2011 Model Solar Car Technical Regulations
Interpretation & Comments (Issue June 2, 2011)

The regulations for in 2011 are significantly simpler and shorter than in 2010. Many minor deletions have been made throughout and the size of the technical portion has been reduced down to about 50% of previous years. A number of sections have been completely removed including the cargo, cargo space, egg driver and cockpit.

Interpreting the requirements of technical specifications can at times be difficult. As an aid to understanding, the Technical Section of the car specifications has been copied below together with comments and interpretations of the requirements given in blue after each section.
For any regulation whose meaning is simple and obvious a comment has not been provided.

Do remember that the purpose of specifications is to either mandate or prohibit nominated features. For you and your car design this really means that anything not mentioned specifically in the regulations is an available option in your design and build project.

8. CAR SPECIFICATION

8.1 Test criteria.
Unless otherwise specified all references to car behaviour and measurements will assume that the car is on a flat, straight section of the track, and in full racing configuration.

8.2 No commercially built cars
Cars must not use any part of the chassis or body of any commercially available model car. This only refers to the structural frame and body, not to the drive train components such as gears, shafts, wheels, tyres, or to suspension and steering components.

This regulation is to ensure the cars are designed and built by the students – viz Victorian or other kit car bodies are precluded.

8.3 Size limit
Maximum car size allowed is 550mm long, 180mm high and 320mm wide and at no time may any part of the car extend sideways more than 190mm from the centre of the guide rail.

This is to ensure that a car will not encroach on the opposing car's running lane or collide with the timing equipment or the track edge in the case of the NSW track. It will be tested during scrutineering by placing the car on a flat surface which has a section of guide channel and the limiting dimensions marked. To test for the maximum distance possible that the car can move away from the centre line of the guide, the car will be pushed both ways until the guide system (presumably rollers) engages with the guide rail.

8.4 Source of power
Only commercially available silicon photovoltaic cells are allowed.

This primarily ensures that competitors are all using panels that are readily available to everyone at low cost. It also ensures the use of cells which respond well to the light spectrum produced by the light boxes used at events to accurately determine panel power output and hence ballasting requirements.

8.5 Solar array and support structure
The solar cells connected together to provide the power which drives the car will be referred to as the array. The complete unit on which the photovoltaic cells (the array) are mounted is the array support structure. The thickness of the array and its support structure must not exceed 30 mm. The structure must be robust enough to enable handling by the scrutineers and officials. The organisers will accept no responsibility for any damage to the solar cells or the solar array.

The 30 mm thickness limit is to delineate the solar array and support structure from the body in order to allow its weighing for ballast calculation.

8.6 Array structure removal
The array and its support structure must be easily and quickly (less than 2 minutes) removable from the car for testing and ballasting purposes. And when removed the car must be capable of free and stable movement.

Free and stable movement is specified to ensure the car does not rely on the solar panel and its support structure to perform the function of a chassis. This prevents the fitting of wheels to a solar panel and calling it a car.

8.7 Non planar arrays
Curved, stepped or multi-planed arrays must be able to be re-configured such that when placed on the flat light box measuring surface, no part of any cell is more than 30 mm away from that surface. The scrutineers will calculate a maximum power value for non conforming panels.

The 30 mm is in effect a flatness tolerance and is included to ensure accurate power measurements of panels that are not a single flat plane. As an example of application to measuring a curved panel, consider a curved panel placed on the flat light box measuring surface. If the curve was convex compared to the light box surface it would be touching in the centre but could be 30 mm above the light box surface at each end. For a concave curve it would be touching at each outer edge and the centre could be 30 mm above the light box surface.

8.8 Solar array wiring.
All wiring on the solar array must be visible. All panels must be presented for scrutineering with a pair of connections marked +ve and –ve for connection to the alligator clips on the power measuring equipment. Teams using panels of their own construction or modified commercial panels must provide a wiring diagram. Where the panel has multiple individual sections to allow for series and parallel connection, teams must supply pairs of connections as described above for each section of the panel. The power of each section will be measured and the values obtained added together. All wiring must be carried out with standard copper or tinned copper conductors.

