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transient measurements”

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Wien, am 20.06.2017

A handwritten signature in black ink, appearing to read 'Manuel Serini', written in a cursive style.

Unterschrift
(Manuel Serini, BSc)

Abstract

This master thesis deals with the experimentally observed difference between transient and steady state current-voltage characteristics of solar cells. The aim of this master thesis is an as fast as possible measurement of the current-voltage characteristic, with respect to the short circuit current, the maximum power point and the open circuit voltage. The theoretic part of this document gives a short overview of the operating mode of a solar cell, the equivalent circuit and the typical current-voltage characteristic. Additionally, the expected behaviour of a solar cell during fast change operating conditions is described. The experimental part of this thesis contains the experimental set-up and the measuring instruments that were used. Afterwards, a comparison of steady-state and quasi-steady-state current-voltage measurement, followed by transient measurements, is given. This will be followed by an interpretation of these measurements in which a relationship to the previously described steady state and transient data is established. Finally the internal capacitance of a solar cell is measured and a fault recovery of the current-voltage characteristic of the transient measurement is done.

Diese Masterarbeit behandelt die experimentell beobachteten Unterschiede in der Strom-Spannungs Kennlinie einer Solarzelle bei transientser Messung und bei einer Messung im stationären Zustand. Das Ziel dieser Masterarbeit ist die möglichst schnelle Bestimmung der Kennlinie einer Solarzelle, unter Berücksichtigung der Kenngrößen: Kurzschlussstrom, maximaler Leistungspunkt und Leerlaufspannung. Der theoretische Teil der Arbeit gibt einen kurzen Überblick über die Funktionsweise einer Solarzelle, das entsprechende Ersatzschaltbild und die zugehörige Strom-Spannungs Kennlinie. Ebenso gehe ich auf das erwartete Verhalten einer Solarzelle bei sich schnell ändernden Betriebsbedingungen ein. Im experimentellen Teil stelle ich den Versuchsaufbau und das verwendete Messequipment vor. Anschließend wird eine stationäre mit einer quasi stationären Messung verglichen, gefolgt von einer transienten Messung. Als weiterer Schritt folgt eine Interpretation der transienten Messung, mit Bezug auf die Unterschiede zwischen transientser und stationärer Messung. Zum Schluss erfolgt eine Messung der internen Kapazität der Solarzelle und die Kennlinienkorrektur der transienten Messung.

Index of abbreviations:

A	Area
AM	Air mass
C	Capacitance
C_{dep}	Depletion capacitance
C_{diff}	Diffusion capacitance
CJO	Capacitance at 0V bias
CO ₂	Carbon dioxide
d	Distance
eV	Electron volt, $1.6021766208 \times 10^{-19} \text{ J} \pm 9.8 \times 10^{-28} \text{ J}^1$
$\hbar$	Reduced Planck constant, $1.054571800 \times 10^{-34} \text{ J}\cdot\text{s} \pm 1.3 \times 10^{-42} \text{ J}\cdot\text{s}^1$
i	Imaginary unit
I	Current
I_d	Current through diode
I_{eff}	Root mean square value of the current
I_{MPP}	Current at maximum power point
I_{OC}	Open circuit current
I_P	Current through parallel resistance
I_{ph}	Photogenerated current
IR	Infrared
I_S	Reverse bias saturation current
I_{SC}	Short circuit current
k	Angular wavenumber
k_B	Boltzmann constant, $1.38064852 \times 10^{-23} \text{ J/K} \pm 7.9 \times 10^{-30} \text{ J/K}^1$
kWh	Kilowatt hour, 3.6 MJ
L	Path through the atmosphere
L_0	Shortest path through the atmosphere
λ	Wavelength
m	Grading coefficient

¹ URL: physics.nist.gov/cuu/Constants [07/03/2017]

MPP	Maximum power point
mSv	Unit of ionizing radiation dose
n	Ideality factor
n_0	Refractive index of air
n_1	Refractive index of anti reflective coating
NO _x	Non stoichiometric nitrogen oxides
n_s	Refractive index of solar cell
P _{MPP}	Power output at MPP
ppm	Parts per million
q	Quantity of elementary charge, $1.6021766208 \times 10^{-19} \text{ C} \pm 9.8 \times 10^{-28} \text{ C}^2$
Q	Charge
Q _{excess}	Amount of stored charge in the neutral region of a pn-junction
Q _{SS}	quasi-steady state
R	Reflectivity
rem	Roentgen equivalent man, 0.01 Sv
rms	Root mean square
R _s	Series resistor
R _p	Parallel resistor
SiO ₂	Silicon dioxide
Si ₃ N ₄	Silicon nitride
SO ₂	Sulfur dioxide
SS	Steady state
T	Temperature
τ	Carrier lifetime
U	Voltage
U ₀	Amplitude of an alternating voltage source
U _d	Voltage at the diode
U _{eff}	Root mean square value of the voltage
UV	Ultraviolet
V _{MPP}	Voltage at maximum power point

² URL: physics.nist.gov/cuu/Constants [07/03/2017]

V_{OC}	Open circuit voltage
V_{SC}	Short circuit voltage
V_{th}	Thermal voltage, $V_{th}=k_B \cdot T/q$
V_J	Built in voltage
W_L	Energy level of the conduction band edge
W_V	Energy level of the valence band edge
ω	Angular frequency, $\omega=2 \cdot \pi \cdot f$
z	Zenith angle
Z_c	Electrical impedance of a capacitor

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I. Introduction:

Before going more into detail, I want to give a short overview of why it is necessary to do research work in the topic of alternative and regenerative energy. I want to start with this chart from the World Economic and Social Survey 2011:

