necessary.

In most cases the current, Y, data will span a wide range of values, for example, three or four orders of magnitude. Because of this it is strongly advised that you weight the data using a weighting factor of $1/(\text{SigmaY})^2$ or $1/(0.1Y)^2$. When you plot the fit, plot Log[Y] vs. X so that you will be able to see the deviations at low Y-values as well as at high Y-values.

This is an implicit function; that is, its value depends on itself. The dependent variable, Y, appears on both sides of the equation. ***FitAll*** uses an iterative method to evaluate this function. Function evaluations are more time consuming than normal and the regression analysis is correspondingly slower.

Often, the best fitting strategy is to first fit your data using the first form of this function, then re-do the fit using the second form and the parameters obtained in the first fit as the starting point for the second.

All currents and voltages are assumed to be greater than or equal to zero.

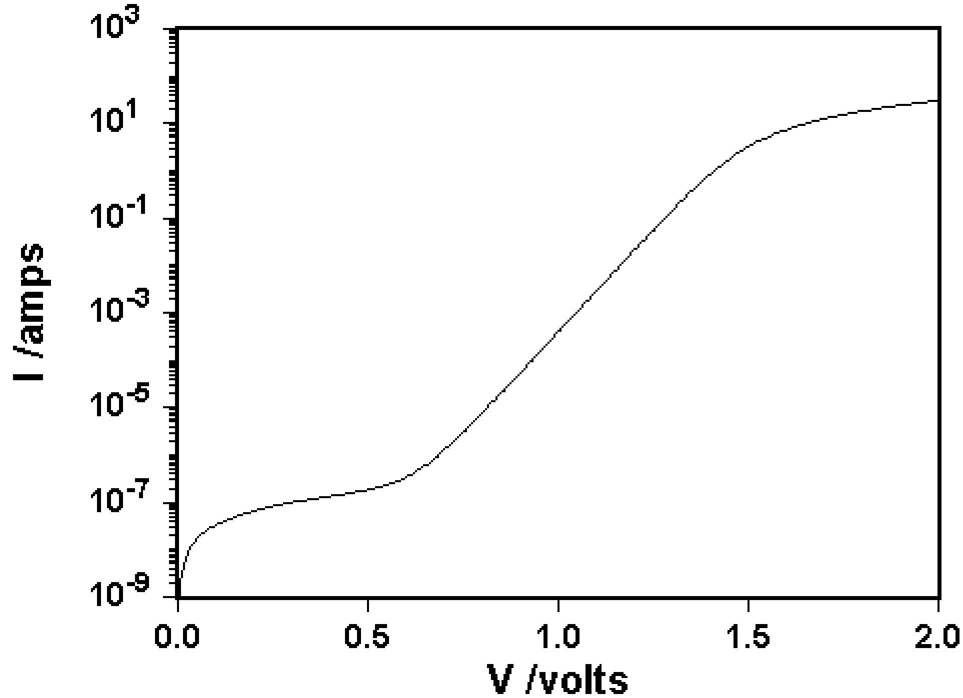
When automatic initial estimates are made, ***FitAll*** assumes that the data are sorted on column number 1, that is, the X-values.

Also See

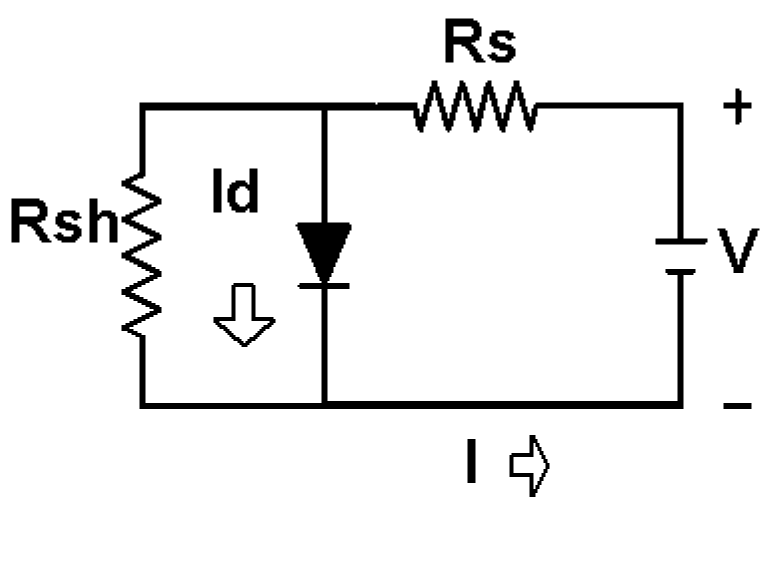
About Solar Cell-Strings And Modules 82

Function 0502 7, which is the same as this function except that it includes the parameter "n" that is a "diode ideality factor". This function assumes that the diode is an ideal diode.

Ftn 0502: Dark Current-Voltage: Non-Ideal



Equivalent Circuit



Equation

There are two variations of this function:

- $$Y = K4 * \left(P2 * \left\{ e^{\left[\frac{K1*X}{(K3*(273.15+K2)*P3)}\right]} -1 \right\} + \frac{X}{K3*P1} \right)$$

- $$Y = K4 * \left(P2 * \left\{ e^{\left[\frac{K1*(X/K3-Y*P4/K4)}{((273.15+K2)*P3)}\right]} -1 \right\} + \frac{(X/K3 - Y*P4/K4)}{P1} \right)$$

in which:

- Y is the measured response, the current in amperes.
- X is the independent variable, the voltage in volts.

NOTE:

It is strongly suggested that you use function 0512 instead of this function.

Function 0512 is the same as this function except that the definitions of the dependent and independent variables are switched. That is, the meanings of X and Y are interchanged.

This difference makes the regression analysis easier.

Constants

Constant	**Name**	**Comments**
K1	q/k	Elementary charge, q = 1.602177E-19 Coulomb, divided by Boltzmann's constant, k = 1.380662E-23 J/ºK Default value is 1.160441151E4 CºK/J
K2	t	Temperature in ºC Default value is 25 ºC.
K3	Ns	Number of series connected solar cells in a cell-string or module-string. Default value is 1.
K4	Np	Number of series connected solar cells in a cell-string or module-string. Default value is 1.

Constant	Name	Comments
K5	Max I /amps	The maximum value of the current, I, that ***FitAll*** will use during the regression analysis. By default this is set to 1.5 times the maximum value of I in the current data set when the function is selected. Manually adjusting this to a lower value may help to reduce the occurrence of "numeric overflow" or "invalid floating point operation" errors during the analysis.

Parameters

Parameter	Name	Comments
P1	Rsh	Shunt resistance in ohms, Ω.
P2	Io	Diode saturation current, in amperes, for recombination mechanisms with ideality factor equal to one.
P3	Nr	Ideality factor, equal to one for an ideal semiconductor diode (See function 0501 3). When doing a fit it is often advantageous to limit the value of Nr to the range 1 to 5.
P4	Rs	Series resistance in ohms, Ω. When doing a fit that includes Rs as a parameter, it is often advantageous to limit it to values greater than or equal to zero. These are the only physically meaningful values of Rs.

Sample Applications

- Characterizing the current-voltage behaviour of semiconductor diodes.
- Characterizing the dark current - voltage behaviour of solar cells.

Remarks

Because of the extreme non linearity of the function, ***FitAll*** may arrive at one of several possible solutions. Manual adjustment of the initial estimates will most likely be necessary.

In most cases the current, Y, data will span a wide range of values, for example, three or four orders of magnitude. Because of this it is strongly advised that you weight the data using a weighting factor of 1/(SigmaY)^2 or 1/(01.Y)^2. When you plot the fit, plot Log[Y] vs. X so that you will be able to see the deviations at low Y-values as well as at high Y-values.

This function is an implicit function; that is, its value depends on itself. The dependent variable, Y, appears on both sides of the equation. ***FitAll*** uses an iterative method to evaluate this function. Function evaluations are more time consuming than normal and the regression analysis is correspondingly slower.

Often, the best fitting strategy is to first fit your data using the first form of this function, then re-do the fit using the second form and the parameters obtained in the first fit as the starting point for the second.

All currents and voltages are assumed to be greater than or equal to zero.

When automatic initial estimates are made, ***FitAll*** assumes that the data are sorted on column number 1, that is, the X-values.

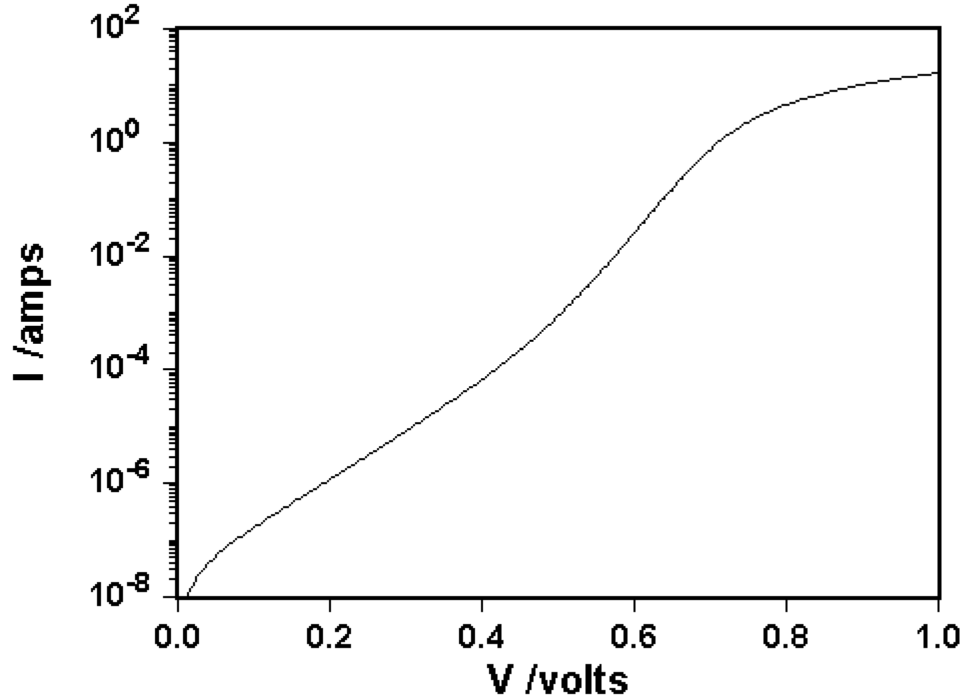
Also See

About Solar Cell-Strings And Modules 82

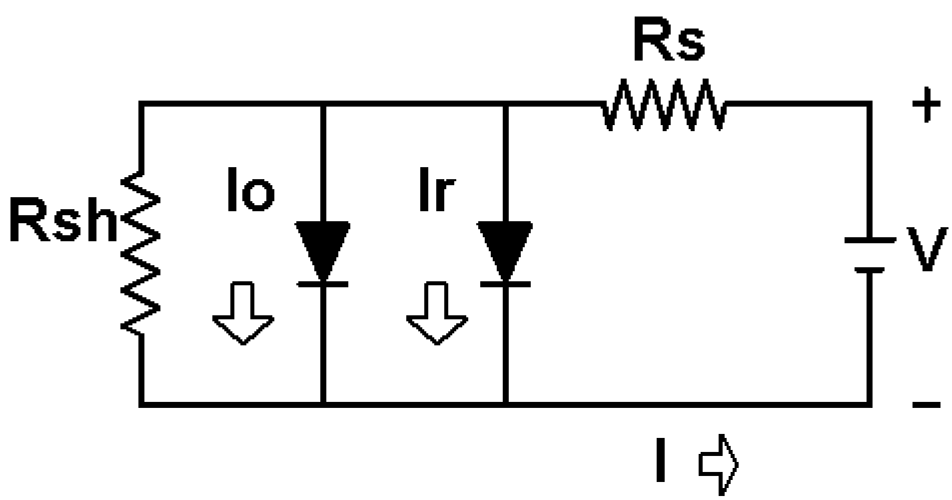
Function 0501 3, which is the same as this function except that it assumes that the diode is an ideal diode; that is, that the diode ideality factor equals 1 (one).

Function 0512 42, which is the same as this function except that the definitions of the dependent and independent variables are switched. That is, the meanings of X and Y are interchanged.

Ftn 0503: Dark Current-Voltage: Sum of Ideal and Non-Ideal:



Equivalent Circuit



Equation

There are two variations of this function:

- $$Y = K4 * \left(P2 * \left\{ e^{\left[\frac{K1 * X}{K3 * (273.15 + K2)}\right]} - 1 \right\} + P3 * \left\{ e^{\left[\frac{K1 * X}{K3 * (273.15 + K2) * P4}\right]} - 1 \right\} + \frac{X}{K3 * P1} \right)$$

- $$Y = K4 * \left(P2 * \left\{ e^{\left[\frac{K1 * (X/K3 - Y * P5/K4)}{(273.15 * K2)}\right]} - 1 \right\} + P3 * \left\{ e^{\left[\frac{K1 * (X/K3 - Y * P5/K4)}{((273.15 + K2) * P4)}\right]} - 1 \right\} + \frac{(X/K3 - Y * P5/K4)}{P1} \right)$$

in which:

- Y is the measured response, the current in amperes.
- X is the independent variable, the voltage in volts.

NOTE:

It is strongly suggested that you use function 0507 instead of this function.

Function 0507 is the same as this function except that the definitions of the dependent and independent variables are switched. That is, the meanings of X and Y are interchanged.

This difference makes the regression analysis easier.

Constants

Constant	Name	Comments
K1	q/k	Elementary charge, q = 1.602177E-19 Coulomb, divided by Boltzmann's constant, k = 1.380662E-23 J/ºK Default value is 1.160441151E4 CºK/J
K2	t	Temperature in ºC Default value is 25 ºC.
K3	Ns	Number of series connected solar cells in a cell-string or module-string. Default value is 1.
K4	Np	Number of series connected solar cells in a cell-string or module-string. Default value is 1.
K5	Max I /amps	The maximum value of the current, I, that ***FitAll*** will use during the regression analysis. By default this is set to 1.5 times the maximum value of I in the current data set when the function is selected. Manually adjusting this to a lower value may help to reduce the occurrence of "numeric overflow" or "invalid floating point operation" errors during the analysis.

Parameters

Parameter	Name	Comments
P1	Rsh	Shunt resistance in ohms, Ω.
P2	Io	Diode saturation current, in amperes, for recombination mechanisms with ideality factor equal to one.
P3	Ir	Diode saturation current, in amperes, for recombination mechanisms with ideality factor not equal to one.

Parameter	Name	Comments
P4	Nr	Ideality factor, equal to one for an ideal semiconductor diode (see function 0501 3).
P5	Rs	Series resistance in ohms, Ω. When doing a fit that includes Rs as a parameter, it is often advantageous to limit it to values greater than or equal to zero. These are the only physically meaningful values of Rs.

Sample Applications

- Characterizing the current-voltage behaviour of semiconductor diodes.
- Characterizing the dark current - voltage behaviour of solar cells.

Remarks

Because of the extreme non linearity of the function, ***FitAll*** may arrive at one of several possible solutions. Manual adjustment of the initial estimates will most likely be necessary.

In most cases the current, Y, data will span a wide range of values, for example, three or four orders of magnitude. Because of this it is strongly advised that you weight the data using a weighting factor of $1/(SigmaY)^2$ or $1/(0.1Y)^2$. When you plot the fit, plot Log[Y] vs. X so that you will be able to see the deviations at low Y-values as well as at high Y-values.

This is an implicit function; that is, its value depends on itself. The dependent variable, Y, appears on both sides of the equation. ***FitAll*** uses an iterative method to evaluate this function. Function evaluations are more time consuming than normal and the regression analysis is correspondingly slower.

Often, the best fitting strategy is to first fit your data using the first variation of the function, then re-do the fit using the second variation and the parameters obtained in the first fit as the starting point for the second.

All currents and voltages are assumed to be greater than or equal to zero.

When automatic initial estimates are made, ***FitAll*** assumes that the data are sorted on column number 1, that is, the X-values.

Also See

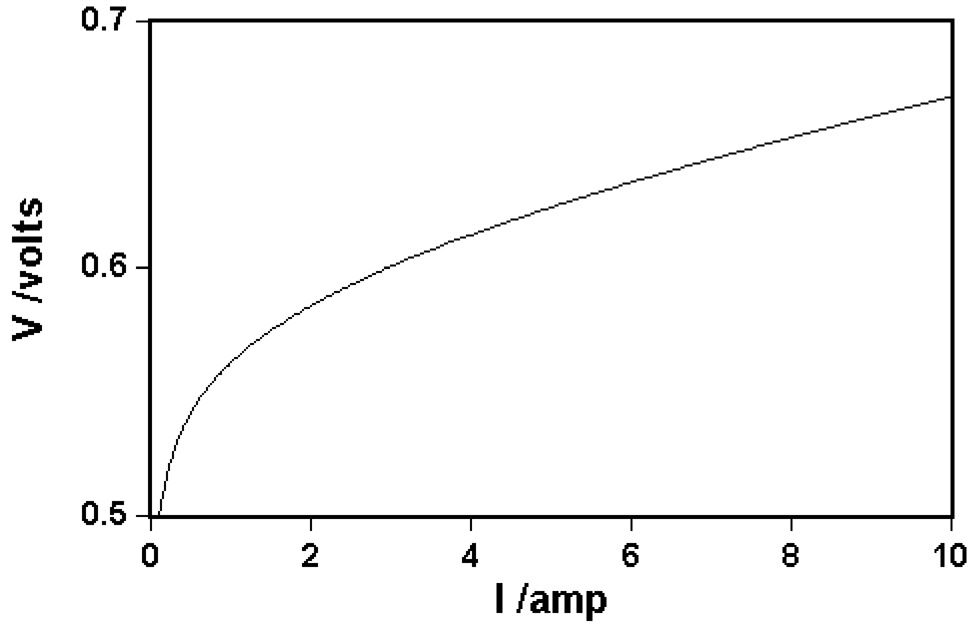
About Solar Cell-Strings And Modules 82

Function 0507 26 is the same as this function except that the definitions of the dependent and independent variables are switched. That is, the meanings of X and Y are interchanged.