8.9 No devices on the array
All mechanical, electrical or electronic devices including the ON/OFF switch and any devices for changing the panel voltage must be separate from the array. A plug, socket or terminal block to allow connection of the panel wiring to the car wiring is allowed.

8.10 Power measurement
The power delivered by the solar array will be assessed by the scrutineers using a light box. Solar panels presented for testing must produce no more than 25 volts open circuit or 2.0 amps short circuit when tested at 1 Sun (nominal AM 1.5), otherwise they will be assigned the value:

Power = (open circuit voltage) x (short circuit amps) x 0.8 watts.

Scrutineers will measure the power output of all panels at a Sun level expected to be the average over the duration of the event. The power figure obtained will be used to ratio up to the power expected at full Sun. This full Sun figure will then be used for all further calculations. Artificial manipulation of Fill Factor is prohibited and will result in disqualification of the team involved.

Use of the average Sun level expected over the duration of the event has now been included in an attempt to make the competition more a measure of car design and build rather than a measure of solar panel characteristics. Confused??? Please take a moment to read the following:

Solar panels have both series and parallel resistance internally within the silicon and externally in the interconnecting wires between the cells where the ratio of these resistances control power output variation with varying light intensity.
For a "good" commercial panel such as a Solarex SX 10, series resistance is in the order of 3 Ohms while parallel/shunt resistance is in the order of 30,000 Ohms. This panel exhibits only a small power variation between the 50% Sun level power that is multiplied by 2 (the power figure used for panel ballasting in the past few years) and the power actually produced at 100% Sun (ie 2 x 50% Sun power ≈ 100% Sun power). This means that it has only a small advantage or disadvantage in the form of ballast being carried compared to its actual power output in high sun racing conditions.
Panels however exist with characteristics that can give them either a notable advantage or a disadvantage (ie 2 x 50% Sun power ≠ actual 100% Sun power). This variation can in the extreme be large and the committee is familiar with, and in possession of, an 8 Watt panel with characteristics (low shunt resistance) that give it a 180 gm ballast advantage at full Sun conditions when its ballasting power is determined by the 50%-Sun-power-multiplied-by-2 method (ie 2 x 50% Sun power < actual 100% Sun power). The same magnitude of ballast variation can and does occur in the opposite direction (high series resistance) where the panel carries ballast for which it has no actual power in high sun (ie 2 x 50% Sun power > actual 100% Sun power).