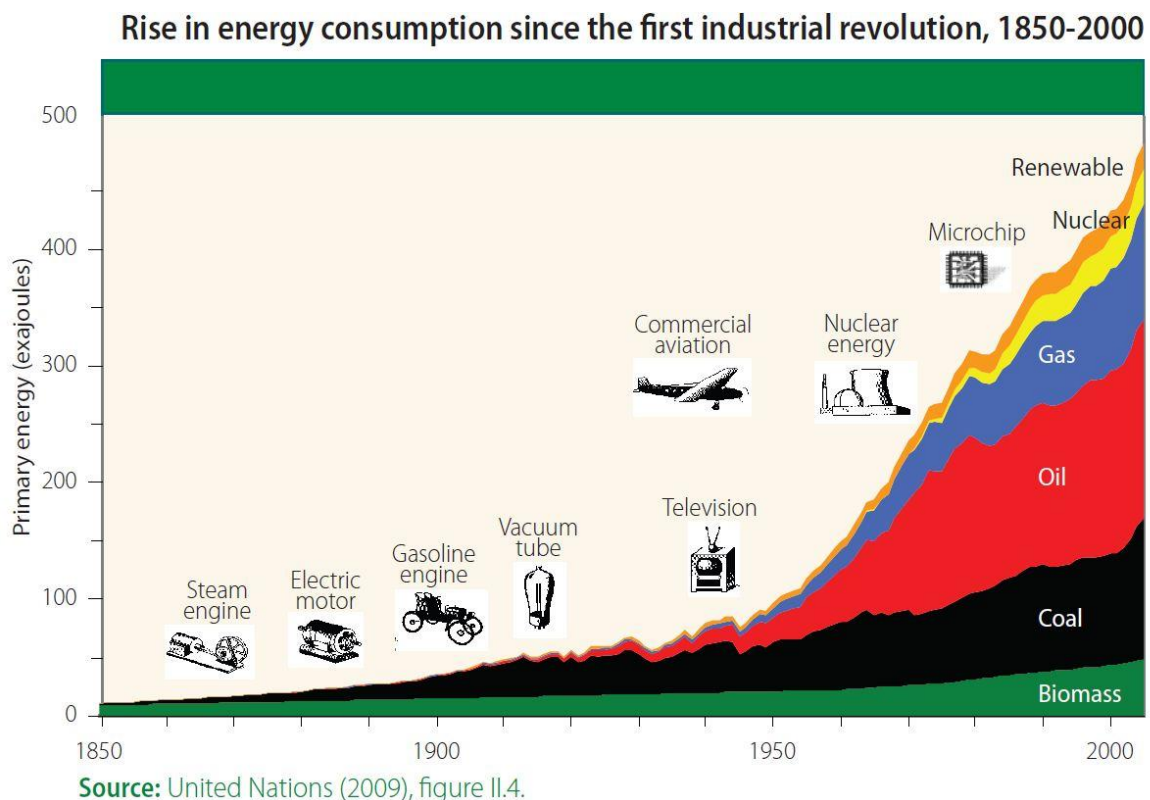


Fig. 1: World energy consumption since 1850³

Fig. 1 shows that the world's energy requirements are increasing continually. Someone could argue that oil, gas, or maybe nuclear power is a practicable way to solve this problem. It can be seen why oil and gas is not really an answer by looking at the CO₂ concentration in the atmosphere. The CO₂ concentration in the atmosphere prior the industrial revolution was in the range of 260 to 280 ppm. Nowadays, it is about 400 ppm.

³ United Nations, 2011

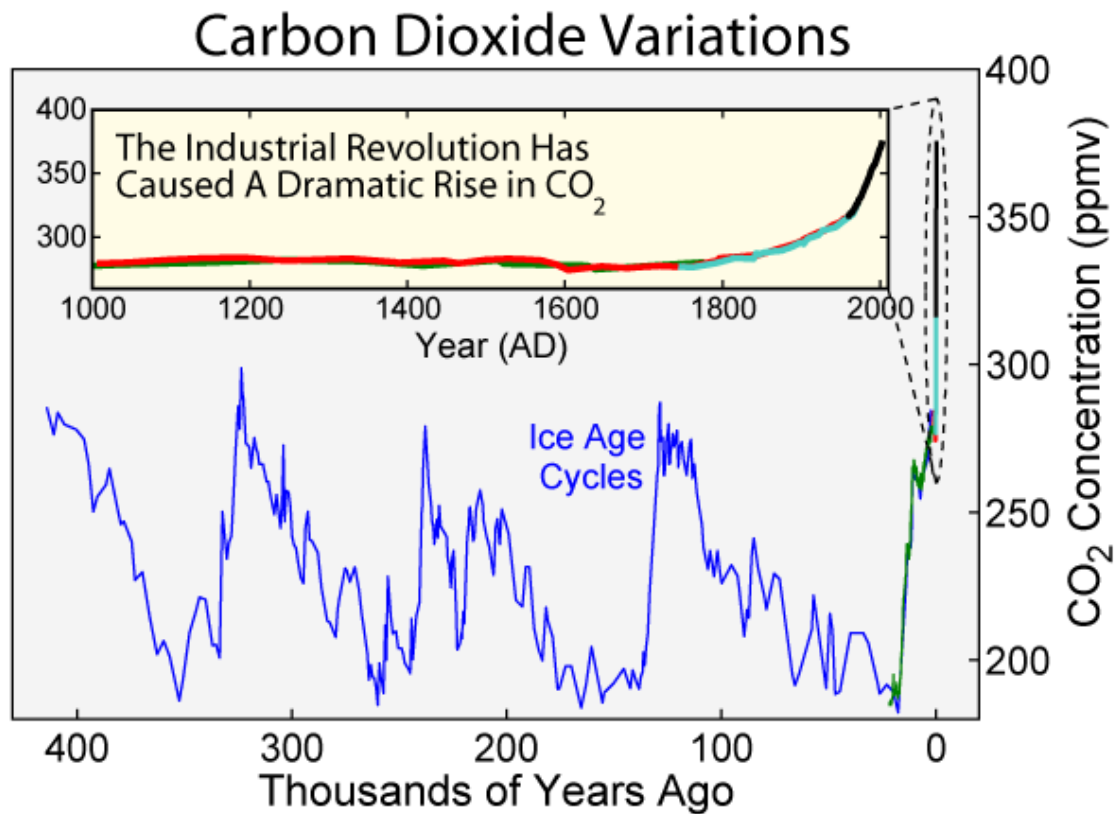


Fig. 2: Variation over time of the CO₂ concentration in the atmosphere⁴

Fig. 2 shows the CO₂ concentration in the atmosphere over the last 400,000 years. It can also be seen that, in pre-industrial times, the CO₂ concentration varied between 200 ppm and 300 ppm, depending on the ice age cycles. At the beginning of the industrial revolution, an alarming trend started: in the last 150 years, mankind has caused a rise from 280 ppm to around 400 ppm of CO₂ in the atmosphere. This is a CO₂ concentration which has never been in the atmosphere in the last 400,000 years. This is continually changing the atmosphere, and has a possible effect on the climate due to the fact that CO₂ is a heat-trapping gas.

