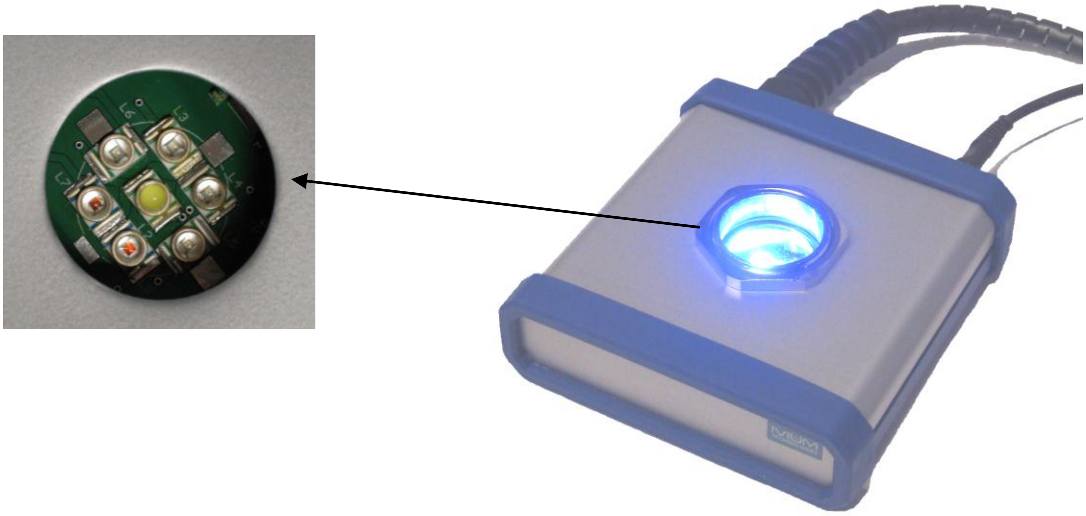
Product Note P9

ModuLight User Guide



The ModuLight-module is a programmable light source that has been designed to investigate photo-electrical devices, such as solar cells. The add-on module will operate in combination with Ivium potentiostats, through the peripheral I/O-port.

The ModuLight, by default, contains 7 LEDs with wavelengths ranging from 460-740 nm. On request LEDs can be exchanged for others from the same product range (see table below).

During operation an LED can be programmatically selected. The sinewave generator of the potentiostat can then be used to modulate the intensity of the LED with a frequency of 10uHz-2MHz. The extensive Solar cell applications that are included in the Ivium software allow a full characterization of the solar cell. The functionality includes E/I curves as function of the light intensity, IMVS/IMPS, and solar cell modelling resulting in all characteristic values of the studied object.

1. Modulight specifications

Mode	Color	Wavelength [nm]	Power [mW]	Digital Code
1	White	4100 K	200lm	IIO
2	Blue	460	976	IOI
3	Green	525	279	IOO
4	Amber	590	203	OII
5	Red	623	461	OIO
6	Deep Red	660	720	OOI
7	Far Red	740	405	OOO
	UV	365	170	Optional
	UV	400	700	Optional
	Cool White	5500 K	220lm	Optional
	Warm White	3100 K	170lm	Optional

Table 1 wavelength specification

Light intensity	can be modulated with the FRAoutput of the build-in sinewave generator of the IviumStat/CompactStat from 10 µHz to 2 MHz.
Bias resolution	16 bit, 0.0015%
Wavelength	set programmatically 465-635 nm in 7 steps
Power	0 - 976 mW
Bandwidth	0 => 2 MHz
power requirements	external adapter: 100-240 V, 45-65Hz at DC-connector: 5 V, 1A
Size	w x d x h = 12 x 13 x 2.5 cm
Weight	0.5 kg
Interfacing/connectivity	HD37, connects to the potentiostat peripheral port
Use	only i.c.w. Ivium potentiostats

2. Installation

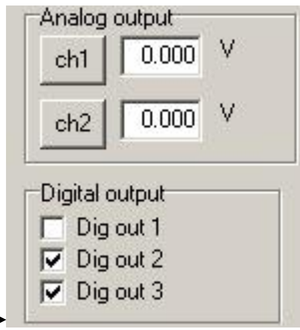
Connect the ModuLight to the HD37 peripheral port of the IviumStat or CompactStat. Connect the external 5V adapter. The ModuLight is now ready for operation, using the IviumSoft-software. The test object (solar cell) can be connected to the cell cable and illuminated with the ModuLight.

The operation of the ModuLight is indepent of its position, i.e. the ModuLight can be placed under, on top, to the side, etc. of the test object.

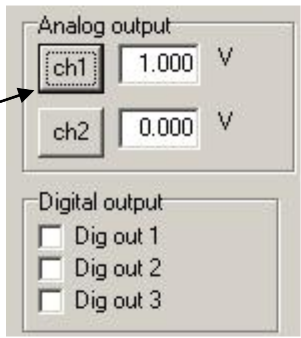
3. Direct operation

The ModuLight can emit a modulated light flux of 6 different wavelengths and 1 wavelength spread (white), using 7 different LED's as light source. The specifications of each wavelength are given in table 1 (above).