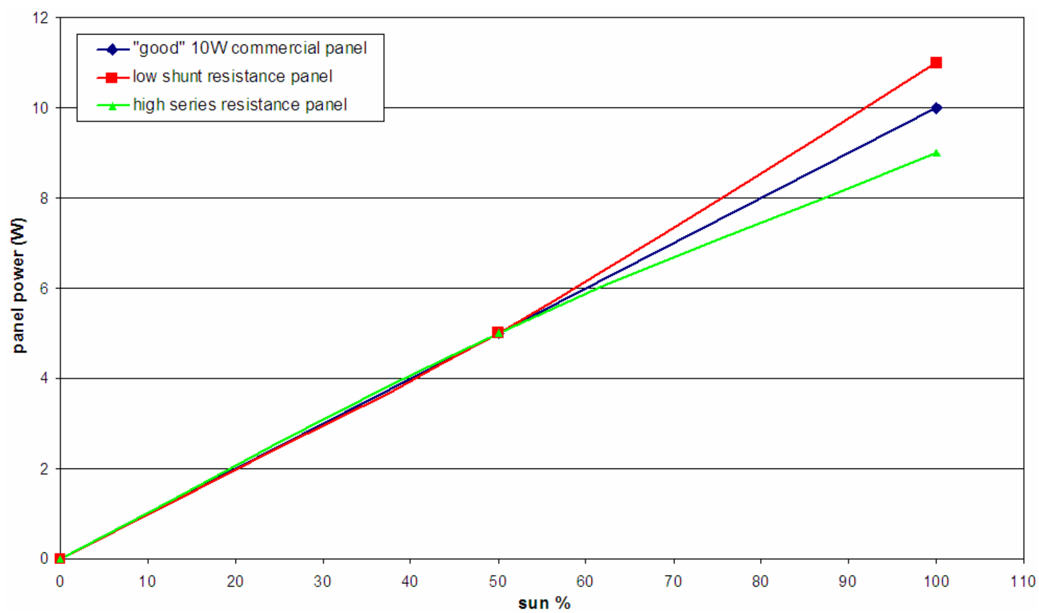


Figure: Power output trends of the panel types listed above with varying light intensity.

The figure above shows the powers of 3 example panels with the different characteristics described ("good" commercial, low shunt resistance and high series resistance) varying with sun %. As can be seen, all three panels produce 5W at 50% Sun. Using the 50%-Sun-power-multiplied-by-2 method as has been the case at the last three national events and most state competitions, this then results in a power figure of 10W being used for ballasting purposes.
It can however be seen that only the "good" commercial panel actually produces 10W at 100% Sun. In this example, the low shunt resistance panel instead produces 11W and the high series resistance panel only 9W. In other words this means that when racing at 100% sun, one panel has an extra Watt for which it hasn't been ballasted for and the other has been ballasted for a Watt that it doesn't actually possess (equivalent to 250 grams when using the 2011 ballasting formula). Doesn't really seem fair does it?
By examining the trends of the three panels, one might also identify that the advantage or disadvantage a panel faces will become increasingly larger and larger with higher sun % (although not as apparent, the advantage/disadvantage should be a reversed slightly in sunlights lower than 50%).

At this point you may then ask why not just measure panel powers at 100% sun as was once done years ago and base ballasting on this? While this would even things out when racing in high sun conditions, it will however only then shift the problem elsewhere as is depicted by the figure below.

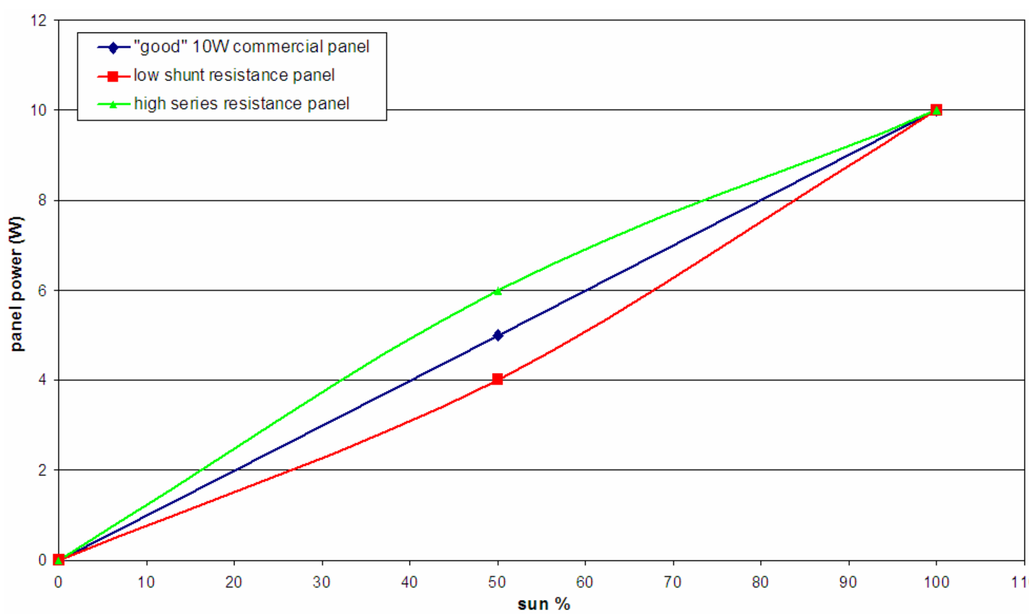


Figure: Power output trends of the 3 panel types measuring 10W at 100% sun.