⁴ URL: http://commons.wikimedia.org/wiki/File:Carbon_Dioxide_400kyr.png [28/05/2015]

1.1 Overview of different types of electric power generation

1.1.1 Nuclear power

A supposedly CO₂-neutral power source is nuclear power. Supposedly, because in reality it is not 100 % CO₂ free. There is CO₂ emission during the building of the power station, emission during the mining and handling of the uranium, and emission during dismantling the power plant and final storage. According to Sovacool,⁵ the mean CO₂ production of a nuclear power is 66 gCO₂e/kWh. Therefore, nuclear power is not CO₂ neutral, but this is not its biggest problem. An often mentioned problem is the range of the mineable uranium. According to Diehl,⁶ the known mineable uranium reserves under 130 USD/Kg will be extinguished in 2080, if demand remains consistent. If there should be an increase in usage of nuclear power, for instance to replace fossil fuel power plants, the uranium resources will run out even earlier. According to Diehl, in a scenario with a moderate increase in nuclear power, the uranium resources will be spent even earlier; in his example for a moderate increase, this will be in 2050. So, according to his study, it is not possible to replace all the fossil fuel power plants with nuclear power plants. However, there are other studies, especially from Japan, which mention the possibility of extracting uranium from sea-water. Nobukawa et al,⁷ state that the extraction costs are estimated at about 42,000 yen/kg uranium. Current exchange rates make 42,000 yen worth about 340 USD, and the price of conventionally-mined uranium is about 110 USD/kg uranium,⁸ making it around three times more expensive. The advantage of extracting uranium out of seawater is the incredible amount of uranium that is dissolved in seawater. According to Bardi,⁹ 4.29x10⁹ tons of uranium is dissolved in the sea, compared to 2.60x10⁶-5.47x10⁶ tons of reserves on land. So there is about 1,000 times more uranium in the sea than on land. According to an annual demand of 65,000 tons of uranium, the reserves in the sea would last for another 50,000 years. Even in

⁵ Sovacool, 2008

⁶ Diehl, 2006

⁷ Nobukawa, 2001

⁸ World Nuclear

⁹ Bardi, 2010

a scenario with all the primary energy coming from nuclear power, these reserves would be sufficient for more than 1,000 years. So the argument of finite resources is not really valid, but with nuclear power other problems come to light. One big problem is the possibility of a big accident like Chernobyl or Fukushima. However, these two are just big accidents; according to Sovacool,¹⁰ not less than 99 accidents that killed a person or involved a damage of more than 50,000 USD happened in nuclear power plants until 2009. But there are also other reasons why nuclear power is not the future of our energy supply. One thing is the emission of radioactivity, even during normal operations. According to Deutsches Atomforum e.V.,¹¹ the additional radiation exposure from a nuclear power plant is 0.001 mSv to 0.01 mSv per year. This is in comparison to an average background radiation of 2.1 mSv; a negligible amount. To make it more clear, a coal power plant emits according to Gabbard,¹² one hundred times more radioactivity than a nuclear power plant. To give some numbers with this statement, a 1000 MWe nuclear power plant emits in normal operations 4.8 person-rem/year, and a 1000 MWe coal power plant emits 490 person-rem/year. Another unsolved problem of nuclear power is the disposal of the nuclear waste. Today there is no final storage solution for highly radioactive waste and spent fuel.¹³ Today, a favoured model for radioactive waste management is to dump the waste in deep geologically stable mines. The geological stability of the mine is necessary, because the highly radioactive waste needs to be removed from the biosphere for a very long time. Fig. 3 gives an overview of how long nuclear waste has to be removed from the biosphere. The waste needs more than a 100,000 years to reduce its radioactivity to the original radioactivity of the uranium ore. This is the minimum time the waste needs to be stored in the disposal zone. Another thing to mention is that the radioactivity of the natural uranium ore is only slightly more than 0.01 % of its radioactivity right after the fuel leaves the nuclear power plant. Thus the radioactivity is around a factor 10,000 higher after its usage in a power plant.

Thus, the main reasons why nuclear power will not be a solution for the world's increasing power demand is the risk of an accident and its potentially enormous consequences, and the unsolved problem of nuclear waste.