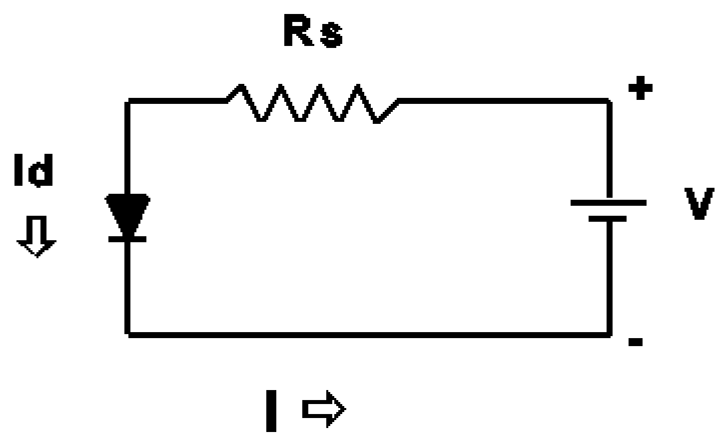
Function 0517 56 is the same as this function except that the definitions of the dependent and independent variables are switched. That is, the meanings of X and Y are interchanged. Also, both diodes are assumed to be non-ideal diodes.

Function 0527 74

Ftn 0504: Dark I-V: Model 1A: High I-range



Equivalent Circuit



Equation

$$Y = K3*\left(\frac{K5*(273.15+K2)}{K1}*Ln\left|\frac{(X/K4+P1)}{P1}\right|+X*P2/K4\right)$$

in which:

- Y is the measured response -- the voltage in volts.

- X is the independent variable -- the current in amperes.

Constants

Constant	Name	Comments
K1	q/k	Elementary charge, q = 1.602177E-19 Coulomb, divided by Boltzmann's constant, k = 1.380662E-23 J/ºK Default value is 1.160441151E4 CºK/J
K2	t	Temperature in ºC. Default value is 25.0 ºC.
K3	Ns	Number of series connected solar cells in a cell-string or module-string. Default value is 1.
K4	Np	Number of cell-strings connected in parallel in a module or PV System. Default value is 1.
K5	n	Ideality factor for the diode. For an ideal diode n = 1. For a non-ideal diode n > 1.

Parameters

Parameter	Name	Comments
P1	Id	Saturation current for the diode, in amperes
P2	Rs	Series resistance in ohms, Ω. Rs >= 0.

Sample Applications

- Characterizing the current-voltage behaviour of semiconductor diodes.
- Characterizing the dark current-voltage behaviour of solar cells.

Remarks

When automatic initial estimates are made, ***FitAll*** assumes that the data are sorted on column number 1, that is, the X-values.

All currents and voltages are assumed to be greater than or equal to zero.

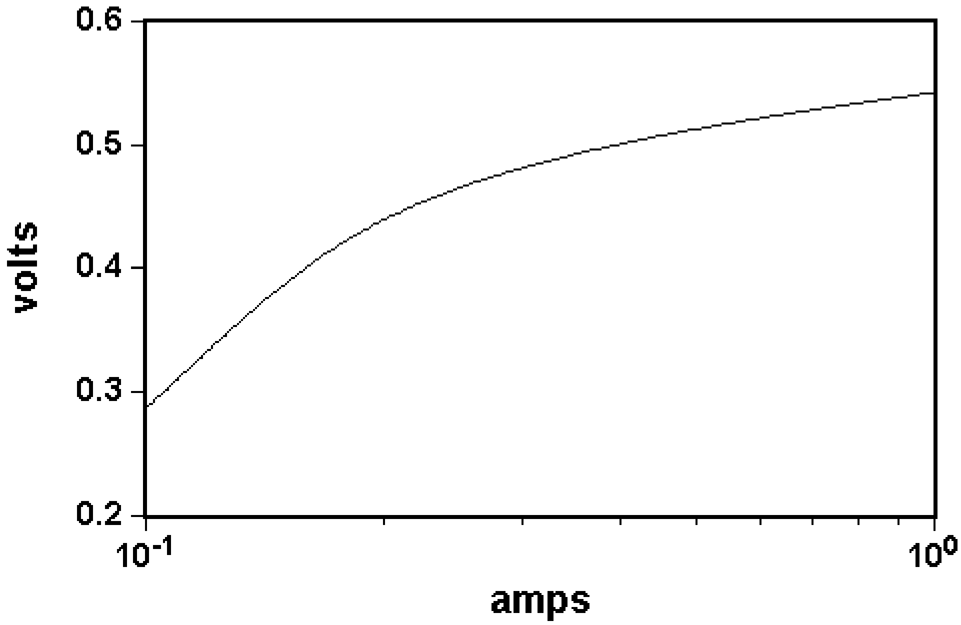
Also See

About Solar Cell-Strings And Modules 82

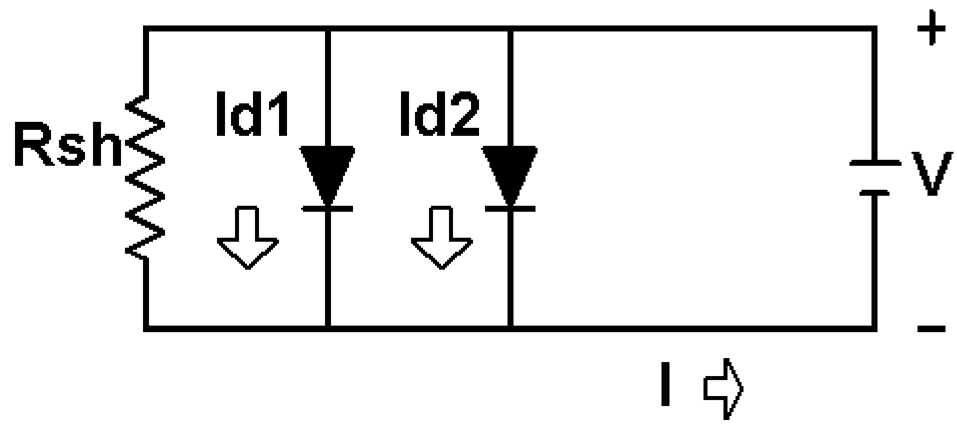
Function 0513 46, which is the same as this function except that it has an extra parameter, P3, which is a voltage offset that *may* be useful in compensating for an instrumental measurement offset (calibration error).

Function 0514 49, which is the same as this function except that the diode ideality factor, constant K3, is treated as a parameter rather than an adjustable constant.

Ftn 0505: Dark I-V: Model 2A: Mid I-range



Equivalent Circuit



Equation

$$Y = K3*P1*\left(\begin{array}{l} X/K4 - P2*\left\{ e^{\left[\frac{K1*Y}{K3*(273.15+K2)}\right]} - 1 \right\} \\ \\ -P3*\left\{ e^{\left[\frac{K1*Y}{K3*P4*(273.15+K2)}\right]} - 1 \right\} \end{array} \right)$$

in which:

- Y is the measured response -- the voltage in volts.
- X is the independent variable -- the current in amperes.

Constants

Constant	Name	Comments
K1	q/k	Elementary charge, q = 1.602177E-19 Coulomb, divided by Boltzmann's constant, k = 1.380662E-23 J/ºK Default value is 1.160441151E4 CºK/J
K2	t	Temperature in ºC. Default value is 25.0 ºC.
K3	Ns	Number of series connected solar cells in a cell-string or module-string. Default value is 1.
K4	Np	Number of cell-strings connected in parallel in a module or PV System. Default value is 1.

Constant	Name	Comments
K5	Max V /V	The maximum value of the voltage, V, that ***FitAll*** will use during the regression analysis. By default this is set to 1.5 times the maximum value of V in the current data set when the function is selected. Manually adjusting this to a lower value may help to reduce the occurrence of "numeric overflow" or "invalid floating point operation" errors during the analysis.

Parameters

Parameter	Name	Comments
P1	Rsh	Shunt resistance in ohms, Ω.
P2	Id1	Saturation current, in amperes, for ideal diode 1, in amperes
P3	Id2	Saturation current, in amperes, for non-ideal diode 2, in amperes
P4	n2	Ideality factor for diode 2. For an ideal diode n = 1. For a non-ideal diode n > 1.

Sample Applications

- Characterizing the current-voltage behaviour of semiconductor diodes.
- Characterizing the dark current-voltage behaviour of solar cells.

Remarks

Because of the exponential nature of this function and the magnitude of the constants, some of the values generated can be very large (or very small) -- in fact, large enough to exceed the numeric range of your computer. If this happens, one or more error messages will appear and the calculations will be terminated.

This is an implicit function; that is, the dependent variable, Y, appears on both sides of the equation. ***FitAll*** uses an iterative method to evaluate this function. Function evaluations are more time consuming than normal and the regression analysis is correspondingly slower.

All currents and voltages are assumed to be greater than or equal to zero.

When automatic initial estimates are made, ***FitAll*** assumes that the data are sorted on column number 1, that is, the X-values.

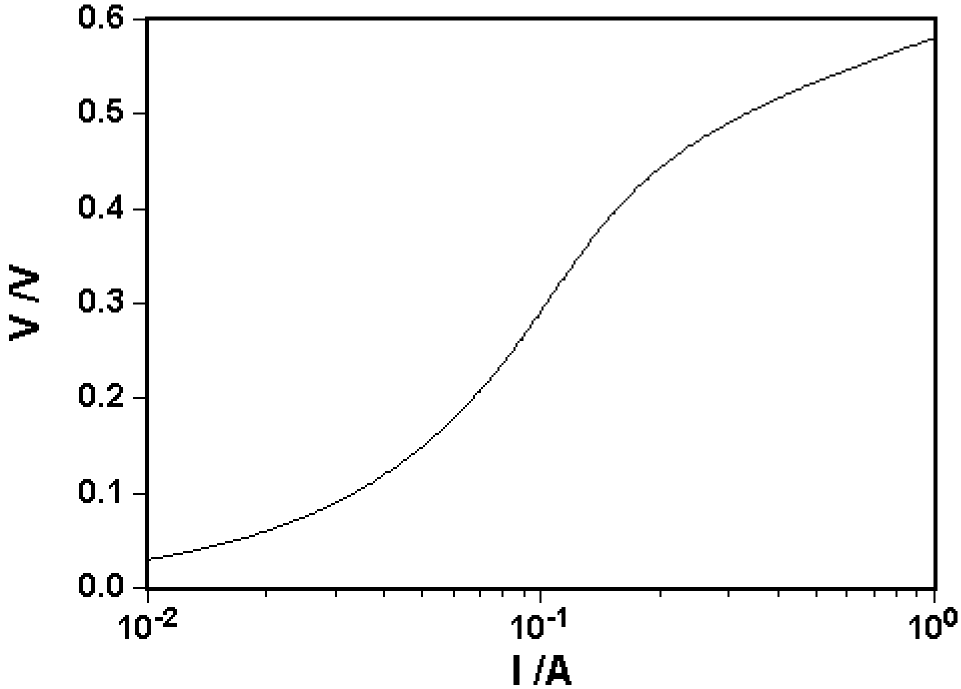
Also See

About Solar Cell-Strings And Modules 82

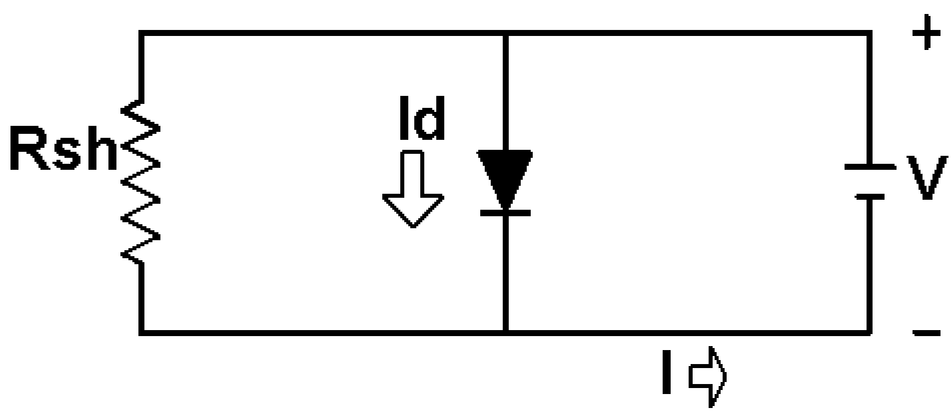
Function 0515 52, which is the same as this function except that diode 1 is treated as a non-ideal diode that may have a value greater than 1.0.

Function 0525 67, which is the same as this function except that it includes a Voltage Offset parameter.

Ftn 0506: Dark I-V: Model 3A: Low I-range



Equivalent Circuit



Equation

$$Y = K3*P1*\left(\begin{array}{l} X/K4 - P2*\left\{ e^{\left[\frac{K1*Y}{K3*(273.15+K2)}\right]} - 1 \right\} \\ \\ -P3*\left\{ e^{\left[\frac{K1*Y}{K3*P4*(273.15+K2)}\right]} - 1 \right\} \end{array} \right)$$

in which:

- Y is the measured response -- the voltage in volts.
- X is the independent variable -- the current in amperes.

Constants

Constant	Name	Comments
K1	q/k	Elementary charge, q = 1.602177E-19 Coulomb, divided by Boltzmann's constant, k = 1.380662E-23 J/ºK Default value is 1.160441151E4 CºK/J
K2	t	Temperature in ºC. Default value is 25.0 ºC.
K3	Ns	Number of series connected solar cells in a cell-string or module-string. Default value is 1.
K4	Np	Number of cell-strings connected in parallel in a module or PV System. Default value is 1.

Constant	Name	Comments
K3	Max V /V	The maximum value of the voltage, V, that ***FitAll*** will use during the regression analysis. By default this is set to 1.5 times the maximum value of V in the current data set when the function is selected. Manually adjusting this to a lower value may help to reduce the occurrence of "numeric overflow" or "invalid floating point operation" errors during the analysis.

Parameters

Parameter	Name	Comments
P1	Rsh	Shunt resistance in ohms, Ω.
P2	Id	Saturation current, in amperes, for the diode, in amperes
P3	n	Ideality factor for the diode. For an ideal diode n = 1. For a non-ideal diode n > 1.

Sample Applications

- Characterizing the current-voltage behaviour of semiconductor diodes.
- Characterizing the dark current-voltage behaviour of solar cells.

Remarks

Because of the exponential nature of this function and the magnitude of the constants, some of the values generated can be very large (or very small) -- in fact, large enough to exceed the numeric range of your computer. If this happens, one or more error messages will appear and the calculations will be terminated.

This is an implicit function; that is, the dependent variable, Y, appears on both sides of the equation. ***FitAll*** uses an iterative method to evaluate this function. Function evaluations are more time consuming than normal and the regression analysis is correspondingly slower.

All currents and voltages are assumed to be greater than or equal to zero.

When automatic initial estimates are made, ***FitAll*** assumes that the data are sorted on column number 1, that is, the X-values.

Also See

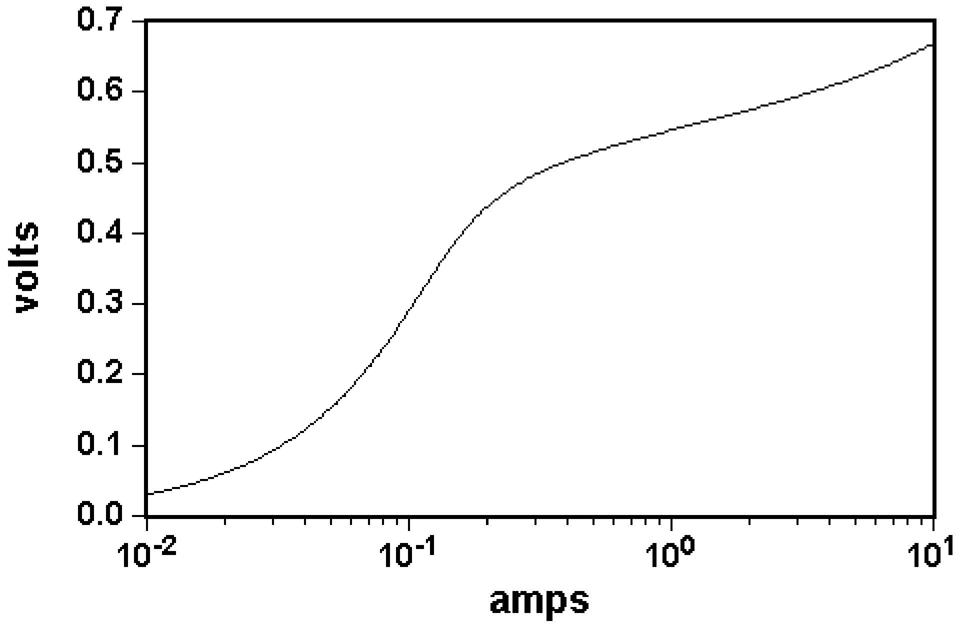
About Solar Cell-Strings And Modules 82

Function 0502 7.