In this latest figure it can now be seen that there is an advantage there for the high series resistance panel (note that this and the low shunt resistance panel are different from those seen in the first figure as they produce 10W at 100% sun).
Unlike in the first figure, the other panels are now however not just disadvantaged from 50% sun onwards, but instead in any sunlights lower than 100%. Given that the average sun % over the course of a competition is typically less than 100%, this scenario tends to be even more unfair on teams and so this is the reason why panels have been measured at 50% sun at events in the last few years.

So what can be done to fix this whole power measurement and panel characteristics issue? Well, unfortunately there is no easy quick-fix solution.

Before continuing on, let's briefly consider why the low shunt resistance and high series resistance panels seen above exhibit the kind of power variations they do with changing sunlight (instead of being virtually linear like the "good" commercial panel).
Without going into too much detail, it basically comes down to the series and shunt resistance balance of the panel which is in turn dependent on the quality of the solar cell and manufacturing process.
"Good" commercial panels with a high Fill Factor (FF) have a low series resistance (ideally zero although this is not achievable in the real world) and high parallel shunt resistance (ideally infinite). These characteristics ensure that power output is basically directly proportional to varying Sun % (ie 2 x 50% Sun power ≈ 100% Sun power).
Poor quality panels with a lower FF are on the other hand however affected by either increased series resistance or reduced shunt resistance and both of these cases are explored in greater depth in Mr. John Jeffery's "Solar Panel Anomalies" and "Low Shunt Resistance Solar Cells" documents which are available on the Tasmanian Model Solar Challenge website (www.tassolarchallenge.org).
As covered by John in his files, these resistances can also be artificially manipulated (this practice has been prohibited by the AIMSCC) but either way (artificial or otherwise) they will cause the power output from a panel to lose linearity (ie 2 x 50% Sun power ≠ 100% Sun power).
As a final note it should be made known that having a low FF does not necessarily mean that a panel is going to be advantaged or disadvantaged. Low FF panels can have both high series and low shunt resistance and this may balance out the ratio between the two. Such a panel may be no better or worse off than a "good" commercial panel (other than it will simply produce less power for the same open circuit voltage and short circuit current).

Returning to the power measurement problem, one answer might be to simply outlaw panels that are dominated by either high series or low shunt resistance. This would however be completely unreasonable given that the majority of panels used in the competition are made up of cells or modules that are not always quality controlled and so their characteristics essentially come down to "the luck of the draw". In addition, virtually no school or team would be able to accurately determine the characteristics of their panel before an event, let alone then have the funds to seek out a replacement if needed.
Another solution to the problem may be to measure panel powers and re-ballast cars before every race with the light box set to the same sun level that is then going to be raced in. This practice would however be far too time consuming and, even if possible, there is still the possibility of the sun intensity changing between the time of power measurement and the start of a race.

The simplest and most realistic compromise that the national committee has instead been able to come up with is to measure panel powers at a Sun level that is expected to be the average over the duration of the event (rather than just a fixed, predefined level as has been the case in the past). In other words, panel powers will be measured at a higher Sun % on sunny days and at a lower Sun % on overcast days.
While this will still not be ideal (especially if it is a highly variable day), it should help reduce or average out any advantage or disadvantage that cars may have over the course of a competition (no matter what the characteristics of the panel).
With this system in place, low shunt resistance panels will then be advantaged (and high series resistance panels disadvantaged) whenever the sun intensity exceeds the average

sunlight. Similarly, high series resistance panels will gain an advantage (and low shunt resistance panels a disadvantage) whenever the sun intensity drops below the average. In comparison a "good" commercial panel can be said to perform with neither an advantage nor a disadvantage at all sun levels.