Color Selection
The color/LED can be selected by using the 3 digital outputs of the peripheral port. The digital codes are given in table 1. (Note that these codes are according to the electronic standards, i.e. counting from right to left). The digital outputs can be accessed in the IviumSoft from the "Direct" tab in the "Extern" tab below. As an example, to choose the color "white", the digital code is "IIO". This means that "Dig out 3" and "Dig out 2" need to be checked and "Dig out 1" is unchecked.



Intensity
The intensity of the light is controlled via the Analog output1. This output has a range of 0 – 4V, which corresponds to a light output of 0–100%. For example enter "1"V into the ch1 field and press "ch1". This will effect a light output of 25% of the chosen color.



Modulation

The modulation of the light is controlled via the AC-output of the peripheral port. The AC-output can be accessed in the IviumSoft from the "Direct" tab in the "AC" tab (bottom window). The rate of modulation is controlled by the Frequency setting. For the AC voltage, 0 – 1V corresponds to a modulation of 0 –100% <u>of the full scale modulation</u> which is added to the dc offset selected. For example, if Analog output ch1 is set to 2V, and the Ac signal Amplitude is set to "0.500" then, upon pressing "Apply", the light will start modulating between 100% intensity and 0% intensity at the chosen frequency (2 Hz in this example). The 2V DC sets the light amplitude at 50% of maximum then 0.5V AC adds a modulation depth of 50% of full scale and so the combined signal oscillates between full-scale amplitude and zero. The calculation of settings required for a particular modulation depth needs to be done with this in mind.

Note1: When controlling the ModuLight from the direct mode, it should be taken into account that communication between PC and Ivium device only takes place once per second. This means that there may be a delay of up to one second before a change takes effect.

Note2: The peripheral port signal output depends on the Ivium instrument type. I.e. when the "Plus-module" option is checked, the AC-output signal is a factor of 5.33 lower than the set value; when the "XR 20V" option is checked, the AC-output signal is a factor of 2 lower than the set value. This means that in these cases the amplitude of the light intensity variation is equally less. If this is an issue, please contact Ivium Technologies for a solution.

4. Running a Method

4.1 Single method

A single method can be run by first setting the desired parameters of the ModuLight, such as wavelength and intensity, in the "Direct" mode tab. Then in the "Method" mode tab, a method can be run. I.e. to measure an E/I curve of a solar cell, the desired wavelenght and intensity can be set, and then the E/I curve can be measured using the linear sweep method.

To run an impedance measurement, first the ModuLight parameters need to be set in the "Direct" mode tab. Then in the "Method" mode tab the desired impedance technique is selected (for example "Constant E"). Then the "Advanced" parameters need to be activated. In the method parameters now "MeasConfig" is available. This parameter determines how and which signals are recorded and shown in the graph (see also paragraph 5).

4.2 Automated methods

Batch mode

In the "BatchMode" it is possible to run several methods successively. In between running the successive methods it is possible to change the wavelength and intensity of the ModuLight. To do this add a "DirectCommand" line in the appropriate place in the batch program. When this line is selected in the Line-properties below, the wavelength can be chosen by ticking the "SetDigOut" box. The boxes for the individual digital outputs become available and by ticking the relevant boxes the wavelength can be chosen. In the same way ticking the "SetDAC" box will make the analog outputs available. Inserting the desired value in the "DAC 1" field will set the intensity of the light.

Mixed mode
In the transient technique "MixedMode" a sequence of operations can be programmed in the window of "Stages" method parameter. In the "Properties for Level", at the bottom of the list the following parameters allow operation of the ModuLight:

- AnOut1: when ticked a value can be entered from 1 - 4 V which determines the intensity of the light 1 - 100% (in the same way as in the direct mode operation, see above).
- Digouts: when ticket an integer value can be entered to select the color. This integer corresponds to an 8 bit conversion for the digital outputs, i.e. 0 = all digouts off; 1 = digout1 on digout2and3 off, etc.

The modulation of the light can be controlled by ticking the "Record ac" box. In the method parameters the frequency and amplitude can be set.

5. Measurement/signal configuration

In the standard electrochemical impedance spectroscopy technique, the impedance is determined using the current and potential directly from the potentiostat/galvanostat. However, for Ivium Potentiostats it is possible to use the instrument as a standalone FRA in combination with other equipment. Additionally, other reference signals can be selected for variations from the classical electrochemical impedance techniques, such as measurements with optical or hydrodynamic signals.

In the IviumSoft at the Impedance techniques, a method parameter is added in Advanced mode: “MeasConfig”.