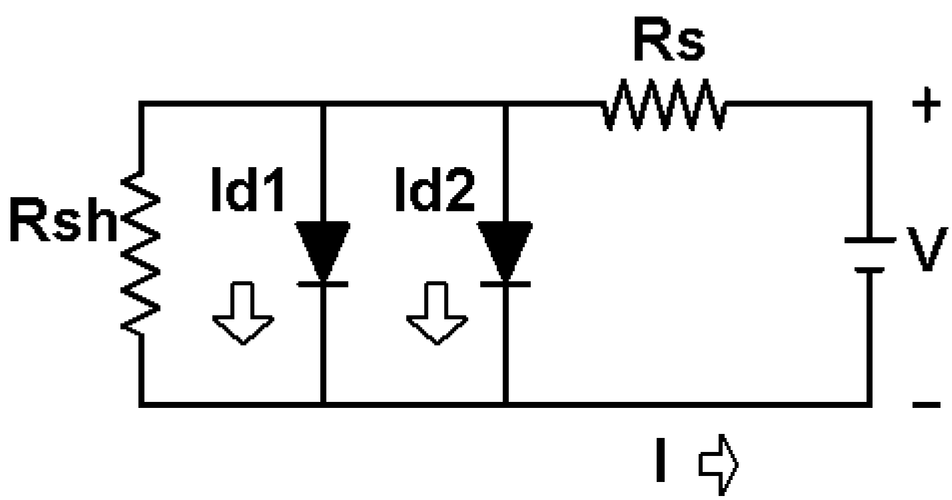
Function 0526 71, which is the same as this function except that it has an extra parameter, P4, which is a voltage offset that *may* be useful in compensating for an instrumental measurement offset (calibration error).

Function 0512 42.

Ftn 0507: Dark I-V: Model 4A: Full I-range



Equivalent Circuit



Equation

$$Y = K3 * \left[P1 * \left(\begin{array}{l} X/K4 - P2 * \left\{ e^{\left[\frac{K1 * (Y/K3 - X * P5/K4)}{(273.15 + K2)}\right]} - 1 \right\} \\ \\ -P3 * \left\{ e^{\left[\frac{K1 * (Y/K3 - X * P5/K4)}{(P4 * (273.15 + K2))}\right]} - 1 \right\} \end{array} \right) + X * P5/K4 \right]$$

in which:

- Y is the measured response -- the voltage in volts.
- X is the independent variable -- the current in amperes.

Constants

Constant	Name	Comments
K1	q/k	Elementary charge, q = 1.602177E-19 Coulomb, divided by Boltzmann's constant, k = 1.380662E-23 J/^{o}K Default value is 1.160441151E4 C^{o}K/J
K2	t	Temperature in ^{o}C. Default value is 25.0 ^{o}C.
K3	Ns	Number of series connected solar cells in a cell-string or module-string. Default value is 1.
K4	Np	Number of cell-strings connected in parallel in a module or PV System. Default value is 1.

Constant	Name	Comments
K5	Max V /V	The maximum value of the voltage, V, that ***FitAll*** will use during the regression analysis. By default this is set to 1.5 times the maximum value of V in the current data set when the function is selected. Manually adjusting this to a lower value may help to reduce the occurrence of "numeric overflow" or "invalid floating point operation" errors during the analysis.

Parameters

Parameter	Name	Comments
P1	Rsh	Shunt resistance in ohms, Ω.
P2	Id1	Saturation current, in amperes, for diode 1, in amperes
P3	Id2	Saturation current, in amperes, for diode 2, in amperes.
P4	n2	Ideality factor for diode 2. For an ideal diode n = 1. For a non-ideal diode n > 1.
P5	Rs	Series resistance in ohms, Ω.

Sample Applications

- Characterizing the current-voltage behaviour of semiconductor diodes.
- Characterizing the dark current-voltage behaviour of solar cells.

Remarks

Because of the exponential nature of this function and the magnitude of the constants, some of the values generated can be very large (or very small) -- in fact, large enough to exceed the numeric range of your computer. If this happens, one or more error messages will appear and the calculations will be terminated.

This is an implicit function; that is, the dependent variable, Y, appears on both sides of the equation. ***FitAll*** uses an iterative method to evaluate this function. Function evaluations are more time consuming than normal and the regression analysis is correspondingly slower.

All currents and voltages are assumed to be greater than or equal to zero.

When automatic initial estimates are made, ***FitAll*** assumes that the data are sorted on column number 1, that is, the X-values.

Also See

About Solar Cell-Strings And Modules 82

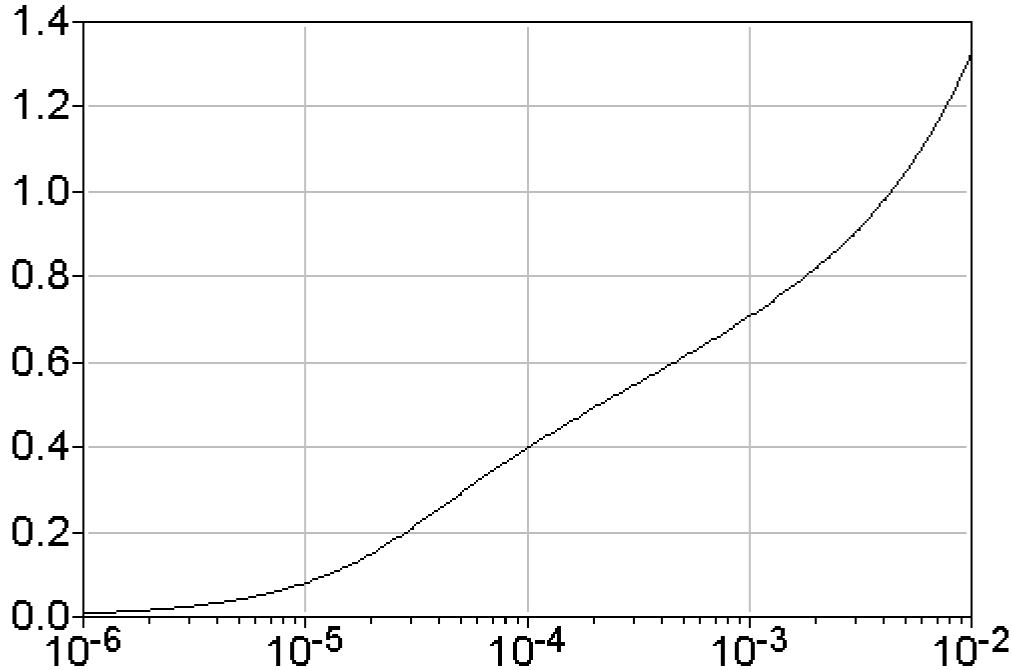
Function 0503 11, which is the same as this function except that the definitions of the dependent and independent variables are switched. That is, the meanings of X and Y are interchanged.

Function 0508 30, which is the similar as this function that does not include the ideal diode in the equivalent circuit.

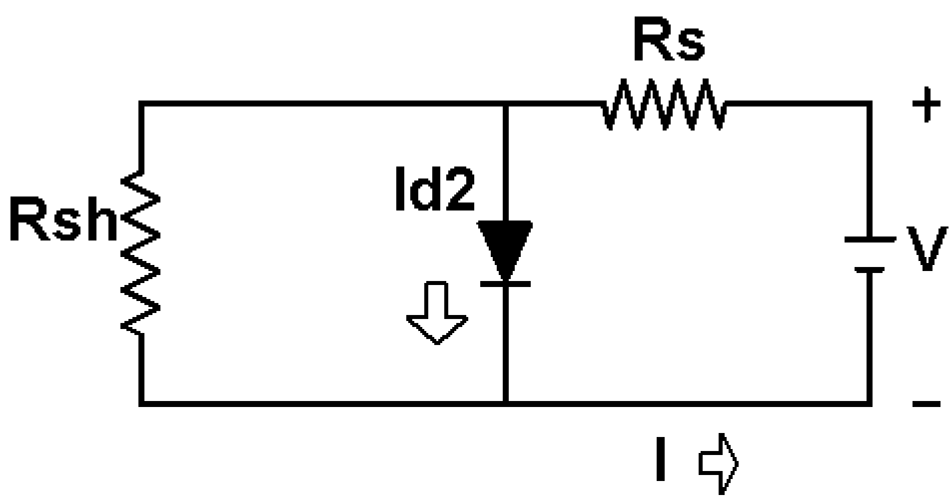
Function 0517 56, which is the same as this function except that both diodes are assumed to be non-ideal diodes; that is, their ideality factors, n, are greater than or equal to 1.

Function 0527 74, which is the same as this function except that it has an extra parameter, P6, which is a voltage offset that *may* be useful in compensating for an instrumental measurement offset (calibration error).

Ftn 0508: Dark I-V: Model 4E: Full I-range: 1 non-ideal diode



Equivalent Circuit



Equation

$$Y = K3^*\left[P1^*\left[X/K4 - P2^*\left\{e^{\left[\frac{K1^*(Y/K3 - X^*P4/K4)}{(P3^*(273.15+K2))}\right]} - 1\right\}\right] + X^*P4/K4\right]$$

in which:

- Y is the measured response -- the voltage in volts.
- X is the independent variable -- the current in amperes.

Constants

Constant	Name	Comments
K1	q/k	Elementary charge, q = 1.602177E-19 Coulomb, divided by Boltzmann's constant, k = 1.380662E-23 J/ºK Default value is 1.160441151E4 CºK/J
K2	t	Temperature in ºC. Default value is 25.0 ºC.
K3	Ns	Number of series connected solar cells in a cell-string or module-string. Default value is 1.
K4	Np	Number of cell-strings connected in parallel in a module or PV System. Default value is 1.
K5	Max V /V	The maximum value of the voltage, V, that ***FitAll*** will use during the regression analysis. By default this is set to 1.5 times the maximum value of V in the current data set when the function is selected. Manually adjusting this to a lower value may help to reduce the occurrence of "numeric overflow" or "invalid floating point operation" errors during the analysis.

Parameters

Parameter	Name	Comments
P1	Rsh	Shunt resistance in ohms, Ω.
P2	Id2	Saturation current, in amperes, for diode 2, in amperes.

Parameter	**Name**	**Comments**
P3	n2	Ideality factor for diode 2. For an ideal diode n = 1. For a non-ideal diode n > 1.
P4	Rs	Series resistance in ohms, Ω.

Sample Applications

- Characterizing the current-voltage behaviour of semiconductor diodes.
- Characterizing the dark current-voltage behaviour of solar cells.

Remarks

Because of the exponential nature of this function and the magnitude of the constants, some of the values generated can be very large (or very small) -- in fact, large enough to exceed the numeric range of your computer. If this happens, one or more error messages will appear and the calculations will be terminated.

This is an implicit function; that is, the dependent variable, Y, appears on both sides of the equation. ***FitAll*** uses an iterative method to evaluate this function. Function evaluations are more time consuming than normal and the regression analysis is correspondingly slower.

All currents and voltages are assumed to be greater than or equal to zero.

When automatic initial estimates are made, ***FitAll*** assumes that the data are sorted on column number 1, that is, the X-values.

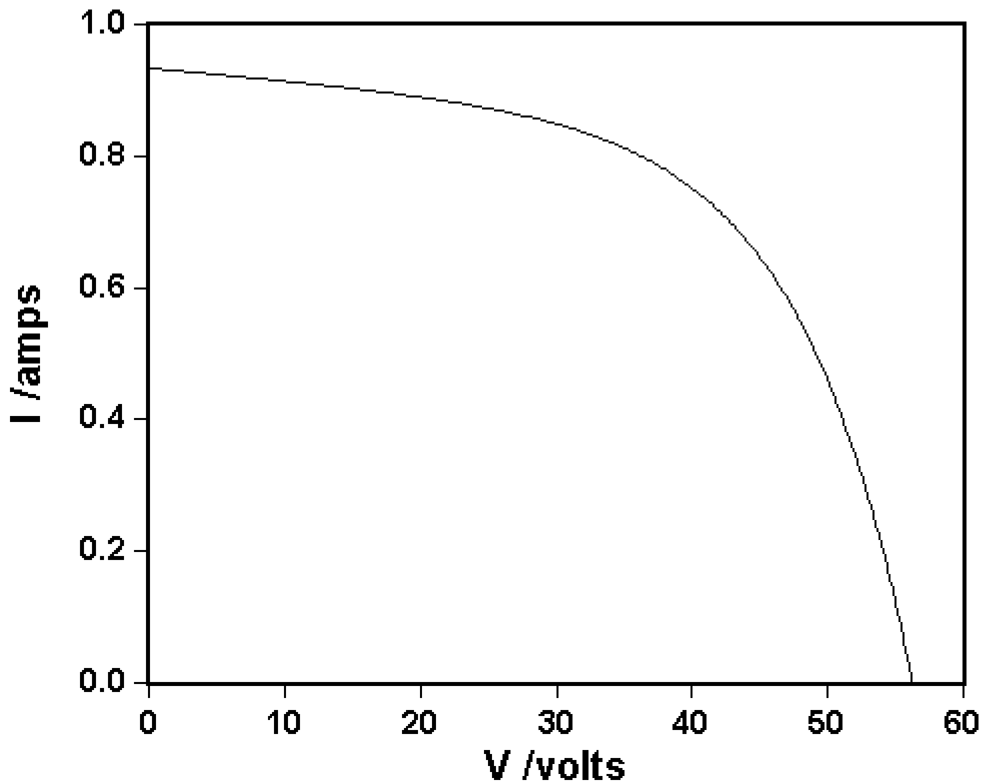
Also See

About Solar Cell-Strings And Modules 82

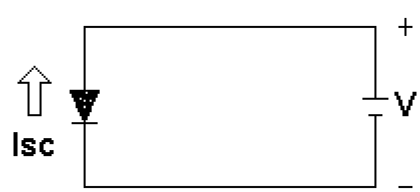
Function 0507 30, which is the similar as this function that has a second ideal diode in the equivalent circuit.

Function 0528 78, which is the same as this function except that it includes a voltage offset parameter.

Ftn 0509: Light I-V: Rs = 0 and Rsh = ∞



Equivalent Circuit



Equation

$$Y = P3 * \{A\}$$

in which

$$A = \frac{e^{k_o * P2} - e^{k_o * X/K4}}{e^{k_o * P2} - 1}$$

and

$$k_o = \frac{K1}{P1*(273.15+K2)}$$

in which

- Y is the cell operating current, I, in amperes.
- X is the cell operating voltage, V, in volts.

Constants

Constant	Name	Comments
K1	q/k	Elementary charge, q = 1.602177E-19 Coulomb, divided by Boltzmann's constant, k = 1.380662E-23 J/ºK Default value is 1.160441151E4 CºK/J
K2	t	Temperature (in ºC). Default value is 25.0 ºC.
K3	Ns	Number of series connected solar cells in a cell-string or module-string. Default value is 1.
K4	Np	Number of cell-strings connected in parallel in a module or PV System. Default value is 1.

Parameters

Parameter	Name	Comments
P1	n	Cell diode ideality factor. For an ideal diode n = 1. For a non-ideal diode n > 1. NOTE: After making the automatic estimates it will be necessary to manually adjust the value of n.
P2	Voc	Voltage at Open Circuit in volts.
P3	Isc	Current at Short Circuit in amperes.

Parameter	Name	Comments
		This corresponds to the "Light Induced" or "Illumination" current.

Sample Applications

- Characterizing the light current-voltage behaviour of solar cells.
- Characterizing the current-voltage behaviour of semiconductor diodes.

Remarks

FitAll's automatic initial estimates are very approximate and may well require manual adjustment, especially the value of n..

All currents and voltages are assumed to be greater than or equal to zero.