In summary, the above (panel measurement at the expected average Sun %) has simply been introduced to reduce the magnitude of any ballasting variation. It is a precaution to minimise the effects (advantage or disadvantage) that panels with less than ideal characteristics will have on the competition.
At the end of the day this will only really affect a relatively small portion of all the solar panels that are presented for scrutineering. The majority of panels otherwise have a reasonable FF and a 50%-Sun-power-multiplied-by-2 power that is within a few percent of the actual 100% Sun power meaning that their ballasting will be influenced by little regardless of how they are measured.

8.11 Temperature correction
As the power output of a silicon solar cell is affected by temperature, the scrutineers will scan all panels with a non-contact thermometer immediately after power testing. The maximum panel temperature recorded will then be used to standardise the power output to the power expected at a temperature of 25^{o}C using the following formula.

$$P_{standardised} = P_{measured} + P_{measured} \times 0.004 \times (T - 25)$$

Where P = power in watts and T = maximum panel temperature in degrees Celsius.
Any ballast required will then be calculated using this standardised power rating.

8.12 Power limit
Panels must register a total power of less than 10 watts. Any panel recording a power above 10 watts will have tape applied by the scrutineers covering portion of each cell in the array. Tape will be applied in integral widths of 19 +/- 1 mm until the power is below 10 watts. Fine tuning of final power will not be allowed. Removal of this tape except by the scrutineers is prohibited. Racing without the appropriate tape in place will result in forfeiture of the race and depending on circumstances disqualification.

The maximum allowed panel power has been reduced to 10 watts. This aims to move towards minimising cost to competitors and vehicle weight, hence reducing any possible injury to spectators or damage to other cars if the car comes off the track. So as not to penalise any competitors with older panels producing more than 10 Watts, any panel over 10 Watts will have tape applied by the scrutineers covering approximately the same % of area on each cell in the array. The tape used will be standard 19 mm wide opaque tape. The scrutineers will attempt to place tape in such a way that the power is reasonably close to the 10 Watts allowed, however once a value less than 10 Watts is attained no fine tuning will be undertaken. Digital photographs will be taken of the masked panels at scrutineering as a guide for the officials. Scrutineers will retest panel power if any doubt exists.

8.13 Array and array support structure weight.
The minimum required combined weight of the solar array, its support structure and ballast **for cars using electronics systems** will be calculated using the formula:

W (solar array and ballast) [grams] = 250 x (Standardised Panel Power [watts]) - 900

The minimum required combined weight of the solar array, its support structure and ballast **for cars not using electronics systems** will be calculated using the formula:

W (solar array and ballast) [grams] = 150 x (Standardised Panel Power [watts]) - 650

The Committee will provide scales to determine array and support structure and ballast weights, measured accurate to +/-5gm.

The use of ballast places emphasis on car design and build quality rather than solar panel power and weight. The formulas above have been arranged in such a way that no particular panel power will be at an advantage or disadvantage over the duration of a race. Please note that these formulas can give a minus weight for low powered panels. Obviously negative weight is impossible, but depending on the panel chosen and its power output a very lightweight panel and consequently a very lightweight car is possible.
It is possible under the new ballasting formulas to build a good car that will have high Sun performance at a level that could lead to car instability and crashing. Do consider this in your design and car set up.

8.14 Use of electronic devices.
Teams may elect to use electronic circuitry for such purposes as solar panel regulation or motor control. During the time trials (usually held on Saturday) they may decide before each individual race whether to use such devices or not. However they must decide before each round of knockout races whether they will run with or without electronic devices for all races to be held in that particular round. During the final, where the best of 5 races determines the winner, the teams may change to electronics or not after the second heat, but must then stick with this configuration for all remaining races.
At scrutineering teams will be required to indicate their intention to run either exclusively with or without electronics or their intention to select between electronics or not during the course of the competition. The scrutineers will record the appropriate weight/s on the car and all cars may be check weighed before or after each race. It will be the team's responsibility to ensure their car is correctly ballasted at all times. Any car found to be incorrectly ballasted will forfeit that race. A repeated offence will result in exclusion.