Table 2

	MeasConfig	**X**	**Y**	**remarks**
0	standard	I we	E	Internal DSG not applied
1	INT_ac I	ac intern	E	Internal DSG not applied
2	INT_ac E	I we	ac intern	
3	EXT_ac EI	X periph.	Y periph.	
4	EXT_ac I	X periph.	E	
5	EXT_ac E	I we	Y periph.	
6	EXT_I INT_E	X periph.	ac intern	
7	EXT_E INT_I	ac intern	Y periph.	
8	DirectE	I we	E	CE as reference, instead of (RE-S)
9	DirectE_INT_I	ac intern	E	CE as reference, instead of (RE-S)
10	DirectE_EXT_I	X periph.	E	
11	BiStat	I we	I we2	
12	EXT_I BiStat	X periph.	I we2	

In standard setting, the impedance is defined as Y/X, which is normally E/I. When other (external) signals are used for X/Y, the meaning of the plotted impedance might be different from the classical interpretation. The software will always display the data as if it were E/I, the user is responsible for any conversions.

Example 1: Solarcell IMPS
The IviumStat/CompactStat AC-out port is used to drive the intensity of the ModuLight, and the AC-photocurrent from the solar cell is to be recorded with reference to the incident light: "Impedance" = Light Intensity/Photo-Current.
The instrument is set to "Impedance Constant E", and the MeasConfig parameter to "INT_ac E". With this parameter-setting, the internal applied AC signal is used as Y, which is the light-intensity here, instead of the cell-potential.

Note that the Ivium Potentiostat potential may be set to short circuit conditions (E=0), but it may also be operated at other potentials, such as maximum power point.

Example 2: Solarcell IMVS
The IviumStat/CompactStat AC-OUT port is used to drive the intensity of the ModuLight, and the AC-photopotential from the solar cell is to be recorded with reference to the incident light: "Impedance" = Photopotential / Light Intensity.
The instrument is set to "Impedance Constant I", and the MeasConfig parameter to "INT_ac I". With this parameter-setting, the internal applied ac signal is used as X, which is the light-intensity here, instead of the cell-current.

Note that the galvanostat current may be set to OCP conditions (I=0), but it may also be operated at other currents, such as maximum power point.

5. Ivium ModuLight Photometry

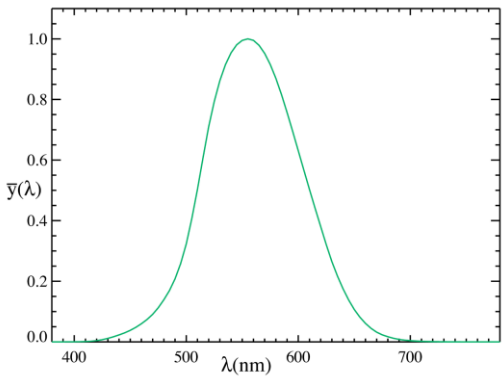
Luminous Flux

The applied LED series is adapted to the so-called luminous efficiency function. This function describes the average sensitivity of the human eye to light at different wavelengths. This means that to obtain a relatively equal light output at different colors the radiant power will vary.

The relationship between luminous and radiant intensity can be described as:

$$I_V = 683 \times I \times \overline{Y}_{(\lambda)}$$

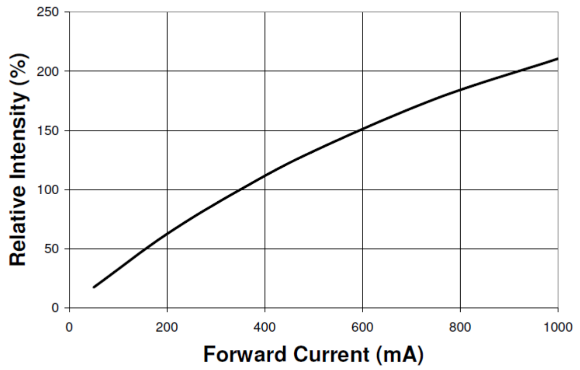
I_V	Luminous Intensity in Lm/sr
I	Radiant Intensity in W/sr
$\overline{Y}_{(\lambda)}$	Luminous Function
sr	Steradium



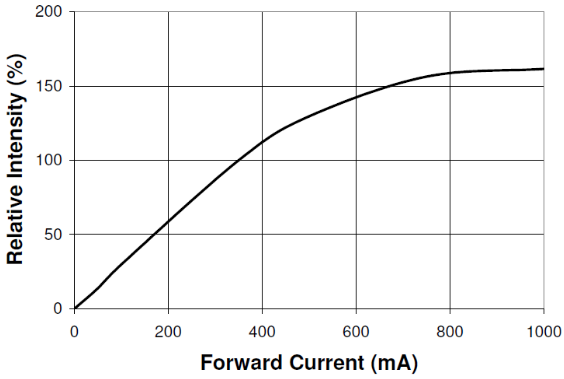
Luminous efficiency function

Luminous Intensity

The 100% intensity of the applied LEDs are specified at 350mA. 350mA is applied when DC is set to 4V and/or AC is set to 1V. The current to relative intensity curves can be found in the next two graphs:



White, Royal Blue, Blue, Cyan, Green



Red, Amber

Example

A measurement at 635nm set to 40lm and 20lm.
As can be found in the led's specifications the red led has an output of 40 lumens at 350mA (4Vdc). In the graph above 50% (20lm) can be set by applying a current of 150mA (1.7Vcd).