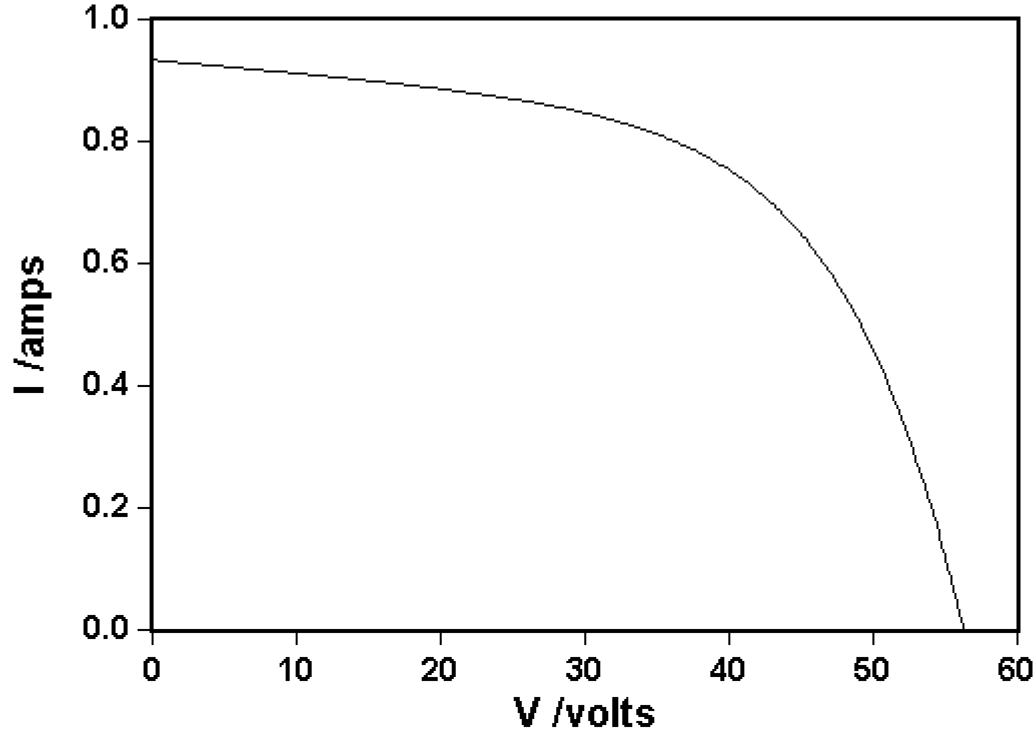
Also See

About Solar Cell-Strings And Modules 82

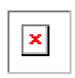
Function 0510 36

Function 0511 39

Ftn 0510: Light I-V: Rs <> 0



Equivalent Circuit



Equation

$$Y = K3*\left(P4*\{A\} + \left[(P4*P2 - P3)*\{A\} + P3 - X/K4 - Y*P2/K3 \right] * \left[\frac{P6 - P4*\{B\}}{(P4*P2 - P3)*\{B\} + P3 - P5 - P6*P2} \right] \right)$$

with

$$A = \frac{e^{k_o*P3} - e^{k_o(X/K4+Y*P2/K3)}}{e^{k_o*P3} - e^{k_o*P4*P2}}$$

$$B = \frac{e^{k_o*P3} - e^{k_o*(P5+P6*P2)}}{e^{k_o*P3} - e^{k_o*P4*P2}}$$

and

$$k_o = \frac{K1}{P1*(273.15+K2)}$$

in which

- Y is the cell operating current, I, in amperes.
- X is the cell operating voltage, V, in volts.

Constants

Constant	**Name**	**Comments**
K1	q/k	Elementary charge, q = 1.602177E-19 Coulomb, divided by Boltzmann's constant, k = 1.380662E-23 J/ºK Default value is 1.160441151E4 CºK/J
K2	t	Temperature (in ºC). Default value is 25.0 ºC.
K3	Ns	Number of series connected solar cells in a cell-string or module-string. Default value is 1.
K4	Np	Number of cell-strings connected in parallel in a module or PV System. Default value is 1.

Parameters

Parameter	**Name**	**Comments**
P1	n	Cell diode ideality factor. For an ideal diode n = 1. For a non-ideal diode n > 1.

Parameter	Name	Comments
P2	Rs	Series resistance in ohms, Ω. (Rs >= 0).
P3	Voc	Voltage at Open Circuit in volts.
P4	Isc	Current at Short Circuit in amperes. This corresponds to the "Light Induced" or "Illumination" current.
P5	Vmp	Voltage at Maximum Power in volts.
P6	Imp	Current at Maximum Power in amperes.

Sample Applications

- Characterizing the light current-voltage behaviour of solar cells.
- Characterizing the current-voltage behaviour of semiconductor diodes.

Remarks

This is an implicit function. That is, the dependent variable, Y, appears on both sides of the equation. ***FitAll*** uses an iterative method to evaluate this function. Function evaluations are more time consuming than normal and the regression analysis is correspondingly slower.

FitAll can and does generate reliable initial estimates of the parameters P[3] to P[6]; however, the initial estimates for the parameters P[1] and P[2] are arbitrary. It is more than likely that the initial estimates of P[1] and P[2] will have to be manually adjusted.

All currents and voltages are assumed to be greater than or equal to zero.

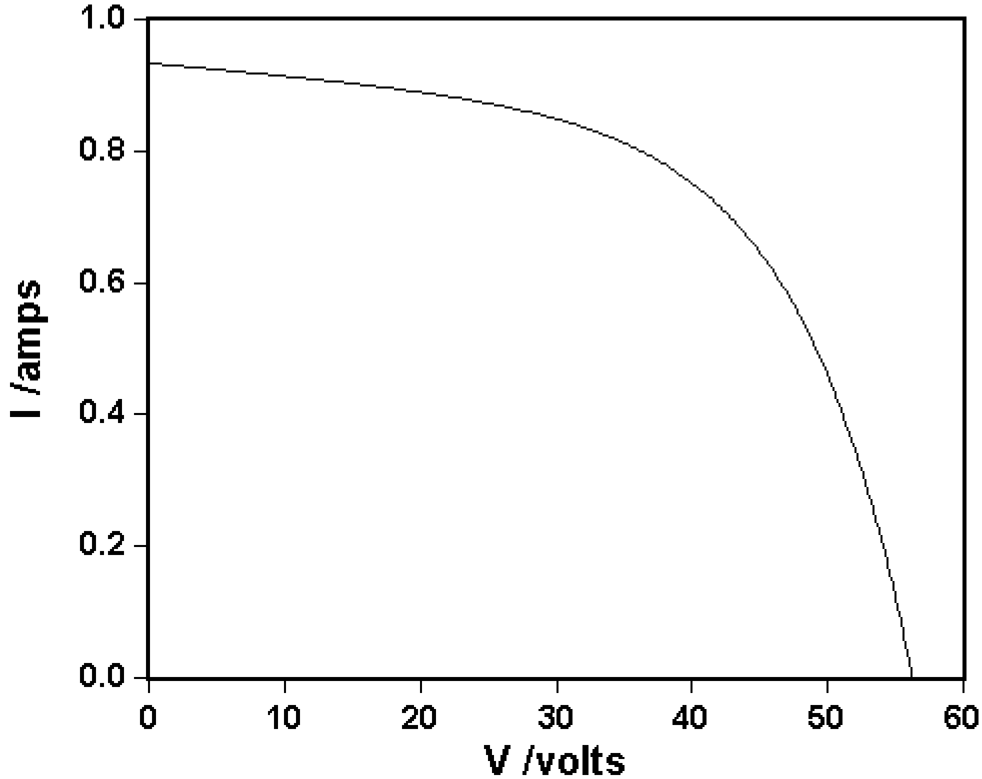
Also See

About Solar Cell-Strings And Modules 82

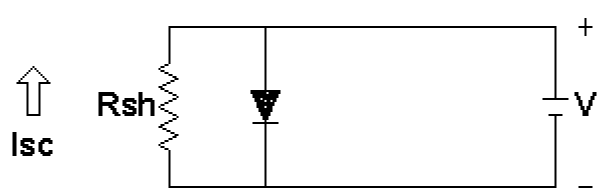
Function 0509 33

Function 0511 39

Ftn 0511: Light I-V: Rs = 0



Equivalent Circuit



Equation

$$Y = K3*\left(P4*\{A\}+\left[\left(-P3\right)*\{A\}+P3-X/K4\right]/P2\right)$$

with

$$A = \frac{e^{k_o*P3} - e^{k_o*X/K4}}{e^{k_o*P3} - 1}$$

and

$$k_o = \frac{K1}{P1*(273.15+K2)}$$

in which

- Y is the cell operating current, I, in amperes.
- X is the cell operating voltage, V, in volts.

Constants

Constant	Name	Comments
K1	q/k	Elementary charge, q = 1.602177E-19 Coulomb, divided by Boltzmann's constant, k = 1.380662E-23 J/ºK Default value is 1.160441151E4 CºK/J
K2	t	Temperature (in ºC). Default value is 25.0 ºC.
K3	Ns	Number of series connected solar cells in a cell-string or module-string. Default value is 1.
K4	Np	Number of cell-strings connected in parallel in a module or PV System. Default value is 1.

Parameters

Parameter	Name	Comments
P1	n	Cell diode ideality factor. For an ideal diode n = 1. For a non-ideal diode n > 1.
P2	Rsh	Cell shunt resistance in ohms, Ω. (Rsh >= 0).
P3	Voc	Open Circuit Voltage in volts.
P4	Isc	Short Circuit Current in amperes.

Parameter	Name	Comments
		This corresponds to the "Light Induced" or "Illumination" current.

Sample Applications

- Characterizing the light current-voltage behaviour of solar cells.
- Characterizing the current-voltage behaviour of semiconductor diodes.

Remarks

FitAll can and does generate reliable initial estimates of the parameters P[3] and P[4]; however, the initial estimates for the parameters P[1] and P[2] are arbitrary. It is more than likely that the initial estimates of P[1] and P[2] will have to be manually adjusted.

All currents and voltages are assumed to be greater than or equal to zero.

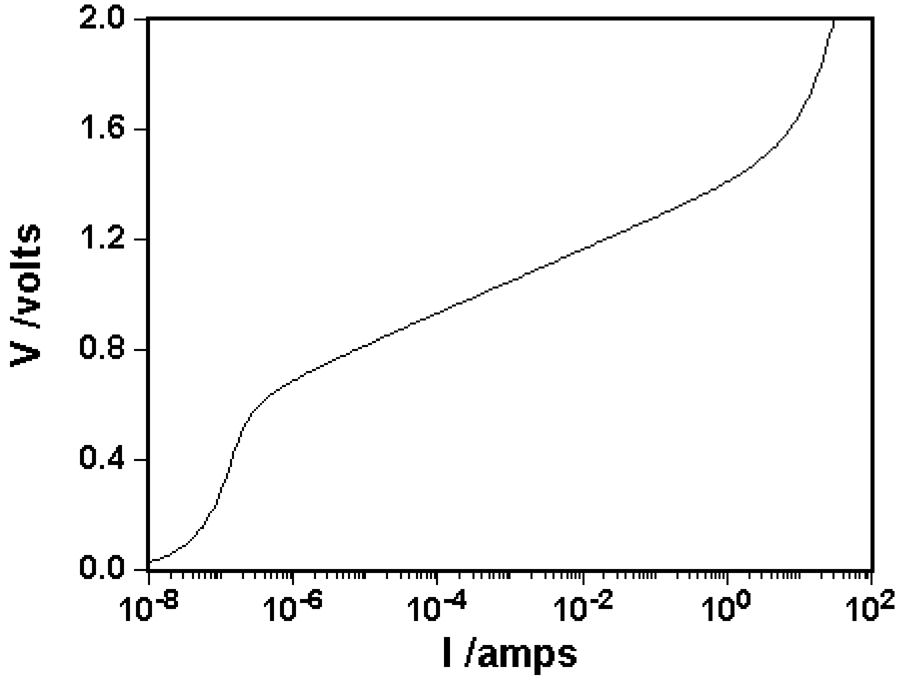
Also See

About Solar Cell-Strings And Modules 82

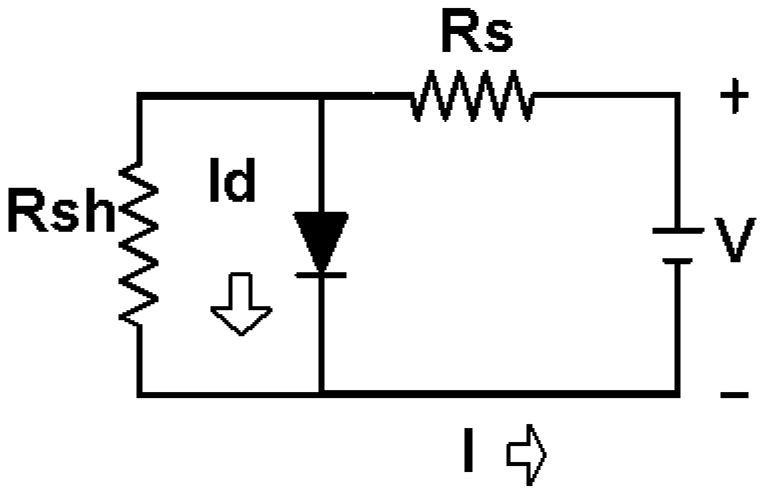
Function 0509 33

Function 0510 36

Ftn 0512: Dark Current-Voltage: Non-Ideal with Rs



Equivalent Circuit



Equation

$$Y = K3 * \left[P1 * \left(X/K4 - P2 * \left\{ e^{\left[\frac{K1 * (Y/K3 - X * P4/K4)}{P3 * (273.15 + K2)} \right]} - 1 \right\} \right) + X * P4/K4 \right]$$

in which:

- Y is the measured response, the voltage in volts.
- X is the independent variable, the current in amperes.

Constants

Constant	Name	Comments
K1	q/k	Elementary charge, q = 1.602177E-19 Coulomb, divided by Boltzmann's constant, k = 1.380662E-23 J/ºK Default value is 1.160441151E4 CºK/J
K2	t	Temperature in ºC. Default value is 25 ºC.
K3	Ns	Number of series connected solar cells in a cell-string or module-string.

Constant	Name	Comments
		Default value is 1.
K4	Np	Number of cell-strings connected in parallel in a module or PV System. Default value is 1.
K5	Max V /V	The maximum value of the voltage, V, that ***FitAll*** will use during the regression analysis. By default this is set to 1.5 times the maximum value of V in the current data set when the function is selected. Manually adjusting this to a lower value may help to reduce the occurrence of "numeric overflow" or "invalid floating point operation" errors during the analysis.

Parameters

Parameter	Name	Comments
P1	Rsh	Shunt resistance in ohms, Ω.
P2	Io	Diode saturation current, in amperes, for recombination mechanisms with ideality factor equal to one.
P3	n	Ideality factor, equal to one for an ideal semiconductor diode. When doing a fit it is often advantageous to limit the value of n to the range 1 to 5.
P4	Rs	Series resistance in ohms, Ω. It is often advantageous to limit Rs to values greater than or equal to zero. These are the only physically meaningful values of Rs.

Sample Applications

- Characterizing the current-voltage behaviour of semiconductor diodes.
- Characterizing the dark current-voltage behaviour of solar cells.

Remarks

This function is an implicit function; that is, its value depends on itself. The dependent variable, Y, appears on both sides of the equation. ***FitAll*** uses an iterative method to evaluate this function. Function evaluations are more time consuming than normal and the regression analysis is correspondingly slower.

All currents and voltages are assumed to be greater than or equal to zero.

When automatic initial estimates are made, ***FitAll*** assumes that the data are sorted on column number 1, that is, the X-values.

Also See

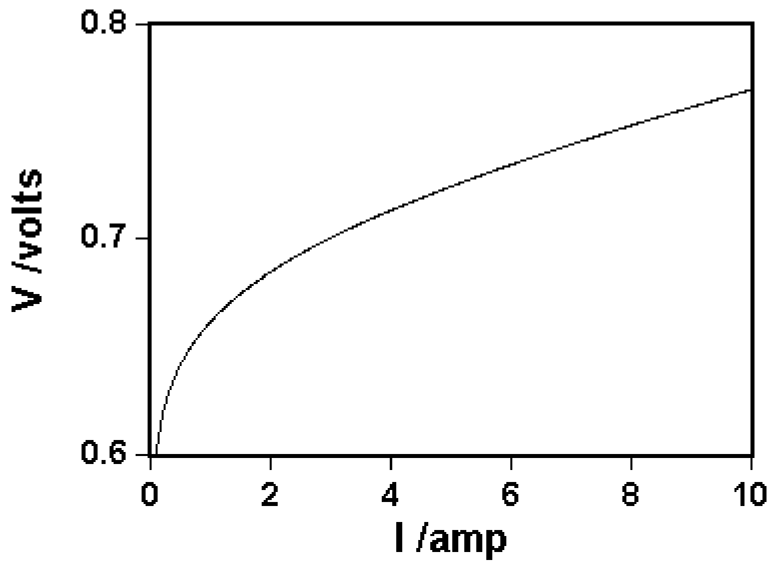
About Solar Cell-Strings And Modules 82

Function 0502 7, which is the same as this function except that the definitions of the dependent and independent variables are switched. That is, the meanings of X and Y are interchanged.

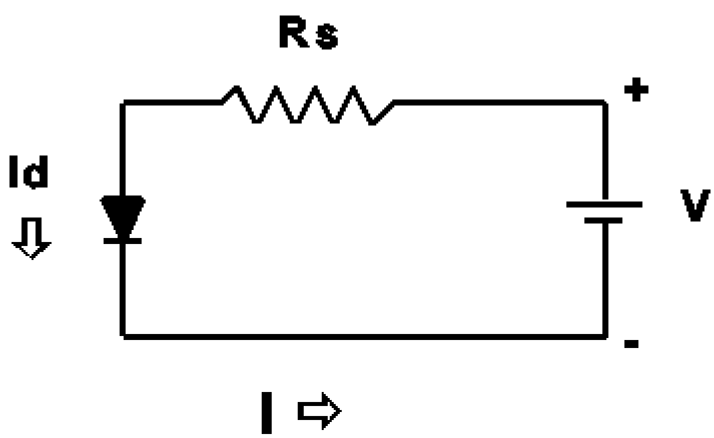
Function 0506 22, which is similar to this function except that the series resistance, Rs, is not present in the equivalent circuit.