The considerable reduction in weight of ballast plus panel is to encourage teams to operate without electronics and thus increase their knowledge and understanding of the interactions between solar panel, motor and chosen gear ratios. This reduction is generous and the operation without electronics has the potential to be rewarding for teams who understand their car, particularly if solar conditions are reasonably constant as they were in 2010 in Perth for the National competition.
NOTE: The new ballast formula will make some cars fast enough at high Sun levels that vehicle instability will become more of an issue. Teams may need to limit the speed of their cars in order to safely negotiate the track.
Teams can decide before each round of knockout races whether they will run with or without electronic devices for all races to be held in that particular round. During the final, where the best of 5 races determines the winner, teams may change to electronics or not after the second heat, but must then stick with this configuration for all remaining races.
It is advised that teams considering to run without electronics undertake as much testing and trialling of their car as possible to ensure that they can quickly reconfigure the car to suit changing sun conditions. If intending to run both with and without electronics then it is strongly recommended that teams run at least one heat of the time trials without electronics to test their ability to correctly configure their car.

With the generous reduction in ballast for non electronic cars it is expected that many more teams will avail themselves of this option compared to in the previous few years. The regulation change from being able to select between either an electronics or no electronics configuration before every race in 2010 to before every knockout round in 2011 has been made to make it easier for the officials to keep track of which cars are and are not running with electronics and more importantly to ensure that cars are correctly ballasted.

8.15 Ballast

Any additional weight required by 8.13 to bring the weight of the solar array and its support structure up to the required minimum is defined as ballast, and must be carried on board the car whenever the car is on the track. Teams should have approximately the correct amount of ballast when presenting for scrutineering. Suitable ballast might include such things as sand and fine gravel, nails, etc. Ballast will not be provided by the scrutineers. Ballast must be suitably contained to prevent possible spillage onto the track. Note, any item or material used as ballast must not perform any function on the car when racing other than acting as the ballast.

8.16 No energy storage systems

No energy storage system, whether electrical, mechanical or chemical, which assists in the performance of the car, will be permitted. Capacitors of less than 0.2F and inductors less than 1mH are allowed as part of the electrical system. Capacitors above 0.047F must be discharged immediately before the race.

8.17 ON/OFF switch

Each car must be fitted with a commercial 'ON/OFF' switch, the ON and OFF positions must be clearly marked and the switch must be in a location easily visible by the official starter when the car is on the start line. Note: the starter is on the left hand side, so typically the switch would be mounted on the left hand side or on the top.

8.18 Car wiring

Where possible all electrical wiring and electronic modules in the car must be reasonably visible. Teams will be required to explain any wiring going into sealed body areas. A simple block wiring diagram will be required if this condition is not met.

8.19 Motors

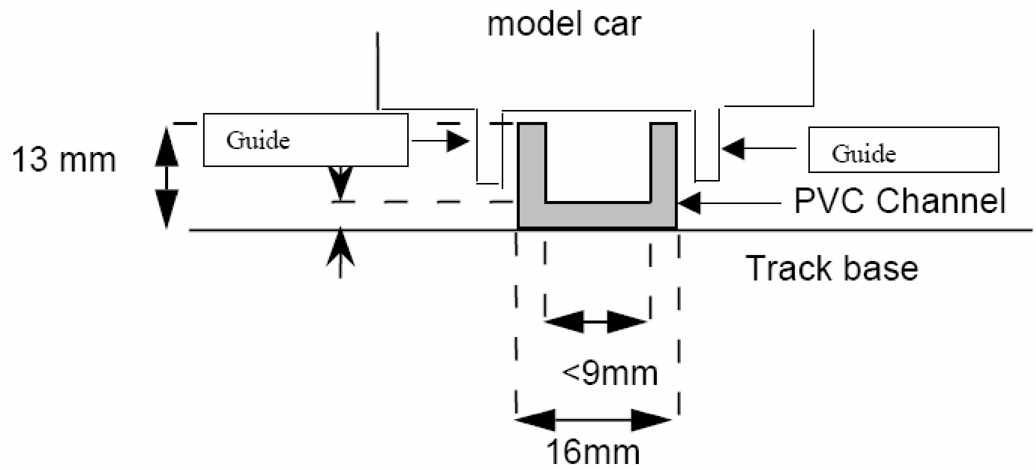
There is no restriction to the type, size, or number of motors that may be fitted to the car. However, the motor manufacturer and/or part number must be made available to the scrutineers for data base information.