$\overline{Y}_{(635)}$ =*0.225*

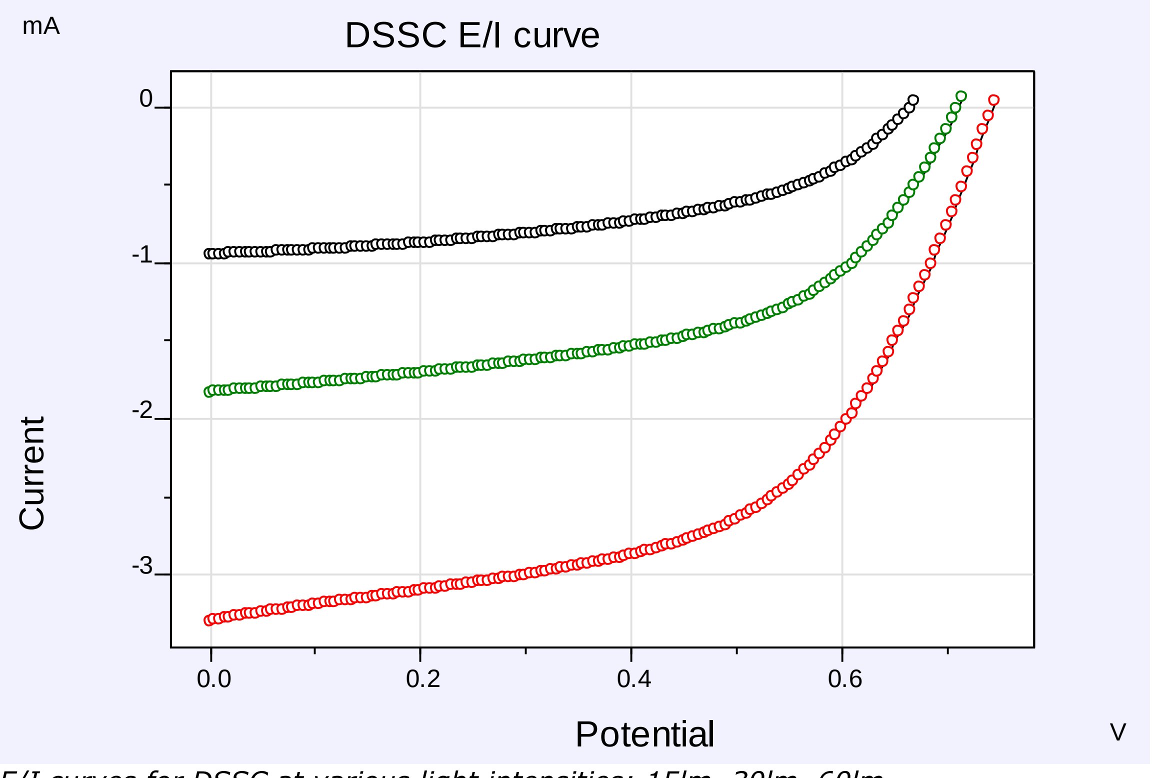
$$I = \frac{I_V}{683 \times \overline{Y}_{(\lambda)}} = \frac{20}{683 \times 0.225} = 130mW$$

6. Experimental example

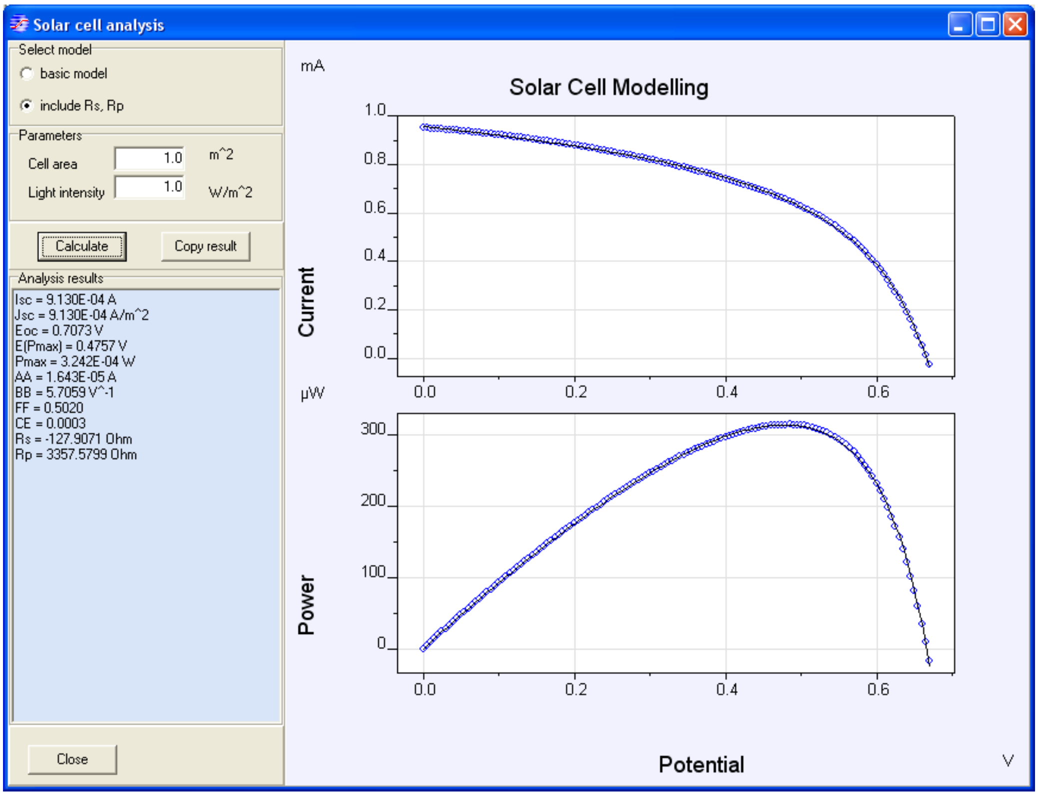
Experiments were conducted with a $1cm^2$ Dye Sensitized SolarCell (DSSC).
The solarcell was connected to an Ivium CompactStat, with WE/S to the positive pole, and CE/RE to the negative pole. (a negative current means that the solarcell is producing power).