Function 0522 60, which is similar to this function except that the equivalent circuit contains two non-ideal diodes. When fitting the data obtained from solar cell modules that contain more than a few cells it is advisable to initially fit the data to this function and then using the resulting parameters as the initial estimates when fitting the same data to function 0522.

Ftn 0513: Dark I-V: Model 1B: High I-range w/ Voltage Offset



Equivalent Circuit



Equation

$$Y = K3 * \left(\frac{K5 * (273.15 + K2)}{K1} * Ln \left| \frac{(X/K4 + P1)}{P1} \right| + X * P2/K4 \right) + P3$$

in which:

- Y is the measured response -- the voltage in volts.
- X is the independent variable -- the current in amperes.

Constants

Constant	Name	Comments
K1	q/k	Elementary charge, q = 1.602177E-19 Coulomb, divided by Boltzmann's constant, k = 1.380662E-23 J/ºK Default value is 1.160441151E4 CºK/J
K2	t	Temperature in ºC. Default value is 25.0 ºC.
K3	Ns	Number of series connected solar cells in a cell-string or module-string. Default value is 1.
K4	Np	Number of cell-strings connected in parallel in a module or PV System. Default value is 1.
K5	n	Ideality factor for the diode. For an ideal diode n = 1. For a non-ideal diode n > 1.

Parameters

Parameter	Name	Comments
P1	Id	Saturation current, in amperes, for the diode, in amperes
P2	Rs	Series resistance in ohms, Ω. Rs >= 0.
P3	Voffset	Voltage Offset, in volts, that *may* compensate for measurement errors due to an instrument calibration issue.

Sample Applications

- Characterizing the current-voltage behaviour of semiconductor diodes.
- Characterizing the dark current-voltage behaviour of solar cells.

Remarks

When automatic initial estimates are made, ***FitAll*** assumes that the data are sorted on column number 1, that is, the X-values.

All currents and voltages are assumed to be greater than or equal to zero.

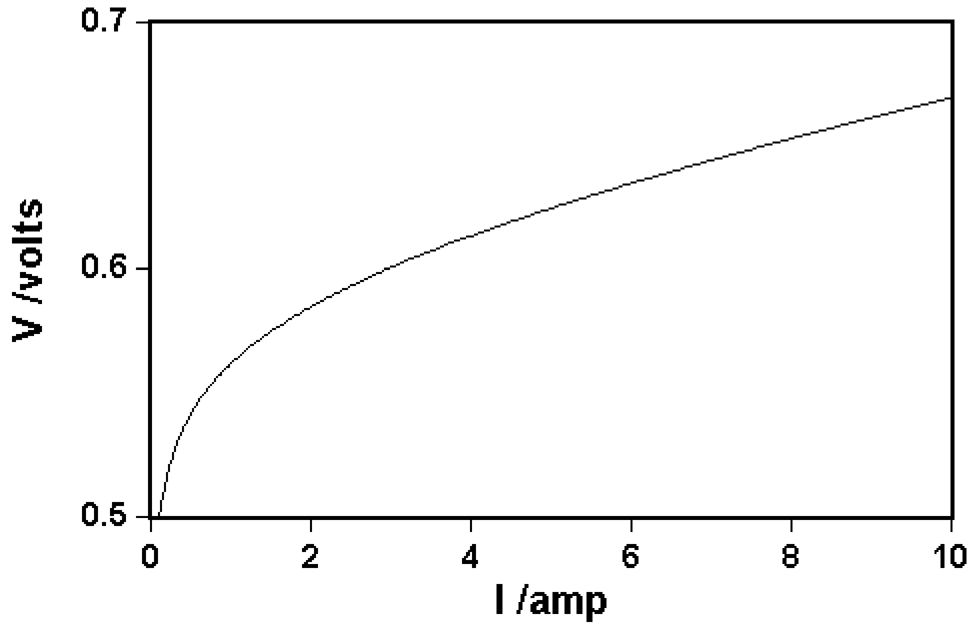
Also See

About Solar Cell-Strings And Modules 82

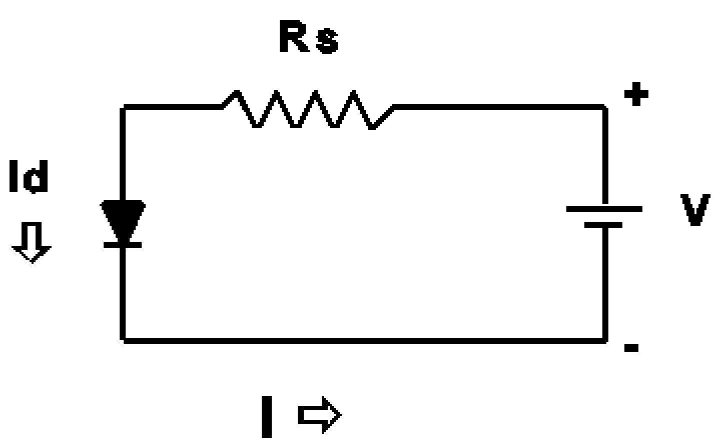
Function 0504 15, which is the same as this function except that it does not include the Voffset parameter.

Function 0514 49, which is the same as this function except that the diode ideality factor, constant K3, is treated as a parameter rather than an adjustable constant and does not include the Voffset parameter.

Ftn 0514: Dark I-V: Model 1C: High I-range: "n" as a Parameter



Equivalent Circuit



Equation

$$Y = K3 * \left(\frac{P3 * (273.15 + K2)}{K1} * \mathrm{Ln} \left| \frac{(X/K4 + P1)}{P1} \right| + X * P2/K4 \right)$$

in which:

- Y is the measured response -- the voltage in volts.
- X is the independent variable -- the current in amperes.

Constants

Constant	Name	Comments
K1	q/k	Elementary charge, q = 1.602177E-19 Coulomb, divided by Boltzmann's constant, k = 1.380662E-23 J/ºK Default value is 1.160441151E4 CºK/J
K2	t	Temperature in ºC. Default value is 25.0 ºC.
K3	Ns	Number of series connected solar cells in a cell-string or module-string. Default value is 1.
K4	Np	Number of cell-strings connected in parallel in a module or PV System. Default value is 1.

Parameters

Parameter	Name	Comments
P1	Id	Diode saturation current in amperes.
P2	Rs	Series resistance in ohms, Ω. Rs >= 0.
P3	n	Ideality factor for the diode. For an ideal diode n = 1. For a non-ideal diode n > 1.

Sample Applications

- Characterizing the current-voltage behaviour of semiconductor diodes.
- Characterizing the dark current-voltage behaviour of solar cells.

Remarks

All currents and voltages are assumed to be greater than or equal to zero.

When automatic initial estimates are made, ***FitAll*** assumes that the data are sorted on column number 1, that is, the X-values.

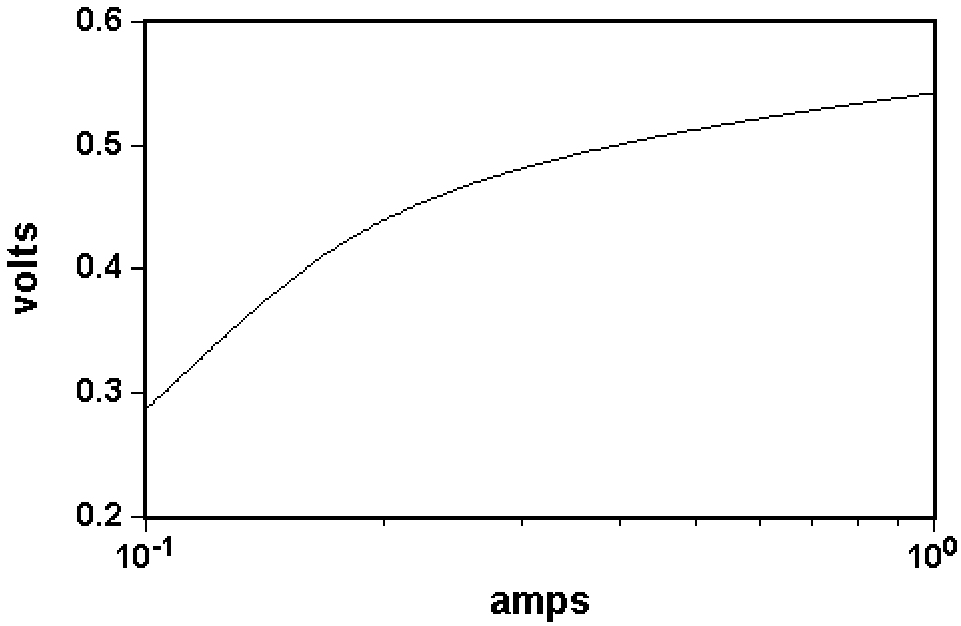
Also See

About Solar Cell-Strings And Modules 82

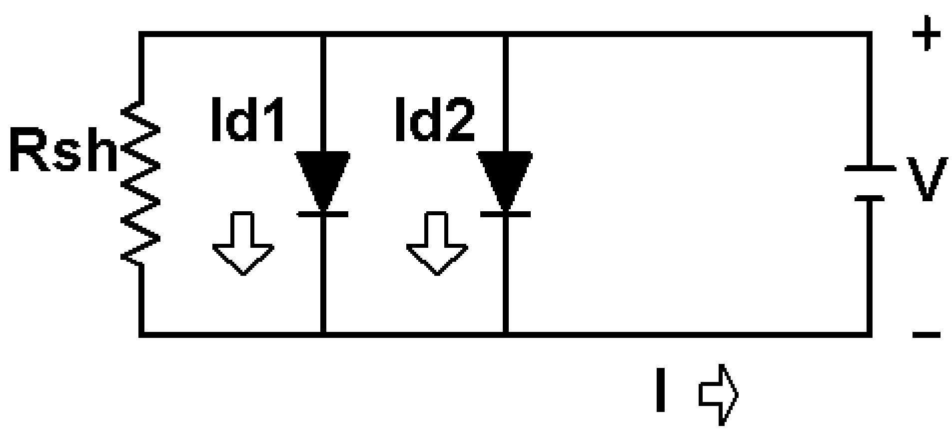
Function 0504 15, which is the same as this function except that the diode ideality factor,parameter P3, is treated as a manually adjustable constant.

Function 0534, which is the same as this function except that the series resistance, P2, is treated as a manually adjustable constant.

Ftn 0515: Dark I-V: Model 2B: Mid I-range: 2 Non-Ideal Diodes



Equivalent Circuit



Equation

$$Y = K3*P1*\left(X/K4 - P2*\left\{ e^{\left[\frac{K1*Y}{K3*P5*(273.15+K2)}\right]} - 1 \right\} - P3*\left\{ e^{\left[\frac{K1*Y}{K3*P4*(273.15+K2)}\right]} - 1 \right\} \right)$$

in which:

- Y is the measured response -- the voltage in volts.
- X is the independent variable -- the current in amperes.

Constants

Constant	Name	Comments
K1	q/k	Elementary charge, q = 1.602177E-19 Coulomb, divided by Boltzmann's constant, k = 1.380662E-23 J/ºK Default value is 1.160441151E4 CºK/J
K2	t	Temperature in ºC. Default value is 25.0 ºC.
K3	Ns	Number of series connected solar cells in a cell-string or module-string. Default value is 1.
K4	Np	Number of series connected solar cells in a cell-string or module-string. Default value is 1.

Constant	Name	Comments
K5	Max V /V	The maximum value of the voltage, V, that ***FitAll*** will use during the regression analysis. By default this is set to 1.5 times the maximum value of V in the current data set when the function is selected. Manually adjusting this to a lower value may help to reduce the occurrence of "numeric overflow" or "invalid floating point operation" errors during the analysis.

Parameters

Parameter	Name	Comments
P1	Rsh	Shunt resistance in ohms, Ω.
P2	Id1	Saturation current, in amperes, for ideal diode 1.
P3	Id2	Saturation current, in amperes, for non-ideal diode 2.
P4	n2	Ideality factor for diode 2. For an ideal diode n = 1. For a non-ideal diode n > 1.
P5	n1	Ideality factor for diode 1. For an ideal diode n = 1. For a non-ideal diode n > 1.

Sample Applications

- Characterizing the current-voltage behaviour of semiconductor diodes.
- Characterizing the dark current-voltage behaviour of solar cells.

Remarks

Because of the exponential nature of this function and the magnitude of the constants, some of the values generated can be very large (or very small) -- in fact, large enough to exceed the numeric range of your computer. If this happens, one or more error messages will appear and the calculations will be terminated.

This is an implicit function; that is, the dependent variable, Y, appears on both sides of the equation. ***FitAll*** uses an iterative method to evaluate this function. Function evaluations are more time consuming than normal and the regression analysis is correspondingly slower.

All currents and voltages are assumed to be greater than or equal to zero.

When automatic initial estimates are made, ***FitAll*** assumes that the data are sorted on column number 1, that is, the X-values.

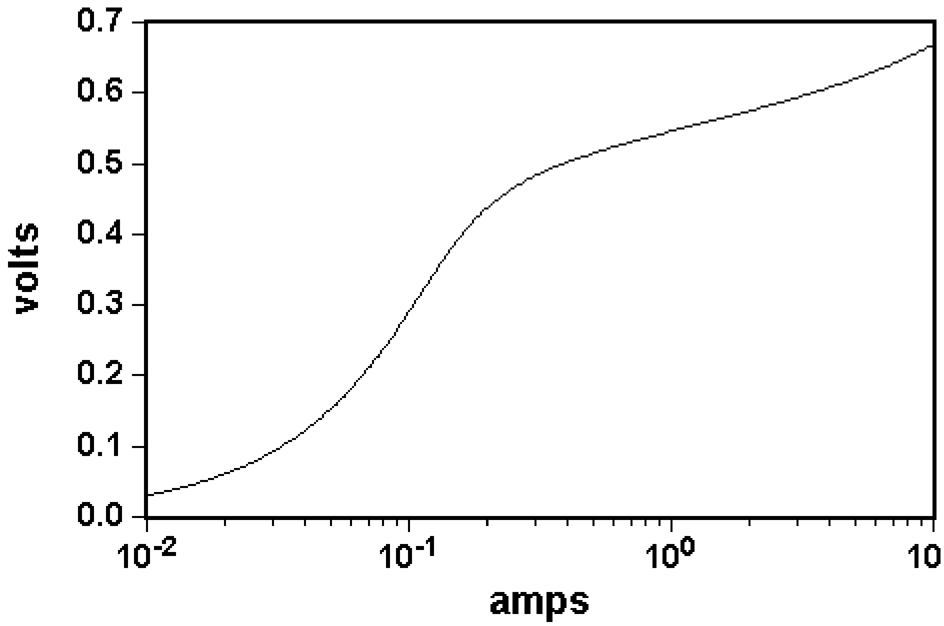
Also See

About Solar Cell-Strings And Modules 82

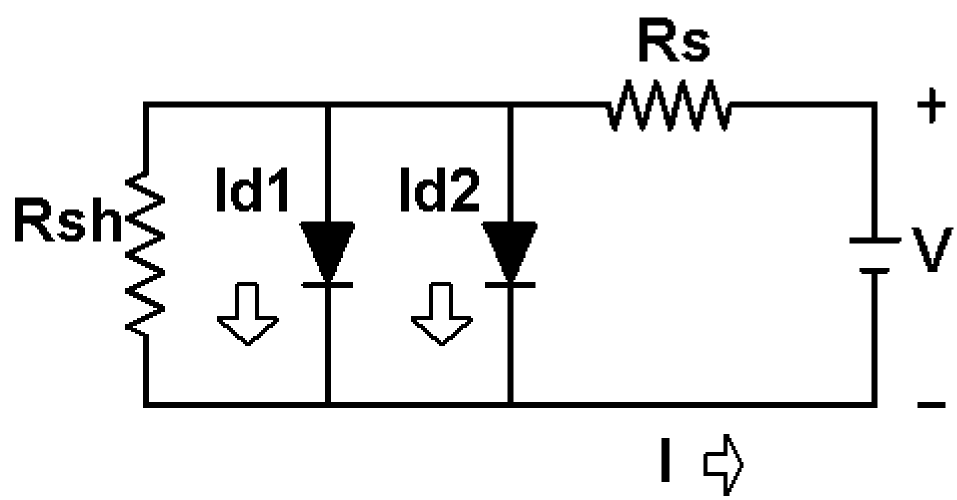
Function 0505 18, which is the same as this function except that diode 1 is treated as an ideal diode; that is, its ideality factor, n1, is assumed to have a value of 1.0.

Function 0525 67.

Ftn 0517: Dark I-V: Model 4B: Full I-range: 2 Non-Ideal Diodes



Equivalent Circuit



Equation

$$Y = K3 * \left[P1 * \left(\begin{array}{c} X/K4 - P2 * \left\{ e^{\left[\frac{K1 * (Y/K3 - X * P5/K4)}{P6 * (273.15 + K2)}\right]} - 1 \right\} \\ \\ - P3 * \left\{ e^{\left[\frac{K1 * (Y/K3 - X * P5/K4)}{P4 * (273.15 + K2)}\right]} - 1 \right\} \end{array} \right) + X * P5/K4 \right]$$

in which:

- Y is the measured response -- the voltage in volts.
- X is the independent variable -- the current in amperes.