¹⁰ Sovacool, 2010

¹¹ Deutsches Atomforum e.V., 2008

¹² Gabbard, 1993

¹³ IAEA

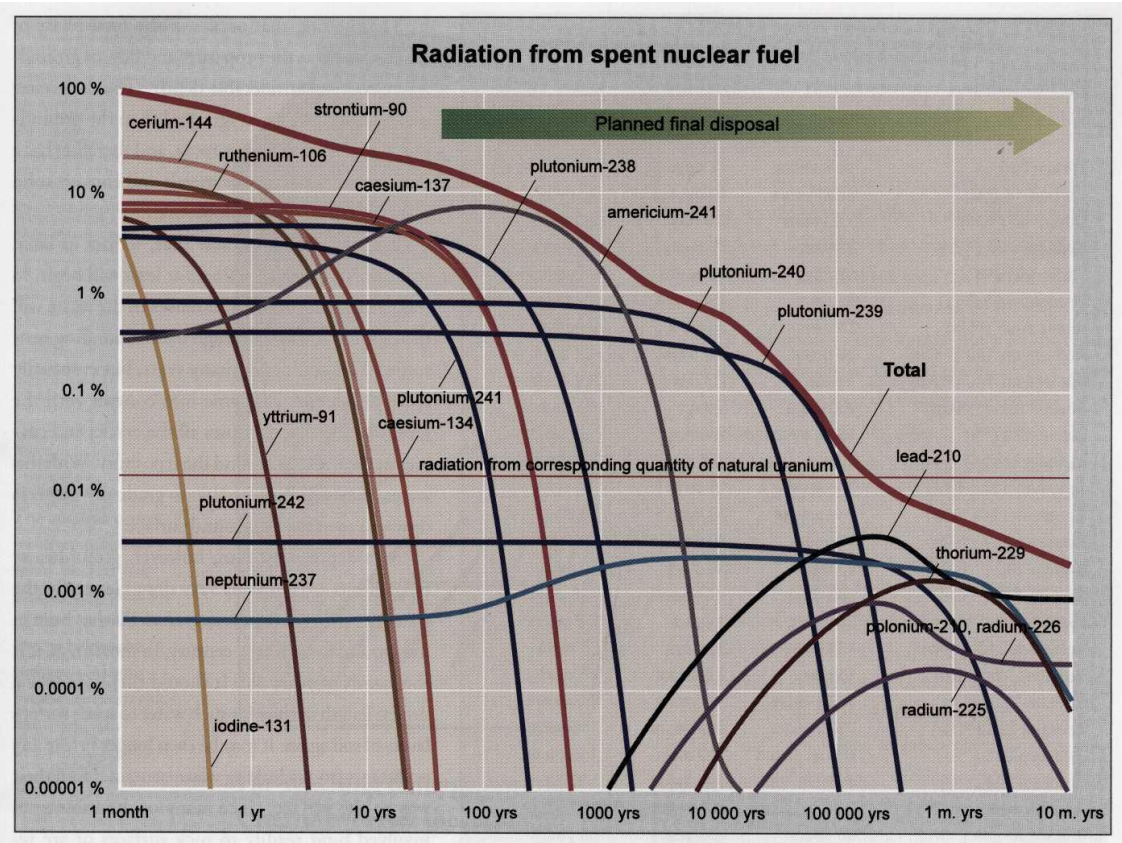


Fig. 3: Decay time of used nuclear fuel¹⁴

¹⁴ URL: http://www.salzburg.gv.at/radioaktivitaet-k_strahlung [07/09/2015], Image from "Will time heal every wound?" (Monitor 17), Swedish Environmental Protection Agency, 2001

1.1.2 Hydropower

Let's have a look at renewable energies. The big advantage of renewable energies is that these energies are assumed to be CO₂ free. Assumed, because if someone takes a closer look there is a small amount of CO₂ emission during the building of the power plant. The oldest and most common renewable energy is hydropower. In 2011, 15.7 %¹⁵ of the world's electricity production came from hydropower, making it the third largest portion of electricity production. Only coal and natural gas have a higher percentage. An advantage of hydro power over wind energy and photovoltaics is its reliable long-term availability. This is an essential thing to provide all types of load only with hydro power. In the hydro power sector there is an essential differentiation between a river power plant and a reservoir power station. These two types of hydroelectric power plants are used for different types of need of electric energy. A river power plant with its steady energy production is mostly used to provide basic load. A storage hydro electric power plant is used to provide peak load. Another big advantage of storage hydro electric power plants is their ability to store energy in a period of oversupply. This is done by pumping water from the lower reservoir into the upper reservoir. This is an advantage over other not as flexible renewable power plants like wind energy and photovoltaics. A big disadvantage of hydro power is its land use. For example, the Balbina hydroelectric plant in Brazil is built on a flat area, so the flooded land covers 2,360 square kilometres.¹⁶ In relation to this large area the electrical output is not so big; the turbines provide only 250 MW. This is due to the low depth of the reservoir. A much better landuse to power output ratio is achieved in hilly locations with a deep reservoir. A big disadvantage of dams is the impact on wildlife. For example, for fish, a dam is an insurmountable barrier. To let fish pass a dam so-called fish passages are installed. These fish passages are ponds separated by a small gap in height, so that the fish can swim from the lower reservoir to the upper. In theory these fish passages sound better than they are, as a fish population has to pass not only one dam. According to Waldman,¹⁷ only 3 % of a fish population passes all the dams and reaches their natural breeding area. Another danger for fish is migrating down the river. Another disadvantage of hydropower is the land it uses; there is often a need to resettle people. However, even if there is no resettlement needed, the impact to CO₂ balance is often negative in the first years. This is due to the amount of biomass that is flooded. These plants die and decompose under anaerobic

¹⁵ The World Bank

¹⁶ Union of Concerned Scientists

¹⁷ Waldman, 2013

conditions. Under these conditions, the biomass is not reduced to CO₂ but rather to methane. The disadvantage of methane is that it is 25 times more aggressive than CO₂ as a greenhouse gas. Another thing to mention about hydropower is its potential. The all over potential, and the actual production in 2008 can be seen in Fig. 4.