As lightsource, the Ivium ModuLight module was used with the 635nm setting, connected to the CompactStat peripheral port with AnalogOut1 and ACout.

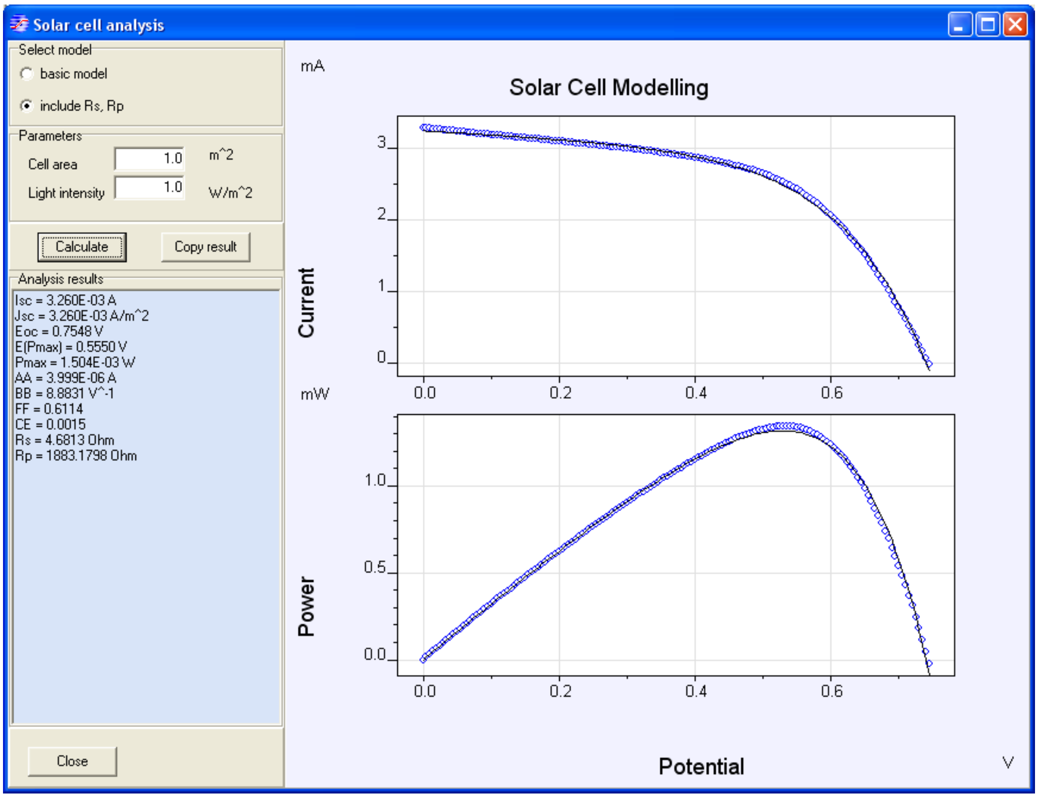
The DC LSV scans were done by first setting the illumination level with AnalogOut1, and thereafter performing a scan. The DC experiments with pulsed light were done with Mixed Mode, setting the Anout1 parameter of the 2nd level to the desired light intensity. The EIS scans were done by first setting the Bias-illumination level with AnalogOut1, and thereafter performing an EIS scan with "MeasConfig" parameter to "Int_AC_E" for potentiostatic scans and "Int_AC_I" for galvanostatic scans. The applied frequency range was 10kHz to 0.1Hz.