Constants

Constant	Name	Comments
K1	q/k	Elementary charge, q = 1.602177E-19 Coulomb, divided by Boltzmann's constant, k = 1.380662E-23 J/ºK Default value is 1.160441151E4 CºK/J
K2	t	Temperature in ºC. Default value is 25.0 ºC.
K3	Ns	Number of series connected solar cells in a cell-string or module-string. Default value is 1.
K4	Np	Number of cell-strings connected in parallel in a module or PV System. Default value is 1.

Constant	Name	Comments
K5	Max V /V	The maximum value of the voltage, V, that ***FitAll*** will use during the regression analysis. By default this is set to 1.5 times the maximum value of V in the current data set when the function is selected. Manually adjusting this to a lower value may help to reduce the occurrence of "numeric overflow" or "invalid floating point operation" errors during the analysis.

Parameters

Parameter	Name	Comments
P1	Rsh	Shunt resistance in ohms, Ω.
P2	Id1	Saturation current for diode 1, in amperes
P3	Id2	Saturation current for diode 2, in amperes.
P4	n2	Ideality factor for diode 2. For an ideal diode n = 1. For a non-ideal diode n > 1.
P5	Rs	Series resistance in ohms, Ω.
P6	n1	Ideality factor for diode 1. For an ideal diode n = 1. For a non-ideal diode n > 1.

Sample Applications

- Characterizing the current-voltage behaviour of semiconductor diodes.
- Characterizing the dark current-voltage behaviour of solar cells.

Remarks

Because of the exponential nature of this function and the magnitude of the constants, some of the values generated can be very large (or very small) -- in fact, large enough to exceed the numeric range of your computer. If this happens, one or more error messages will appear and the calculations will be terminated.

This is an implicit function; that is, the dependent variable, Y, appears on both sides of the equation. ***FitAll*** uses an iterative method to evaluate this function. Function evaluations are more time consuming than normal and the regression analysis is correspondingly slower.

All currents and voltages are assumed to be greater than or equal to zero.

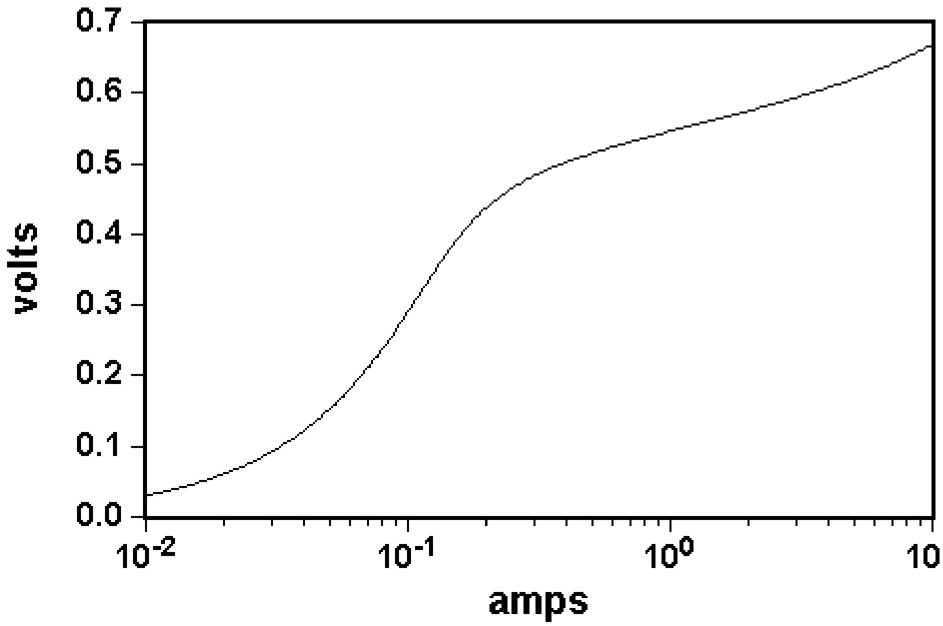
When automatic initial estimates are made, ***FitAll*** assumes that the data are sorted on column number 1, that is, the X-values.

Also See

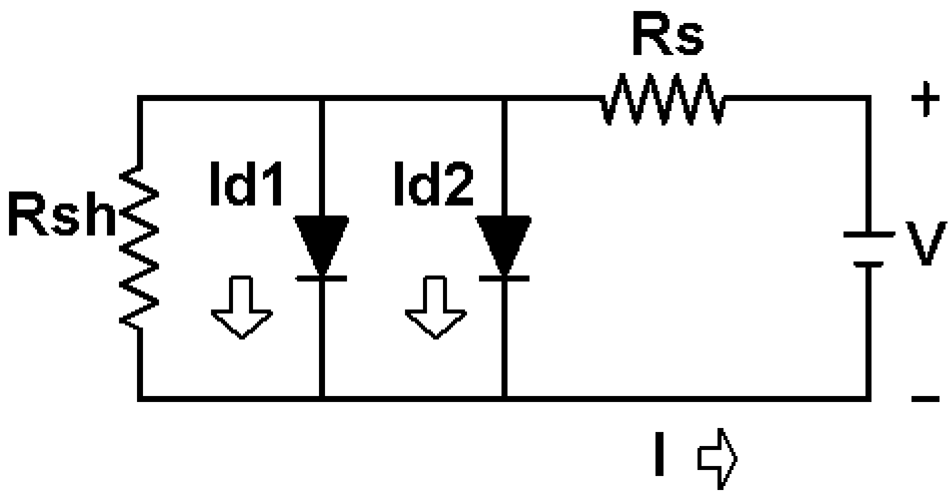
About Solar Cell-Strings And Modules 82

Function 0507 26, which is the same as this function except that one of the diodes is assumed to be an ideal diode; that is, it has an ideality factor, n, equal to 1.

Ftn 0522: Dark I-V: Model 4D: Full I-Range: 2 Non-Ideal Diodes with Rs



Equivalent Circuit



Equation

$$Y = K3 * \left[P1 * \left(X/K4 - P2 * \left\{ e^{\left[\frac{K1 * (Y/K3 - X * P4/K4)}{P3 * (273.15 + K2)} \right]} - 1 \right\} - P5 * \left\{ e^{\left[\frac{K1 * (Y/K3 - X * P4/K4)}{P6 * (273.15 + K2)} \right]} - 1 \right\} \right) + X * P4/K4 \right]$$

in which:

- Y is the measured response, the voltage in volts.
- X is the independent variable, the current in amperes.

Constants

Constant	Name	Comments
K1	q/k	Elementary charge, q = 1.602177E-19 Coulomb, divided by Boltzmann's constant, k = 1.380662E-23 J/^{o}K Default value is 1.160441151E4 C^{o}K/J

Constant	**Name**	**Comments**
K2	t	Temperature in ºC. Default value is 25 ºC.
K3	Ns	Number of series connected solar cells in a cell-string or module-string. Default value is 1.
K4	Np	Number of cell-strings connected in parallel in a module or PV System. Default value is 1.
K5	Max V /V	The maximum value of the voltage, V, that ***FitAll*** will use during the regression analysis. By default this is set to 1.5 times the maximum value of V in the current data set when the function is selected. Manually adjusting this to a lower value may help to reduce the occurrence of "numeric overflow" or "invalid floating point operation" errors during the analysis.

Parameters

Parameter	**Name**	**Comments**
P1	Rsh	Shunt resistance in ohms, Ω.
P2	Id1	Diode saturation current, in amperes, for diode 1.
P3	n1	Ideality factor, equal to one for an ideal semiconductor diode.
P4	Rs	Series resistance in ohms, Ω. It is often advantageous to limit Rs to values greater than or equal to zero. These are the only physically meaningful values of Rs.
P5	Id2	Diode saturation current, in amperes, for diode 2.
P6	n2	Ideality factor, equal to one for an ideal semiconductor diode.

Sample Applications

- Characterizing the current-voltage behaviour of semiconductor diodes.
- Characterizing the dark current-voltage behaviour of solar cells.

Remarks

This function is an implicit function; that is, its value depends on itself. The dependent variable, Y, appears on both sides of the equation. ***FitAll*** uses an iterative method to evaluate this function. Function evaluations are more time consuming than normal and the regression analysis is correspondingly slower.

All currents and voltages are assumed to be greater than or equal to zero.

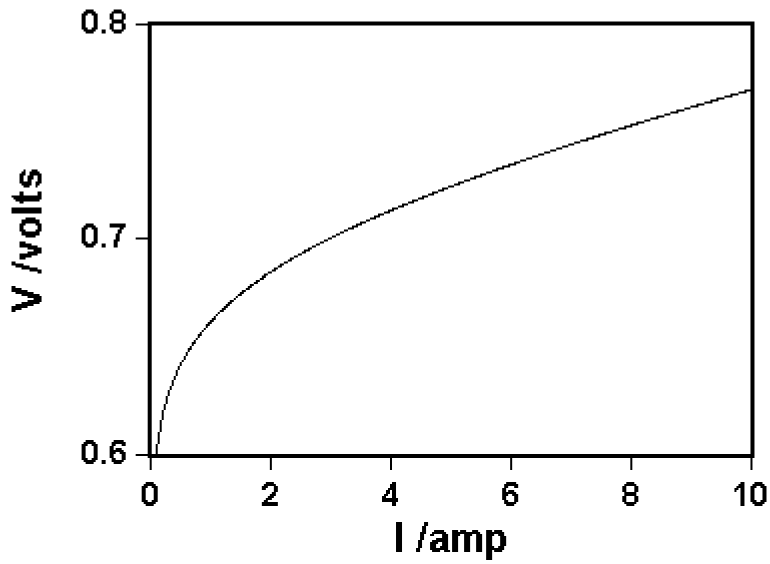
Often the best approach is to initially fit the data using function 0512 and then fitting it to this function.

Also See

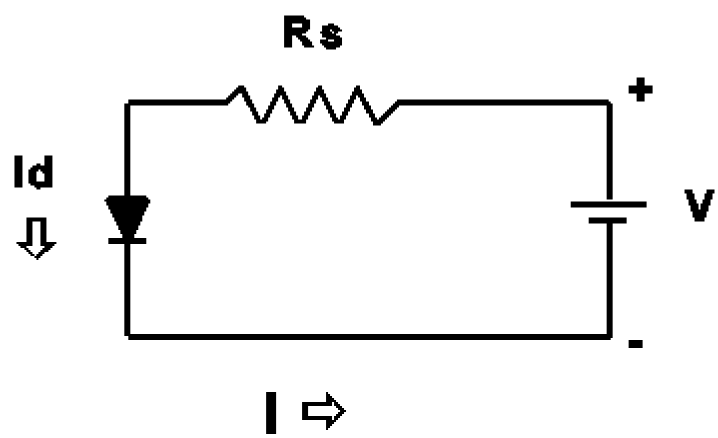
About Solar Cell-Strings And Modules 82

Function 0512 42, which is similar to this function, but the equivalent circuit contains only one diode..

Ftn 0524: Dark I-V: Model 1D: High I-range: w/ Voltage Offset



Equivalent Circuit



Equation

$$Y = K3 * \left(\frac{P3 * (273.15 + K2)}{K1} * \mathrm{Ln} \left| \frac{(X / K4 + P1)}{P1} \right| + X * P2 / K4 \right) + P4$$

in which:

- Y is the measured response -- the voltage in volts.
- X is the independent variable -- the current in amperes.

Constants

Constant	Name	Comments
K1	q/k	Elementary charge, q = 1.602177E-19 Coulomb, divided by Boltzmann's constant, k = 1.380662E-23 J/ºK Default value is 1.160441151E4 CºK/J
K2	t	Temperature in ºC. Default value is 25.0 ºC.
K3	Ns	Number of series connected solar cells in a cell-string or module-string. Default value is 1.
K4	Np	Number of cell-strings connected in parallel in a module or PV System. Default value is 1.

Parameters

Parameter	Name	Comments
P1	Id	Saturation current for diode, in amperes
P2	Rs	Series resistance in ohms, Ω. Rs >= 0.
P3	n	Ideality factor for the diode. For an ideal diode n = 1. For a non-ideal diode n > 1.
P4	Voffset	Voltage Offset, in volts, that *may* compensate for measurement errors due to an instrument calibration issue.

Sample Applications

- Characterizing the current-voltage behaviour of semiconductor diodes.
- Characterizing the dark current-voltage behaviour of solar cells.

Remarks

All currents and voltages are assumed to be greater than or equal to zero.

When automatic initial estimates are made, ***FitAll*** assumes that the data are sorted on column number 1, that is, the X-values.

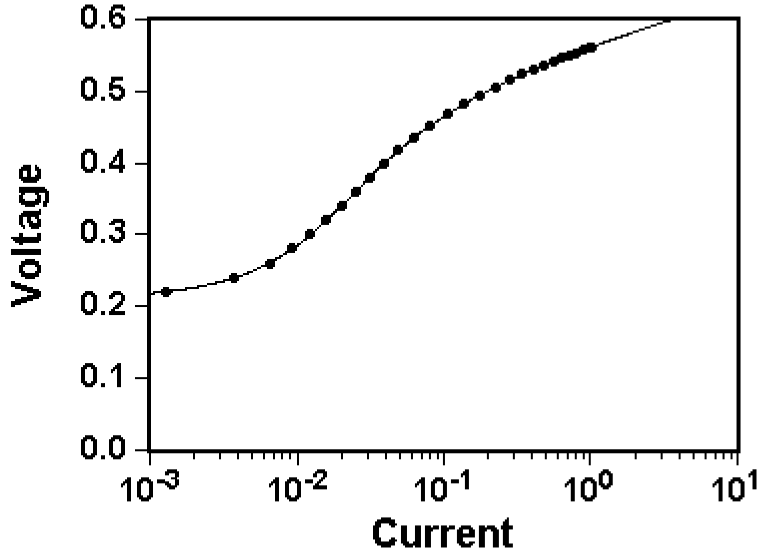
Also See

About Solar Cell-Strings And Modules 82

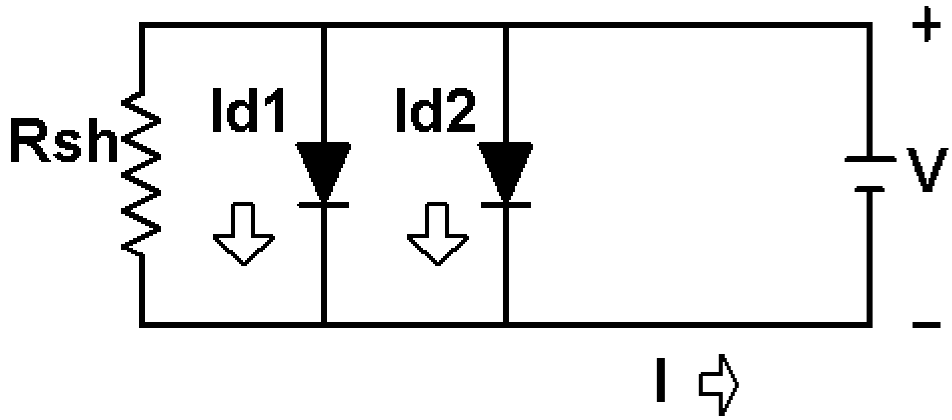
Function 0504 15, which is the same as this function except that the diode ideality factor, parameter P3, is treated as a manually adjustable constant and does not include the Voffset parameter.

Function 0514 49, which is the same as this function except that it does not include the Voffset parameter.

Ftn 0525: Dark I-V: Model 2C: Mid I-range w/ Voltage Offset



Equivalent Circuit



Equation

$$Y = K3 * P1 * \left(\begin{array}{l} X/K4 - P2 * \left\{ e^{\left[\frac{K1 * (Y - P5)}{K3 * (273.15 + K2)} \right]} - 1 \right\} \\ \\ - P3 * \left\{ e^{\left[\frac{K1 * (Y - P5)}{K3 * P4 * (273.15 + K2)} \right]} - 1 \right\} \end{array} \right) + P5$$

in which:

- Y is the measured response -- the voltage in volts.
- X is the independent variable -- the current in amperes.

Constants

Constant	Name	Comments
K1	q/k	Elementary charge, q = 1.602177E-19 Coulomb, divided by Boltzmann's constant, k = 1.380662E-23 J/ºK Default value is 1.160441151E4 CºK/J
K2	t	Temperature in ºC. Default value is 25.0 ºC.
K3	Ns	Number of series connected solar cells in a cell-string or module-string. Default value is 1.
K4	Np	Number of cell-strings connected in parallel in a module or PV System. Default value is 1.

Constant	Name	Comments
K5	Max V /V	The maximum value of the voltage, V, that ***FitAll*** will use during the regression analysis. By default this is set to 1.5 times the maximum value of V in the current data set when the function is selected. Manually adjusting this to a lower value may help to reduce the occurrence of "numeric overflow" or "invalid floating point operation" errors during the analysis.

Parameters

Parameter	Name	Comments
P1	Rsh	Shunt resistance in ohms, Ω.
P2	Id1	Saturation current for ideal diode 1, in amperes
P3	Id2	Saturation current for non-ideal diode 2, in amperes
P4	n2	Ideality factor for diode 2. For an ideal diode n = 1. For a non-ideal diode n > 1.
P5	Voffset	Voltage Offset, in volts, that *may* compensate for measurement errors due to an instrument calibration issue.