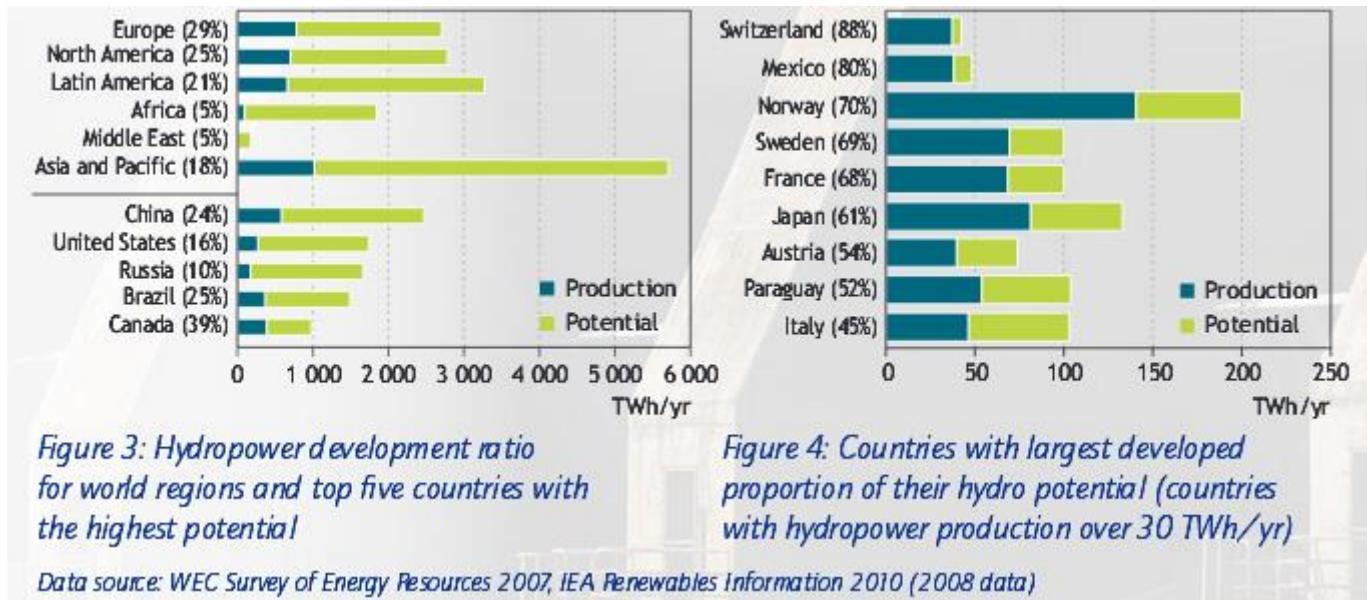


Fig. 4: Potential of hydropower in different regions¹⁸

In global 19 % of worldwide available hydropower is used, with a wide differentiation through the countries. This equates to 3,427 TWh/y.¹⁹ Even in theory, it would only be possible, if all the potential is used, to produce 83 % of worldwide needed electrical power at present with hydropower. Another thing to look at is the CO₂ emission of hydropower. That hydropower is not CO₂ neutral can be realised by looking at the CO₂ balance during the building of the dam and the possible construction work in the riverbed. Therefore, the average overall CO₂ output during the hydropower plant's lifetime is 4 to 18 gCO₂/kWh.²⁰ In comparison to the 550 to 950 gCO₂/kWh²¹ of a fossil fuel power plant, this is an excellent value. Another thing to mention about the CO₂ balance of hydropower is the existence of few power plants with a plenty high CO₂ equivalent. For example the Balbina dam in Brazil has an output of

¹⁸ IEA, 2010

¹⁹ Worldwatch, 2013

²⁰ Tremblay

²¹ U.S. Energy Information Administration, 2016

4,277-40,203 gCO₂/kWh.²² An explanation for this extremely high value is found in the topology of this dam. The average water depth is only 10 m,²³ and the flooded area was original rainforest.

1.1.3 Wind power

The second most used renewable energy is wind power, with an electricity production of 173 TWh/y²⁴ in 2009. An advantage of wind power is its low footprint. A 5MW wind turbine uses only 13-20 square metres²⁵ for its base. The distance between two wind turbines, should not be under 3-10 rotor diameters,²⁶ which is around 180 m to 800 m. If this condition does not apply, the turbines produce less energy due to wind shadowing. Another disadvantage of newer wind turbines is the need for rare earth elements. Newer wind turbines don't have a gear mechanism, so the rotor is directly linked with the generator. This is done because if a gearbox fails replacing is not easy and leads to a longer downtime.²⁷ Therefore especially offshore, gearless wind turbines are used. Without a gearbox the generator is driven at the same speed as the rotor. To generate acceptable electric output at this low speed of rotating, strong magnets are needed, which require rare earth elements. According to the U.S. Department of Energy, the supply risk of rare earth elements is quite high.

²² Yang, 2014

²³ Kemenes, 2011

²⁴ Jacobson, 2009

²⁵ Jacobson, 2009

²⁶ Planning Portal

²⁷ Fraunhofer Institut für Windenergie und Energiesystemtechnik, 2012

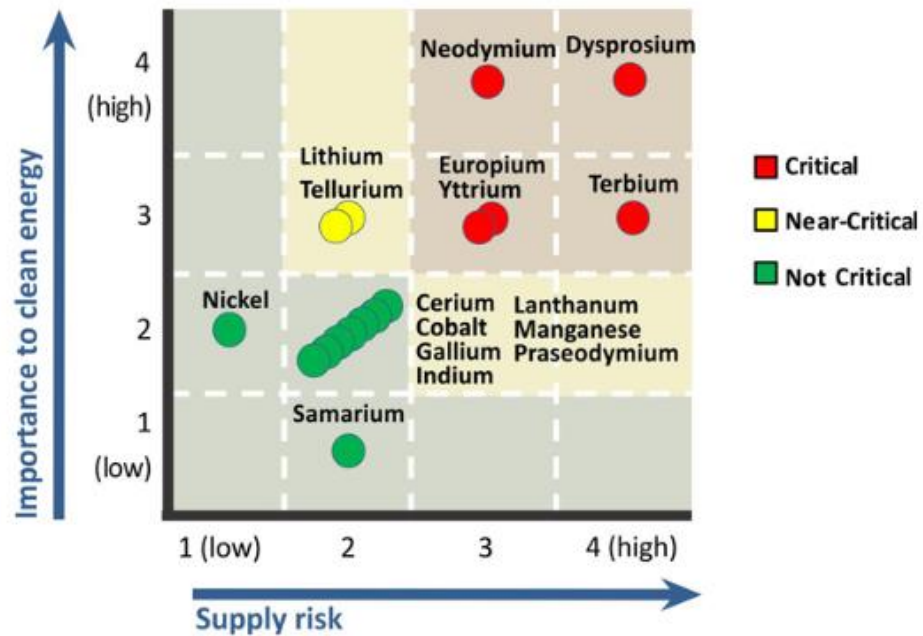


Figure ES-2. Medium-Term (2015–2025) Criticality Matrix

Fig. 5: Supply risk of different rare earth elements²⁸

The theoretical potential of wind power is 630 PWh/y, with a technical potential of 410 PWh/y.²⁹ Nowadays only a small fraction of usable wind power is used. Related to different wind speed, in average the capacity factor of a wind turbine is only 25 percent.³⁰ The amount of generated power strongly varies from hour to hour. Therefore it is important to reliably predict the power production reliably, which is mostly not so good as desired. Such a production curve and the predictions for four days in advance can be seen in Fig. 6.