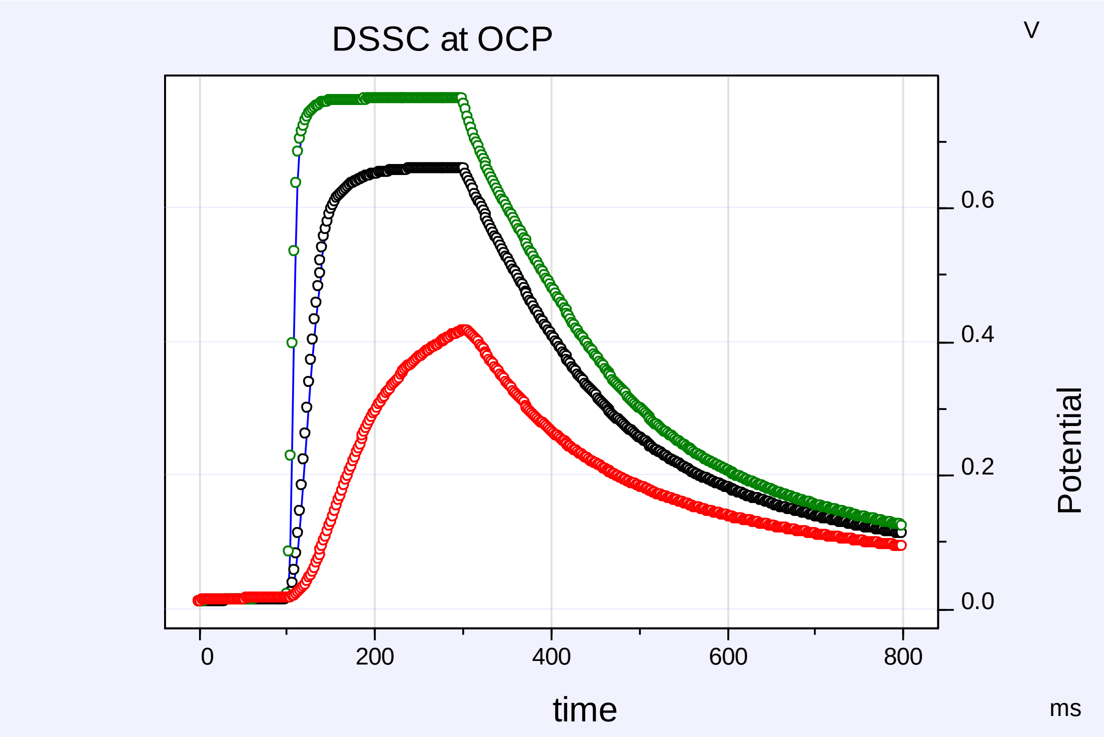
E/I curves for DSSC at various light intensities: 15lm, 30lm, 60lm



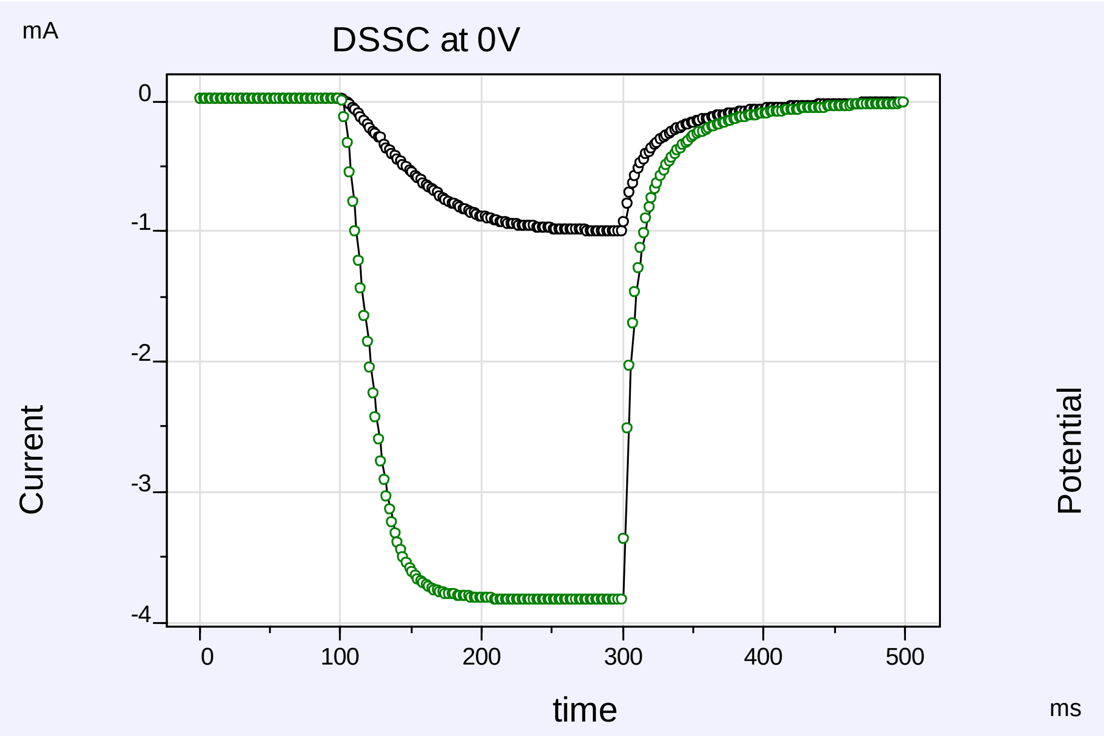
Screenshot of the solarcell modeling circuit, using the 15lm intensity curve