Sample Applications

- Characterizing the current-voltage behaviour of semiconductor diodes.
- Characterizing the dark current-voltage behaviour of solar cells.

Remarks

Because of the exponential nature of this function and the magnitude of the constants, some of the values generated can be very large (or very small) -- in fact, large enough to exceed the numeric range of your computer. If this happens, one or more error messages will appear and the calculations will be terminated.

This is an implicit function; that is, the dependent variable, Y, appears on both sides of the equation. ***FitAll*** uses an iterative method to evaluate this function. Function evaluations are more time consuming than normal and the regression analysis is correspondingly slower.

All currents and voltages are assumed to be greater than or equal to zero.

When automatic initial estimates are made, ***FitAll*** assumes that the data are sorted on column number 1, that is, the X-values.

Also See

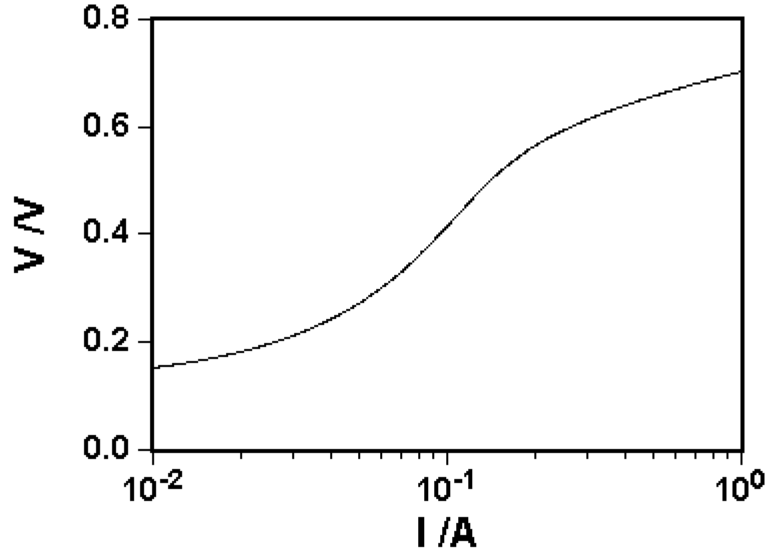
About Solar Cell-Strings And Modules 82

Function 0505 18, which is the same as this function except that it does not include the Voffset parameter.

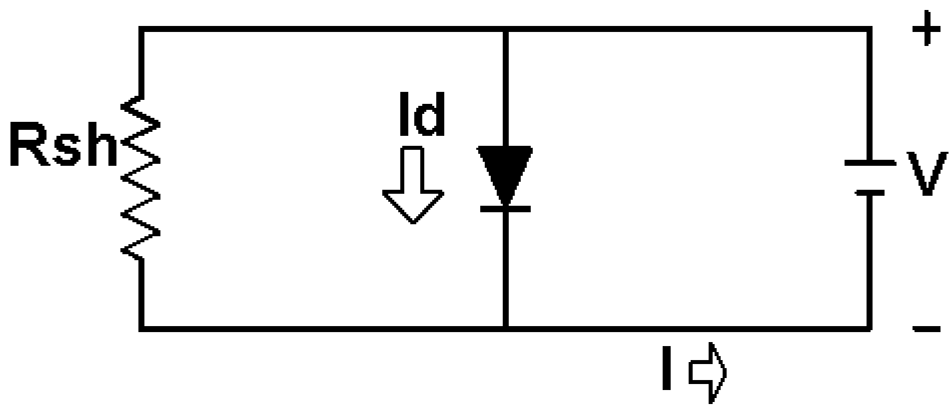
Function 0515 52.

Function 0527 74.

Ftn 0526: Dark I-V: Model 3B: Low I-range w/ Voltage Offset



Equivalent Circuit



Equation

$$Y = K3 * P1 * \left(X/K4 - P2 * \left\{ e^{\left[\frac{K1*(Y - P4)}{(K3*P3*(273.15+K2))}\right]} - 1 \right\} \right) + P4$$

in which:

- Y is the measured response -- the voltage in volts.
- X is the independent variable -- the current in amperes.

Constants

Constant	Name	Comments
K1	q/k	Elementary charge, q = 1.602177E-19 Coulomb, divided by Boltzmann's constant, k = 1.380662E-23 J/ºK Default value is 1.160441151E4 CºK/J
K2	t	Temperature in ºC. Default value is 25.0 ºC.
K3	Ns	Number of series connected solar cells in a cell-string or module-string. Default value is 1.
K4	Np	Number of cell-strings connected in parallel in a module or PV System. Default value is 1.
K5	Max V /V	The maximum value of the voltage, V, that ***FitAll*** will use during the regression analysis. By default this is set to 1.5 times the maximum value of V in the current data set when the function is selected. Manually adjusting this to a lower value may help to reduce the occurrence of "numeric overflow" or "invalid floating point operation" errors during the analysis.

Parameters

Parameter	Name	Comments
P1	Rsh	Shunt resistance in ohms, Ω.
P2	Id	Saturation current for the diode, in amperes
P3	n	Ideality factor for the diode. For an ideal diode n = 1. For a non-ideal diode n > 1.

Parameter	Name	Comments
P4	Voffset	Voltage Offset, in volts, that *may* compensate for measurement errors due to an instrument calibration issue.

Sample Applications

- Characterizing the current-voltage behaviour of semiconductor diodes.
- Characterizing the dark current-voltage behaviour of solar cells.

Remarks

Because of the exponential nature of this function and the magnitude of the constants, some of the values generated can be very large (or very small) -- in fact, large enough to exceed the numeric range of your computer. If this happens, one or more error messages will appear and the calculations will be terminated.

This is an implicit function; that is, the dependent variable, Y, appears on both sides of the equation. ***FitAll*** uses an iterative method to evaluate this function. Function evaluations are more time consuming than normal and the regression analysis is correspondingly slower.

All currents and voltages are assumed to be greater than or equal to zero.

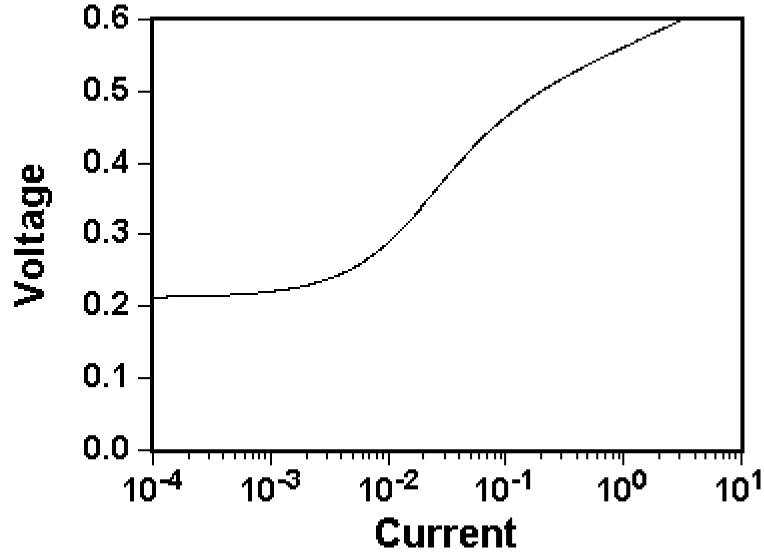
When automatic initial estimates are made, ***FitAll*** assumes that the data are sorted on column number 1, that is, the X-values.

Also See

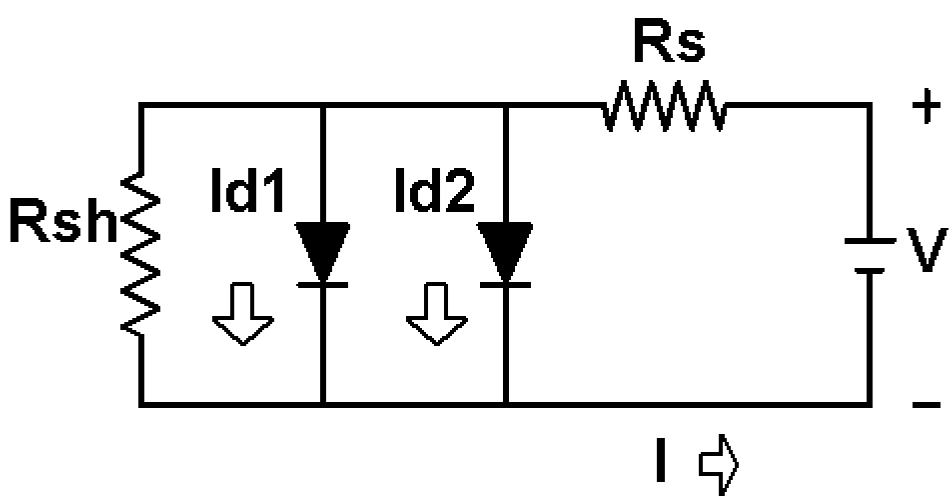
About Solar Cell-Strings And Modules 82

Function 0506 22, which is the same as this function except that it does not include the voltage offset parameter.

Ftn 0527: Dark I-V: Model 4C: Full I-range: w/ Voltage Offset



Equivalent Circuit



Equation

$$Y = K3 * \left[P1 * \left(X/K4 - P2 * \left\{ e^{\left[\frac{K1 * ((Y - P6)/K3 - X * P5/K4)}{(273.15 + K2)}\right]} - 1 \right\} - P3 * \left\{ e^{\left[\frac{K1 * ((Y - P6)/K3 - X * P5/K4)}{(P4 * (273.15 + K2))}\right]} - 1 \right\} \right) + X * P5/K4 \right] + P6$$

in which:

- Y is the measured response -- the voltage in volts.
- X is the independent variable -- the current in amperes.

Constants

Constant	Name	Comments
K1	q/k	Elementary charge, q = 1.602177E-19 Coulomb, divided by Boltzmann's constant, k = 1.380662E-23 J/ºK Default value is 1.160441151E4 CºK/J
K2	t	Temperature in ºC. Default value is 25.0 ºC.
K3	Ns	Number of series connected solar cells in a cell-string or module-string. Default value is 1.
K4	Np	Number of cell-strings connected in parallel in a module or PV System. Default value is 1.

Constant	Name	Comments
K5	Max V /V	The maximum value of the voltage, V, that ***FitAll*** will use during the regression analysis. By default this is set to 1.5 times the maximum value of V in the current data set when the function is selected. Manually adjusting this to a lower value may help to reduce the occurrence of "numeric overflow" or "invalid floating point operation" errors during the analysis.

Parameters

Parameter	Name	Comments
P1	Rsh	Shunt resistance in ohms, Ω.
P2	Id1	Saturation current for diode 1, in amperes
P3	Id2	Saturation current for diode 2, in amperes.
P4	n2	Ideality factor for diode 2. For an ideal diode n = 1. For a non-ideal diode n > 1.
P5	Rs	Series resistance in ohms, Ω.
P6	Voffset	Voltage Offset that *may* compensate for measurement errors due to an instrument calibration issue.

Sample Applications

- Characterizing the current-voltage behaviour of semiconductor diodes.
- Characterizing the dark current-voltage behaviour of solar cells.

Remarks

Because of the exponential nature of this function and the magnitude of the constants, some of the values generated can be very large (or very small) -- in fact, large enough to exceed the numeric range of your computer. If this happens, one or more error messages will appear and the calculations will be terminated.

This is an implicit function; that is, the dependent variable, Y, appears on both sides of the equation. ***FitAll*** uses an iterative method to evaluate this function. Function evaluations are more time consuming than normal and the regression analysis is correspondingly slower.

All currents and voltages are assumed to be greater than or equal to zero.

When automatic initial estimates are made, ***FitAll*** assumes that the data are sorted on column number 1, that is, the X-values.

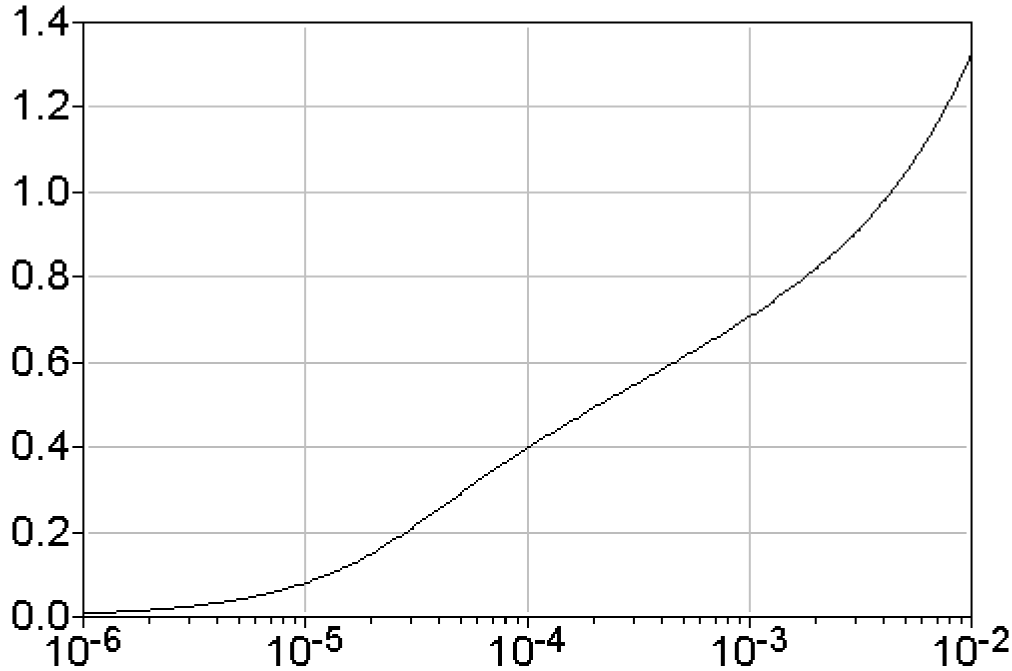
Also See

About Solar Cell-Strings And Modules 82

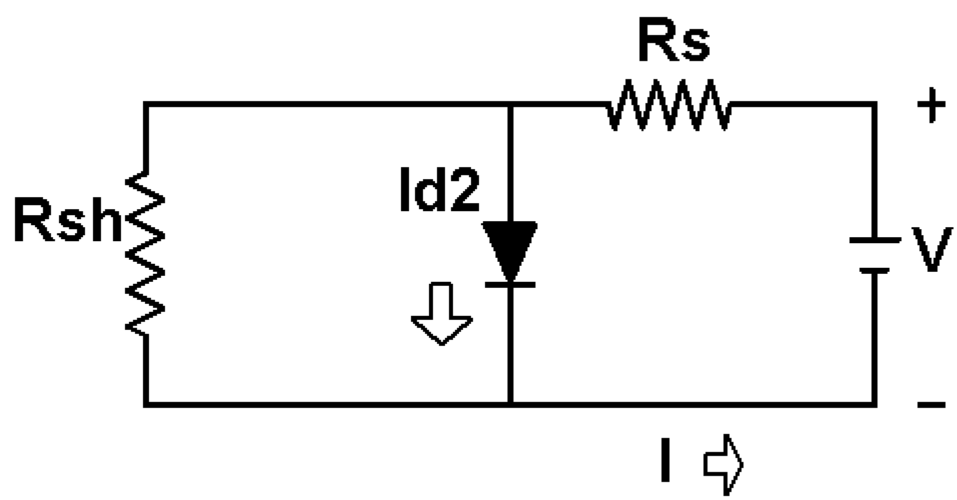
Function 0507 26, which is the same as this function except that it does not include the voltage offset parameter.

Function 0517 56, which is the same as this function except that it does not include the voltage offset parameter and treats both diodes as non-ideal.

Ftn 0528: Dark I-V: Model 4F: Full I-range: 1 non-ideal diode w/ V offset



Equivalent Circuit



Equation

$$Y = K3^*\left[P1^*\left[X/K4 - P2^*\left\{e^{\left[\frac{K1^*((Y-P5)/K3-X^*P4/K4)}{(P3^*(273.15+K2))}\right]} - 1\right\}\right] + X^*P4/K4\right]$$

in which:

- Y is the measured response -- the voltage in volts.
- X is the independent variable -- the current in amperes.

Constants

Constant	Name	Comments
K1	q/k	Elementary charge, q = 1.602177E-19 Coulomb, divided by Boltzmann's constant, k = 1.380662E-23 J/ºK Default value is 1.160441151E4 CºK/J
K2	t	Temperature in ºC. Default value is 25.0 ºC.
K3	Ns	Number of series connected solar cells in a cell-string or module-string. Default value is 1.
K4	Np	Number of cell-strings connected in parallel in a module or PV System. Default value is 1.
K5	Max V /V	The maximum value of the voltage, V, that ***FitAll*** will use during the regression analysis. By default this is set to 1.5 times the maximum value of V in the current data set when the function is selected. Manually adjusting this to a lower value may help to reduce the occurrence of "numeric overflow" or "invalid floating point operation" errors during the analysis.

Parameters

Parameter	Name	Comments
P1	Rsh	Shunt resistance in ohms, Ω.

Parameter	Name	Comments
P2	Id2	Saturation current, in amperes, for diode 2, in amperes.
P3	n2	Ideality factor for diode 2. For an ideal diode n = 1. For a non-ideal diode n > 1.
P4	Rs	Series resistance in ohms, Ω.
P5	Voffset	Voltage Offset that *may* compensate for measurement errors due to an instrument calibration issue.