²⁸ U.S. Department of Energy, 2012

²⁹ Jacobson, 2009

³⁰ Pieper

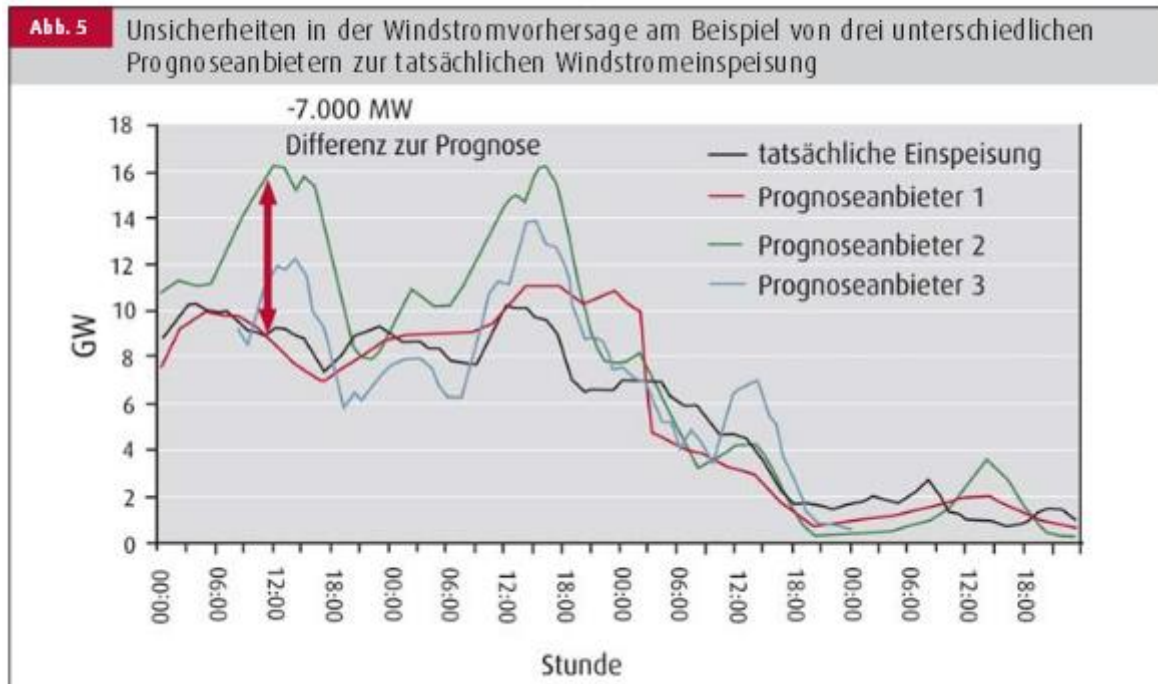


Fig. 6: Prediction of wind power³¹

So even the best prediction has only an accuracy of around 10 %, therefore for wind energy it is important to supply peak load electricity plants. Concerning the influence of wind turbines on bird life, it can be said that wind turbines are not responsible for many losses. In the USA, only 10,000 to 40,000³² birds were killed per year by wind turbines; in comparison to the millions of birds which were killed by traffic, this is negligible. However the distribution between different bird species is not uniform: the losses of raptors are disproportional high.³³ For some species, the losses due to wind turbines may affect the population. For bats, the situation is similar. In Germany, 220,000 bats were killed per year by wind turbines.³⁴ It is possible to significantly reduce the number of bats that are killed by shutting off the wind turbines during nights with a low wind speed, because bats usually fly only when the wind speed is under 8m/s and it is not raining.³⁵ If wind turbines were shut off at these times the energy loss will be only 0.75 % to 1.46 %.³⁶

³¹ Pieper

³² Bio Consult SH GmbH Co.KG, 2010

³³ Bio Consult SH GmbH Co.KG, 2010

³⁴ Fledermausschutz-rlp, 2012

³⁵ Nyári, 2015

³⁶ Fledermausschutz, 2014

1.1.4 Geothermal power

The third most used renewable energy for electricity generation is geothermal power. Currently 57.6 TWh/y³⁷ are produced by geothermal energy. Geothermal energy uses the heat of the earth from a depth of up to 5 km. Nowadays, geothermal power plants are using only aquifer with hot water. Today, no commercial geothermal power plants are used, that inject cold water into hot dry rock and pump up the heated water.³⁸ Only some types of geothermal power plants pump cold water into hot rocks, but only to increase steam production.³⁹ All current geothermal power plants use hot water or steam from depth. There are three types of geothermal power plants, depending on the geological conditions: dry steam power plants, flash steam power plants and binary cycle power plants. Dry steam and flash steam power plants work with a fluid temperature between 200 °C and 320 °C.⁴⁰ The difference between dry steam and flash steam power plants is the usage of the steam. In a dry steam power plant, the steam is directly used by a steam turbine. In a flash steam power plant, hot water, usually hotter than 180 °C, under high pressure pours out of the earth. Due to the high pressure, the water is still liquid. This high temperature water is converted to steam by reducing the pressure. In a binary power plant, the fluid temperature is in the range of 70 °C to 170 °C.⁴¹ The fluid is led through a heat exchanger in order to boil an organic working fluid with a lower boiling point. In all types of geothermal power plants, the used fluid is reinjected back into another drill hole. For geothermal power production, not the terrestrial heat flow is used, but rather the stored heat. This leads to a cooling of the rocks, therefore the lifetime of a drill hole is in the range of 50 years.⁴² After this, the rock is cooled in a surrounding of around one km, and the time needed to reheat this cooled area is in the range of hundreds to a thousand years.⁴³ The fluid from the depth often contains additional gases like NO_x, SO₂ or CO₂. Some of these gases are emitted into the atmosphere. The sulphides are converted into sulphur, but other gases like CO₂ are released into the atmosphere. Therefore, the CO₂ balance for geothermal energy is not zero. The

³⁷Jacobson, 2009

³⁸ Energy Efficiency and Renewable Energy, 1997

³⁹ Kaplan, 2008

⁴⁰ Eliasson, 2011

⁴¹ Goldstein, 2011

⁴² Agemar, 2014

⁴³Bayrisches Landesamt für Umwelt, 2003/2016

average CO₂ outcome for California geothermal power plants is 81 gCO₂/kWh.⁴⁴ Another aspect is the availability of geothermal power. Although 1390 PWh/y is theoretically available, the technical potential due to cost limitations is only 0.57-1.21 PWh/y.⁴⁵ An advantage of geothermal power is its ability to produce basic load power.⁴⁶

1.1.5 Solar power

The next largest used renewable energy is solar energy. Currently, 11.4 TWh/y comes from photovoltaics. A big advantage of photovoltaics over other renewable energies is the enormous potential of the sun. Therefore, for photovoltaics the theoretical potential is 14900 PWh/y of which 3000 PWh/y can be technically used. Just for comparison, the world's electric power production in 2005 was 18.24 PWh.⁴⁷ With photovoltaics it is possible to produce all the world's electricity, using renewable energy sources. Although this fact is a big benefit of photovoltaics, there are still some disadvantages. The first disadvantage is that photovoltaics only produces power during the day, so during night and cloudy days it is still necessary to provide other forms of energy. An approach to solve this issue is by converting the power into hydrogen. This hydrogen can be stored like natural gas and reconverted into electrical power. A disadvantage of this solution is the efficiency, which is only around 34-44 %.⁴⁸ Another thing to mention is the space requirements of photovoltaics. For 1 MW, an area of 5,000 to 10,000 m² is needed. This can be unused areas, like roofs or waste land. Another idea is to assemble the solar cells in a desert. The advantages of this are that the desert area is unused and has a higher number of sunshine hours. For comparison, in Germany there are 1,600 hours of sunshine per year, whereas in the Sahara there are 3,000 hours. The area requirements for supplying different parts of the world can be seen in Fig. 7.