8.20 Wheels

There is no limit as to the number, location, or the diameter of wheels. To reduce damage to the track, knife-edge wheels are not allowed. Each wheel must be at least 1mm wide or have a radius of 0.6mm on the running surface.

8.21 Steering

Each car must incorporate a means of steering around the track. The guide rails as described in 4.3 are approximately 16mm wide and 13mm high. The steering mechanism must be designed to operate on the outside of the guide rail.



The diagram above shows the guide channel and a typical guide layout. The photographs below depict actual guides installed on cars and may be of some help in describing what is normally done.

Note that the guides are usually ball bearings or rollers to reduce friction. It is typical to have 2 sets of guides with one set at the front and another at the rear (below).

This photograph (below) of a different car shows how close to the ground guides are normally positioned.

8.22 Removable Drag Plate

The car must include a fixed, flat, rigid, transverse, vertical, rectangular plate of minimum area 200 square cm. and minimum thickness 2 mm. This plate must be easily and quickly removable for measuring during scrutineering. The plate must be one piece and not have any holes or cut outs whatsoever inside the designated area when in place on the car. A drawing of the plate and calculations proving the minimum area to be presented at scrutineering.

The inclusion of a drag plate introduces significant aerodynamic drag. New contestants can easily construct a simple car with an external drag plate. Such a car could have quite acceptable performance but by enclosing the drag plate within an aerodynamic body even better performance could be obtained. The use of bodywork however complicates the design requiring a trade off between aerodynamics, weight and complexity of build.
Note that the 200 square cm plate is required to be rectangular. The intent here is that the required 200 square cm area can be easily verified at scrutineering. The plate can be any shape desired but there must be a rectangular area of at least 200 square cm contained within the plate.
The reference to holes or cut outs when in place on the car means that the plate may have holes for screws that mount the plate to the car. These holes would obviously be filled by the screws when mounted in place and so the plate would indeed be free of holes.

8.23 Body/Chassis

A car body is completely optional. Any bodywork must not form part of the solar array or array support structure. The body may however form all or part of the chassis. The car must have a chassis or frame with sufficient structural integrity to allow free and stable movement with the ballast and solar array removed.

Again reiterated here, the bodywork (if any) must not form part of the solar array or array support structure. As before, this is to enable delineation between the solar array, its support structure and bodywork for the purposes of ballast determination.
Free and stable movement without the solar panel and ballast in place is a check to prove that the solar array and ballast do not form part of the car chassis or frame. They will almost certainly add to the overall strength and stiffness of the car when fully assembled though and this will be considered acceptable.

8.24 Side Panels

The car must have two side panels capable of retaining their shape at all times for attaching numbers and sponsors logos. These must be easily seen by spectators while the car is racing. They will be located one on each side of the car. Each side panel must be capable of supporting a sticker 100mm long and 50mm high. Allowed curvature of the side panels is 20 mm vertically and 15 mm horizontally.

8.25 Solar panel cover.

All teams should provide a suitable opaque cover which will completely shade the active area of their solar array for use at the starting position. The use of the cover is to assist the officials detect and eliminate any hidden illegal energy storage devices. The cover must be a flat sheet of rigid material capable of supporting sponsors logos. The use of flexible items such as clothing, towels or similar will not be accepted. If teams do not provide a suitable cover, the organisers will provide a cover of their choosing. The organizers will not be responsible for any problems created by the use of this cover.