Sample Applications

- Characterizing the current-voltage behaviour of semiconductor diodes.
- Characterizing the dark current-voltage behaviour of solar cells.

Remarks

Because of the exponential nature of this function and the magnitude of the constants, some of the values generated can be very large (or very small) -- in fact, large enough to exceed the numeric range of your computer. If this happens, one or more error messages will appear and the calculations will be terminated.

This is an implicit function; that is, the dependent variable, Y, appears on both sides of the equation. ***FitAll*** uses an iterative method to evaluate this function. Function evaluations are more time consuming than normal and the regression analysis is correspondingly slower.

All currents and voltages are assumed to be greater than or equal to zero.

When automatic initial estimates are made, ***FitAll*** assumes that the data are sorted on column number 1, that is, the X-values.

Also See

About Solar Cell-Strings And Modules 82

Function 0508 30, which is the same as this function except that it does not include the voltage offset parameter.

Appendix

About Solar Cell-Strings, Modules, Module-Strings & PV Systems 82

Getting Help 87

Adding Functions to FitAll 88

Acknowledgments 89

About Solar Cell-Strings, Modules, Module-Strings & PV Systems

Prior to ***FitAll*** version 8 all of the solar cell functions were derived to describe the characteristics of a **single solar cell**.

Now ***FitAll***'s solar cell functions can be used to directly analyze the I-V data from solar "cell-string" and module measurements to obtain the characteristics of an "average" solar cell within the "cell-string" or module.

For the purposes of the following discussion it is helpful to define several terms.

Cell-String: A device that contains one or more, say 60 or 72, solar cells that are connected in series.

Module: A device that contains one or more cell-strings connected in parallel.

Module-String: A device that contains one or more modules connected in series.

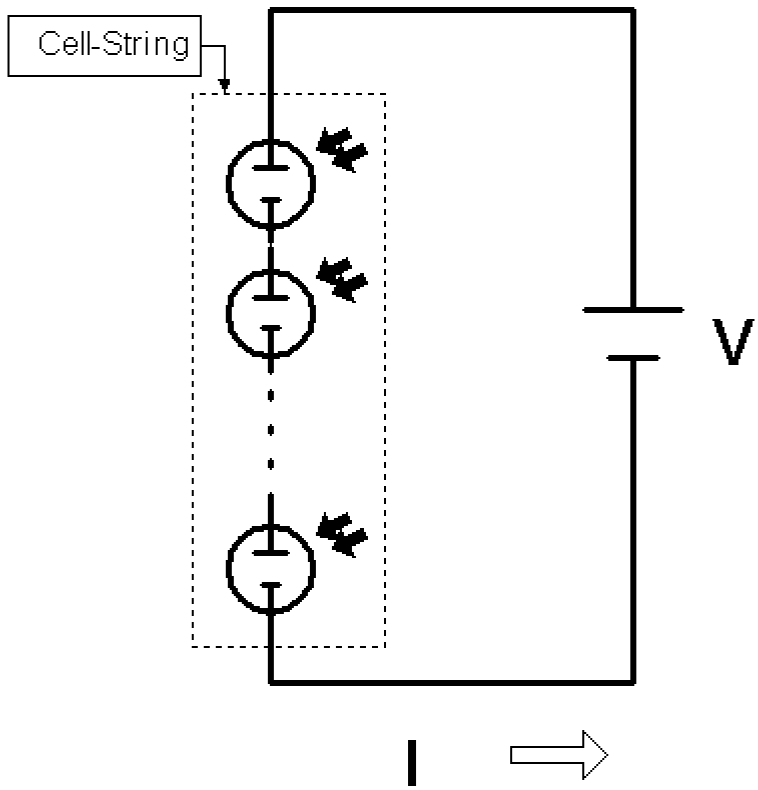
PV System: A device that contains one or more module-strings connected in parallel.

Ns: Number of series connected solar cells in a cell-string or module-string.

Np: Number of cell-strings connected in parallel in a module or PV System.

Solar Cell-String

Equivalent Circuit



Remarks

As can be seen from the equivalent circuit:

1. The current through each solar cell is equal to the total current flowing through the cell-string.

2. The voltage drop across each solar cell is equal to the total voltage divided by the number of solar cells, Ns, in the cell-string. That is, the voltage drop across each of the solar cells equals **V/Ns.**

3. The above **assumes** that all of the solar cells are **identical**. When ***FitAll***'s solar cell functions are used with an appropriate value of Ns, the number of cells in series, the resulting cell parameters correspond to those of an individual solar cell in the cell-string.

4. In the real world, the solar cells will not be identical and the resolved cell parameters will correspond to those of an "average" solar cell in the cell-string.

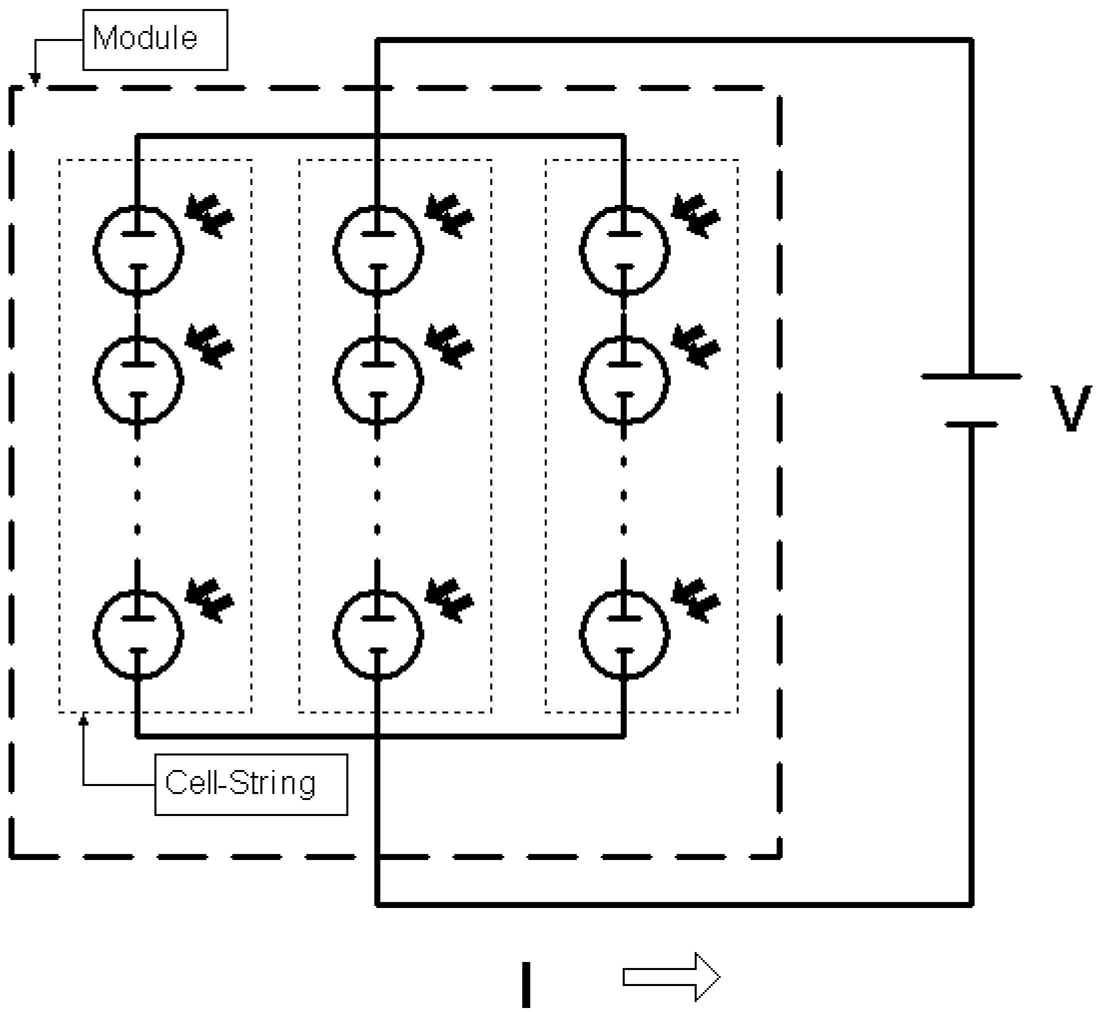
5. If one, or more, of the cells in the cell-string has degraded, the regression analysis may not yield typical "single-cell" parameter values.

   When measurements are made over time the changes in the cell parameter values *may* help to diagnose the issue causing the cell-string's reduced performance.

6. If one, or more, of the cells in the cell-string has failed in a "short-circuit" condition the value of Ns should be reduced by the number of cells that have short-circuited. It is not easy to know or determine whether one or more cells have short-circuited. One approach is to reduce the value of Ns and re-do the analysis to see if the resulting fit gives more reasonable results.

Solar Module

Equivalent Circuit



Remarks

The above equivalent circuit describes a Module that contains three cell-strings connected in parallel.

This corresponds to a "typical" solar module in which each cell-string contains the same number of cells, say 60.

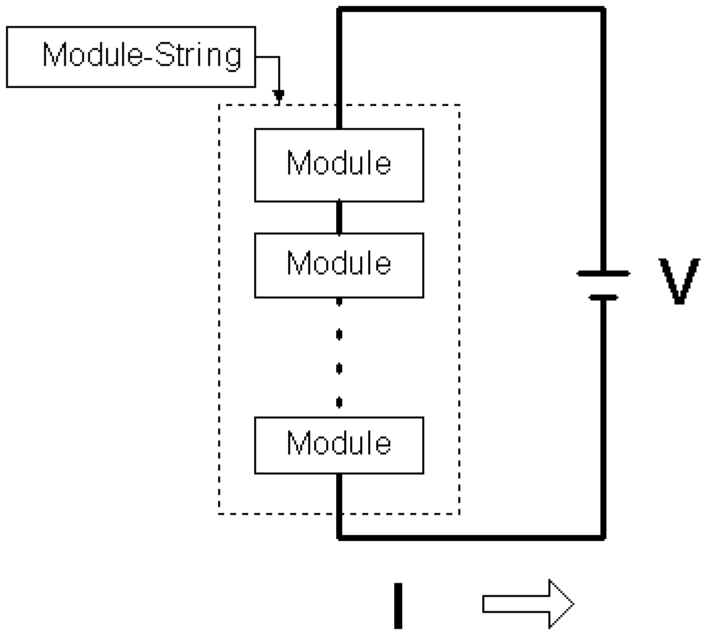
When analyzing the IV data obtained from this module:

1. The value of Ns should be set to 60, because that is the number of solar cells in each cell-string.

2. The value of Np should be set to three, 3, because that is the number of cell-strings that are connected in parallel.

Solar Module-String

Equivalent Circuit



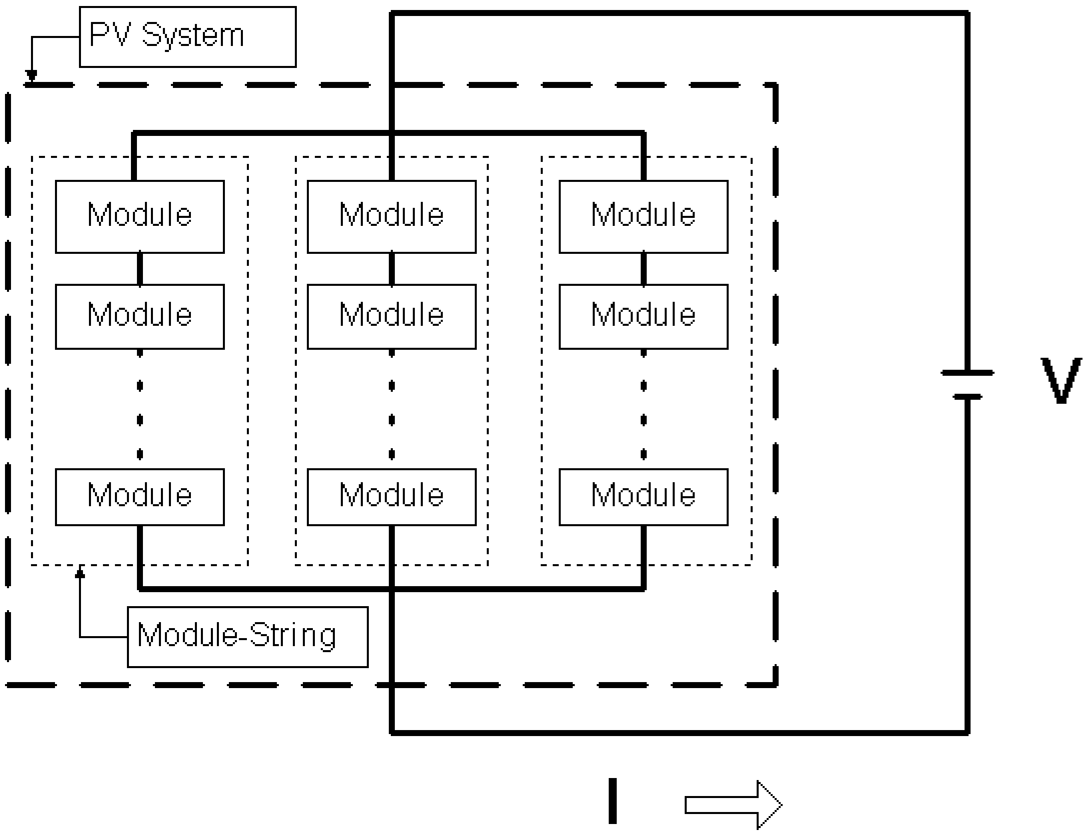
Remarks

The above equivalent circuit describes a module-string that contains several modules connected in series.

When analyzing I-V data obtained for a module-string the values of Ns and Np are arrived at in a analogous manner to that used for cell-strings and modules.

Solar PV System

Equivalent Circuit



Remarks

The above equivalent circuit describes a PV System that contains three module-strings connected in parallel.

When analyzing I-V data obtained for a PV System the values of Ns and Np are arrived at in a analogous manner to that used for cell-strings and modules.

Getting Help

To get technical or other assistance from MTR Software you can:

Visit MTR Software's website at:

www.fitall.com

Email MTR Software at:

support@fitall.com

Write to MTR Software at:

MTR Software

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Telephone MTR Software at:

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Describe your problem or difficulty as completely as you can. We will try to answer your query quickly and completely.

You should also include your email address as well as your daytime, evening and weekend telephone numbers.

Adding Functions to FitAll

There are four ways to add your own specialized functions to ***FitAll***.

1. In ***FitAll*** version 10 you can use the new "Scripted Function" feature to add functions that can be defined by a one-line expression and contains one independent variable, X. and up to ten parameters, P.

2. You can contact ***MTR*** **Software** to get a quotation on the cost of creating a custom ***FitAll*** **Function Library** for you.

3. The ***FitAll*** **Programmer's Guide**, which is included with ***FitAll*** **Research Edition**, explains:

   - how to modify the supplied source code for the User Defined ***FitAll*** **Function Libraries** and

   - how to compile them using Embarcadero / CodeGear / Borland Delphi version 5 to XE2, **FreePascal** version 2.2 or later and **Lazarus** version 1.0 or later. FreePascal and Lazarus are open source Pascal compilers available from www.freepascal.org and www.lazarus.freepascal.org . Lazarus is highly recommended.

4. You can contact ***MTR*** **Software** and request that the function be added to one of ***FitAll***'s **Function Libraries**.

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Index

- A -

Acknowledgments 89

- C -

Cell-String
  solar 82
Contacting MTR Software 87
Current-Voltage 3, 7, 11, 42, 60

- D -

Dark Current-Voltage 3, 7, 11, 42, 60
Dark I-V 15, 18, 22, 26, 30, 46, 49, 52, 56, 64, 67, 71, 74

- E -

Exponential 18, 22, 26, 30, 52, 56, 67, 71, 74

- F -

Function 3, 7, 11, 15, 18, 22, 26, 30, 33, 36, 39, 42, 46, 49, 52, 56, 60, 64, 67, 71, 74
  Current-Voltage 3
  exponential 18, 22, 26, 30, 52, 56, 67, 71, 74
  implicit 3, 7, 11, 18, 22, 26, 30, 36, 39, 42, 52, 56, 60, 67, 71, 74
  logarithmic 15, 46, 49, 64
  solar cell 3, 7, 11, 15, 18, 22, 26, 30, 33, 36, 39, 42, 46, 49, 52, 56, 60, 64, 67, 71, 74
Function Reference 2

- H -

Help 87
How to
  contact MTR Software 87

- I -

Implicit 3, 7, 11, 18, 22, 26, 30, 36, 39, 42, 52, 56, 60, 67, 71, 74

- M -

Module
  solar 82
Module-String
  solar 82

- P -

PV System
  solar 82

- S -

Solar
  cell-string 82
  module 82
  module-string 82
  PV System 82
Solar Cell
  Dark Current-Voltage 3, 7, 11, 42, 60
  Dark I-V: Model 1: High I-range 15, 46, 49, 64
  Dark I-V: Model 2: Mid I-range 18, 52, 67
  Dark I-V: Model 3: Low I-range 22, 71
  Dark I-V: Model 4: Full I-range 26, 30, 56, 74
  Light I-V 33, 36, 39