⁴⁴ Holm, 2012

⁴⁵ Jacobson, 2009

⁴⁶ Kutscher, 2000

⁴⁷ Jacobson, 2009

⁴⁸ Stern, 2011

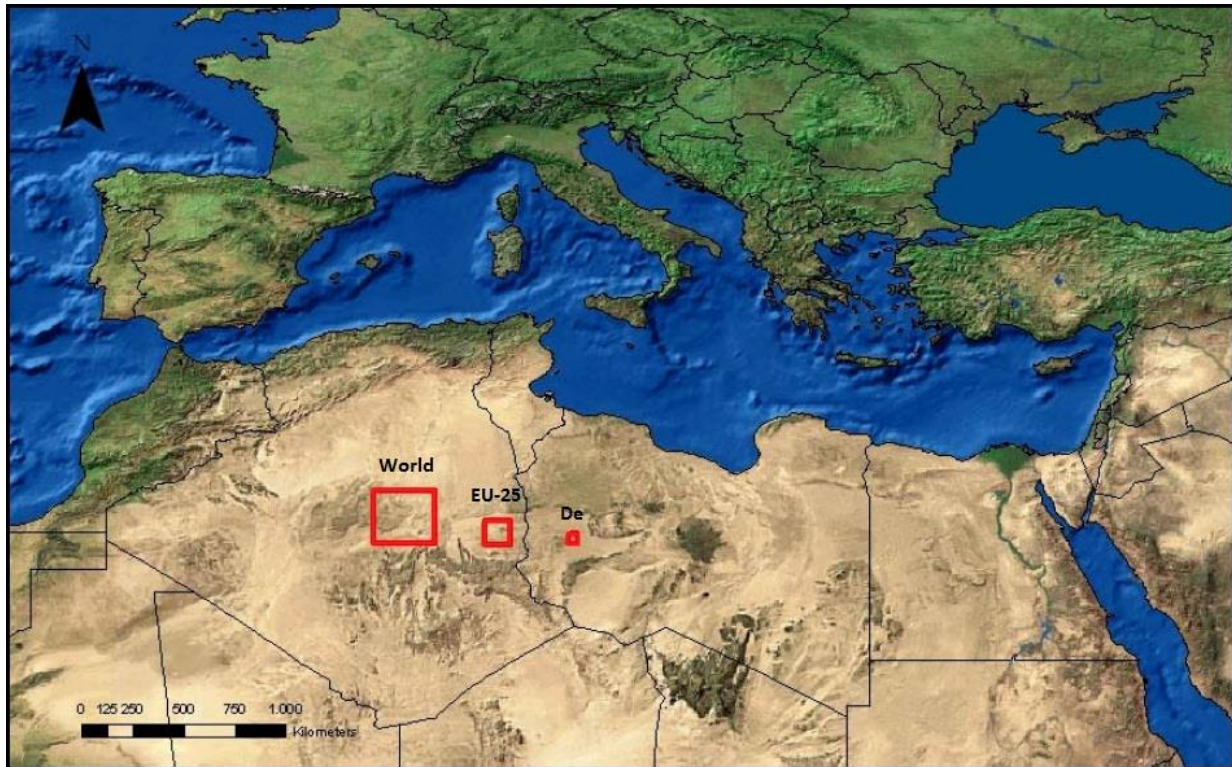


Fig. 7: Space needed for supplying different areas with electricity⁴⁹

Compared to the size of the Sahara Desert, the needed areas are quite small, although the square for supplying the EU has still a length of 125km.

1.2 History of photovoltaics and the usage of solar cells

The first person who described the observation of the photovoltaic effect was Alexandre Bequerell in 1839. He discovered that an electrolytic cell produces a little bit more current under illumination than in the dark. In 1873, Willoughy Smith observed that selenium changes its resistance under illumination. Werner Siemens constructed the first technical device using the photovoltaic effect; he built a photometer out of selenium. The first solar cell that could be used as a power source was built in 1883 by Charles Fritz. His solar cell was built out of two thin gold layers and a selenium plaster between these layers. The whole cell was covered in glass. This first solar cell had an efficiency of less than 1 %. The first solar cells based on silicon were built in 1954 by Bell Labs. These first silicon solar cells had an efficiency of 4 %, which was improved to 6 % by using another doping element one year later. These first silicon solar cells were the first commercially relevant cells and were used to power telephone stations in the countryside. Aside these special cases, solar cells were not widely used, but

⁴⁹ URL: <https://upload.wikimedia.org/wikipedia/commons/e/ed/Fullneed.jpg> [01/08/2016]

this changed in the 1960s with the space flights. For the next decades, outer space was the only major field of application. This changed in the 1970s during the oil crisis. Since the middle of the 1970s, there have been more solar cells produced for terrestrial use than for use in space. In 1981, the first solar-powered aircraft was built by Paul MacCready. This aircraft had more than 16,000 solar cells, with a total power of 3 kW. Paul MacCready flew this aircraft from France to England across the English Channel. One year later in 1982, Hans Tholstrup drove the first solar-powered car for 20 days almost 2,800 miles across the Australian continent from Sydney to Perth. He was 10 days quicker than the first gasoline powered car. In 1990, in Germany the “*1000 Dächer Programm*” started. An intent of this program was the government-funded installation of solar cells on private houses. Another intent was to collect data about decentralised power production. The last big demonstration of the usability of solar power was in 2016 when the airplane Solar Impulse was able to fly around the world powered only by photovoltaics.