8.26 School and Car Name

Each entry must have its school name (possibly abbreviated) and car name shown on the car in letters at least 10mm high and visible when racing. These can be attached to any part of the car, other than the side panels.

Definition of terms

Two terms have been used in these regulations which may not be familiar to competitors. These are ***Air Mass AM 1.5*** *(which is commonly used by manufacturers to test panel output under* ***Standard Test Conditions****) and* ***Fill Factor****.*

Air Mass AM 1.5 *refers to the energy and spectrum of Sunlight after it has passed through a distance of 1.5 times the thickness of the earth's atmosphere. (Note 1.5 times the atmospheric thickness occurs when the angle between the vertical and the sun is 48.2 Deg.) The actual energy striking the earth's surface at AM 1.5 is 970 Watts/square metre but this is rounded up to 1000 Watts/square metre in the standard. For full details see "Applied Photovoltaics" Second Edition by Stuart R Wenham, Martin A Green, Muriel E Watt and Richard Corkish.*

Standard test conditions (STC)*: The testing conditions under which the nominal output power of photovoltaic cells or modules is measured. Irradiance level is 1,000 W/m², with the reference air mass 1.5 solar spectral irradiance distribution and cell or module temperature of 25°C. (http://www.iea-pvps.org/pv/glossary.htm)*

Fill Factor *is the ratio of a cell or panel's actual maximum output power (V_{mp} x I_{mp}) to the product of its Open Circuit Voltage and Short Circuit Current (V_{oc} x I_{sc}).Graphically, this can be represented by the rectangular areas bounded by the extrapolated lines for the V_{mp}, I_{mp}, V_{oc} and I_{sc} values on the IV curve (where the maximum panel power corresponds to the area of the largest rectangle that will fit in under the IV curve)*
Fill Factor is a measure of panel quality and its parasitic resistances where the higher the FF the higher the quality of panel.

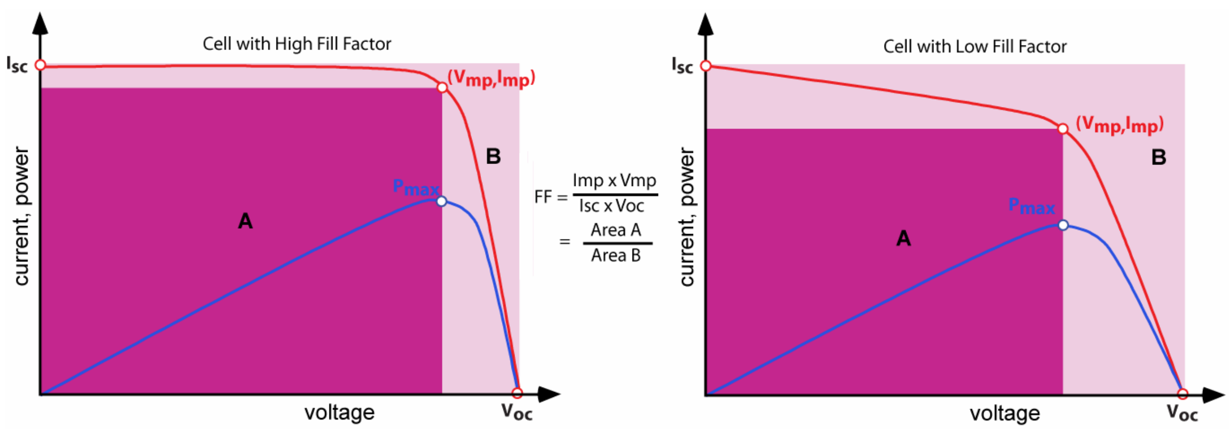


Figure: Graphical representation of a solar cell or panel with a high (left) and low (right) FF (http://pvcdrom.pveducation.org/CELLOPER/ff.htm)