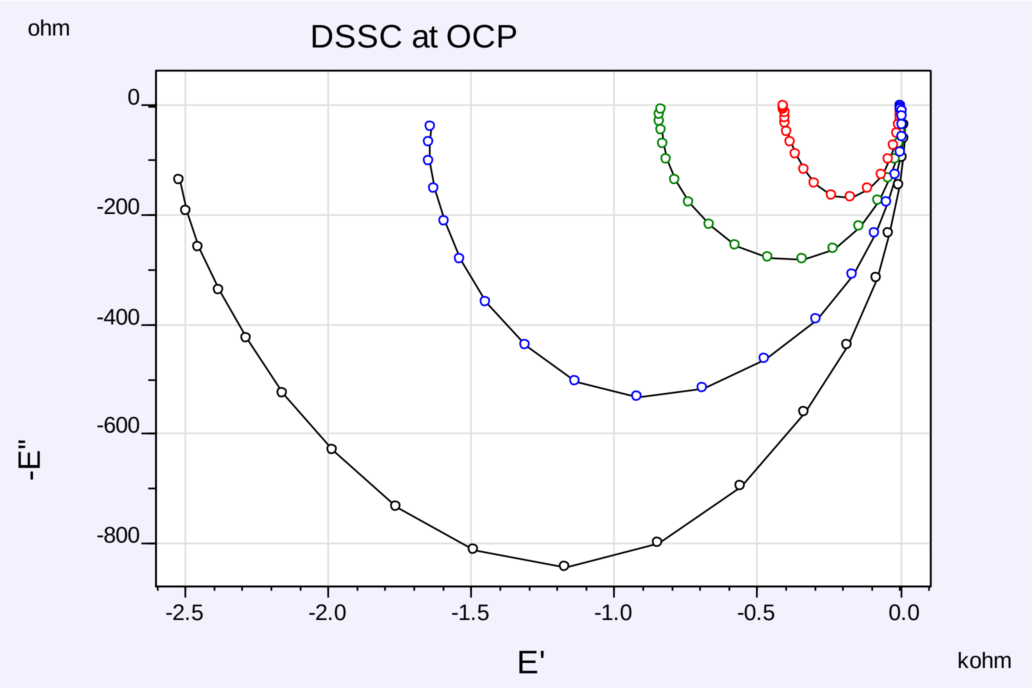
Screenshot of the solarcell modeling circuit, using the 60lm intensity curve



Open Cell Potential of DSSC for variable intensity light pulses



Current response of DSSC at Estat 0V, for variable intensity light pulses



IMVS photo-electric-impedance of a DSSC at OCP, at various light intensities, left to right: 15lm,18lm,23lm,30lm

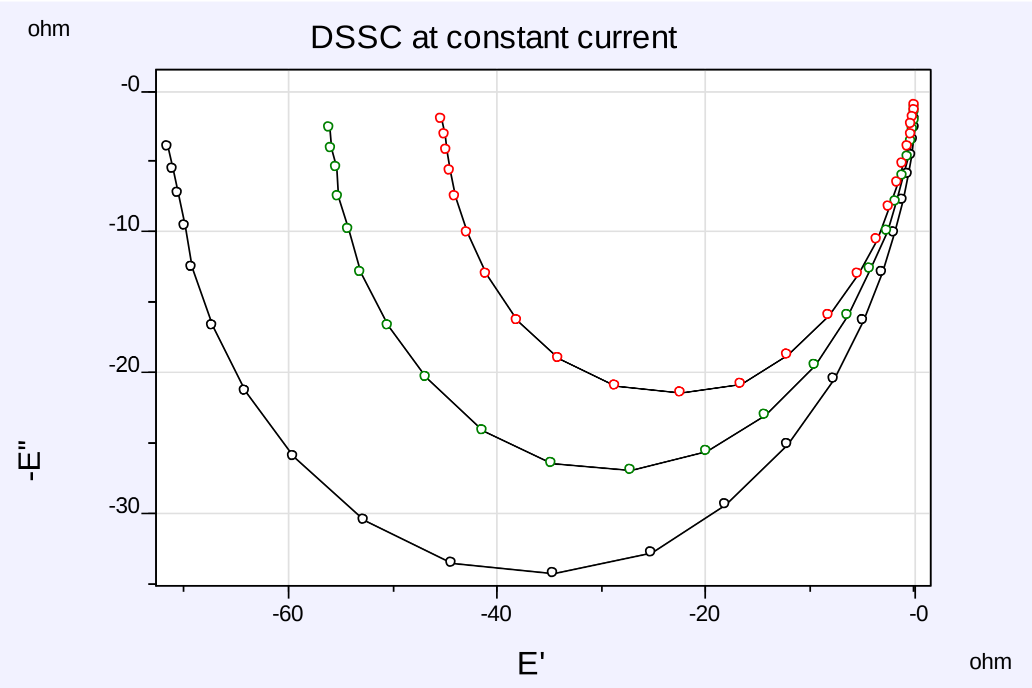


Photo-electric-impedance of a DSSC at various constant currents, 0.1Hz to 1kHz, at fixed light intensities of 60lm, left to right: 0mA (OCP), 1mA, 3 mA

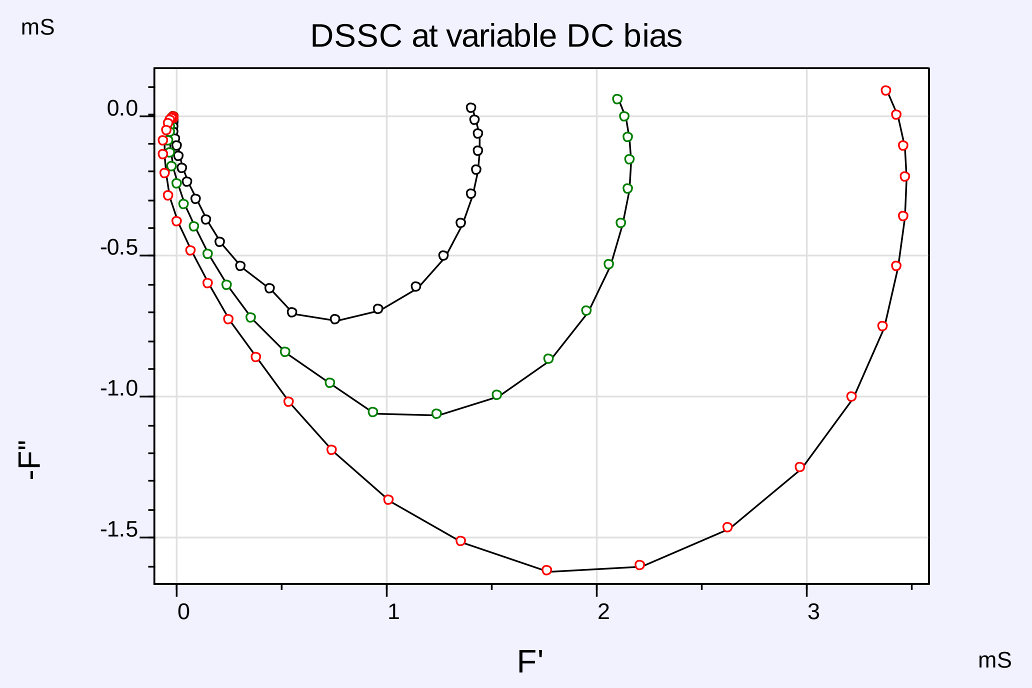


Photo-electric-admittance of DSSC at various DC bias, at fixed light intensity of 60lm, left to right: 0.7V, 0.6V, 0.0V(IMPS)

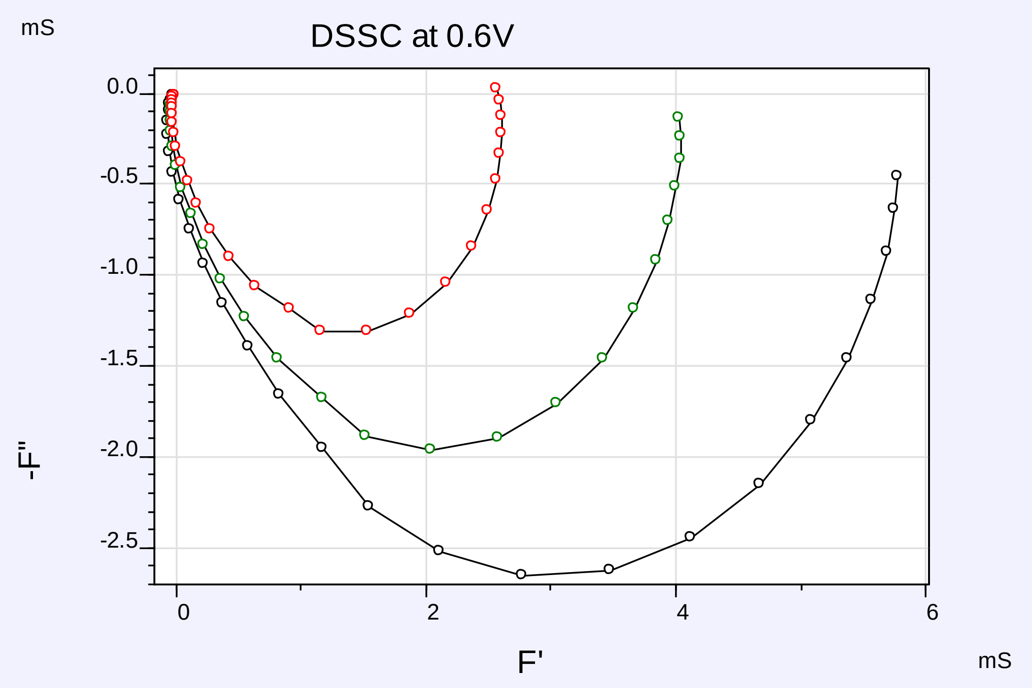


Photo-electric-admittance of DSSC at 600mV DC, at various light intensities, left to right: 15lm,30lm,60lm

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