II. Theory

2.1 General points about the solar spectrum

Since the primary energy source is the sun the first step is to look at the solar spectrum. The temperature of the surface of the sun is around 5800 K. At this temperature, almost every element is ionised, so the model of a black body agrees in a good way; because of the ionisation there are many nearby emission lines. Therefore, the emission spectrum of the sun behaves in agreement to Planck's law. At this point, we should introduce the influence of the atmosphere on the solar spectrum. In the atmosphere, there are many molecules which absorb parts of the solar spectrum. For example, the ozone layer absorbs light in the UV range, and steam absorbs light in the IR range (see Fig. 8).

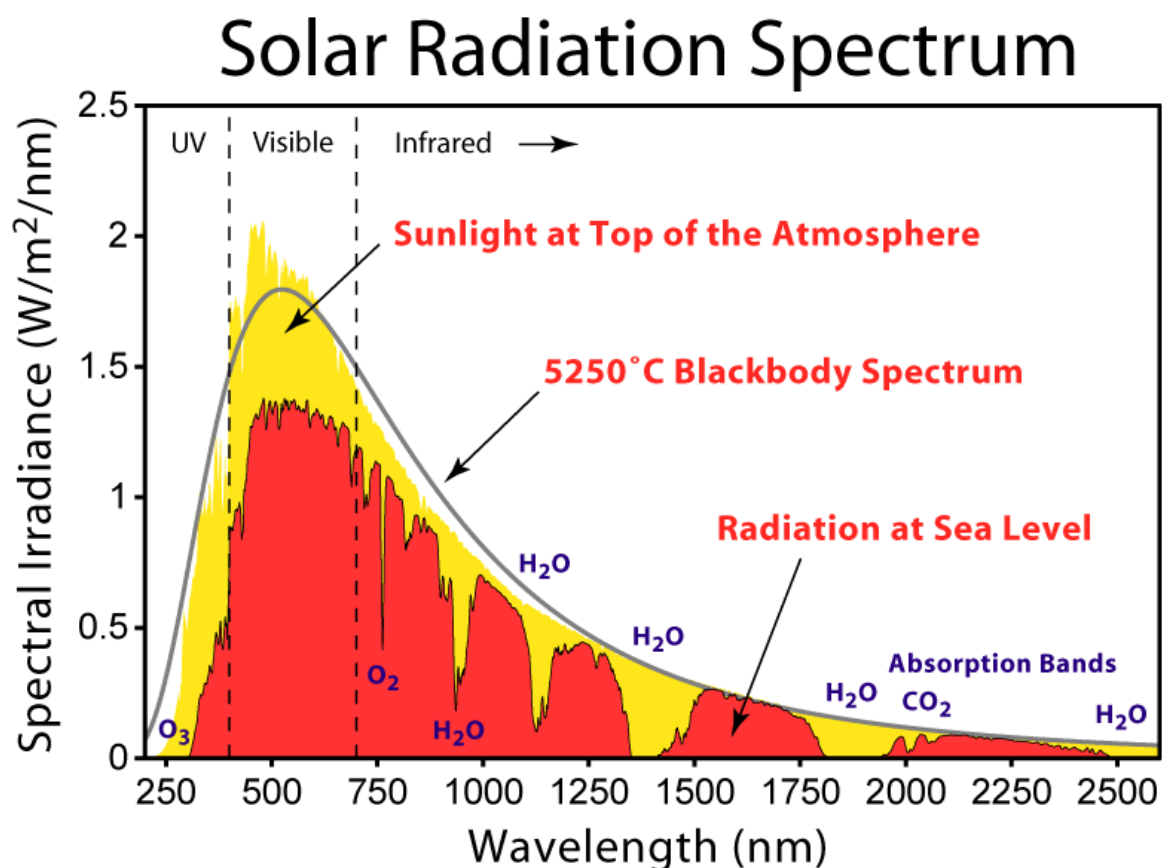


Fig. 8: Solar spectrum at ground level and at the top of the atmosphere⁵⁰

⁵⁰ URL: http://en.wikipedia.org/wiki/File:Solar_Spectrum.png [02/06/2014].

2.1.1 Influence of the atmosphere

The solar spectrum at ground level also depends on the length of the path of the light through the atmosphere. This length is a function of the zenith angle and is measured with the air mass coefficient. Air mass 0 stands for the spectrum with no atmosphere and air mass 1 stands for the spectrum after the light has passed one atmosphere. There can also be a factor of more than 1. This means that the sun is not in zenith angle, so the light has to pass a longer way through the atmosphere. The shortest pass L_0 is when the sun is perpendicular to the horizontal plane of the earth surface, thus for all other conditions the pass, L , through the atmosphere is longer.

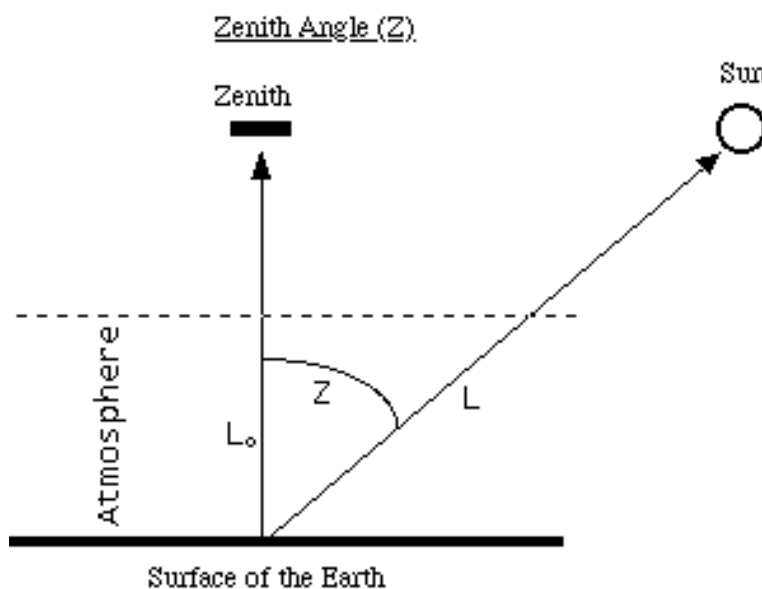


Fig. 9: Zenith angel and pass through atmosphere⁵¹

An approximation of the air mass is given by equation 2.1 where z is the angle between the zenith and the incoming irradiation.

$$AM = \frac{L}{L_0} \approx \frac{1}{\cos z} \quad (2.1)$$

Equation 2.1 is only an approximation for a flat atmosphere. In detail the air mass can be calculated with Kasten and Young's equation or with a spherical

⁵¹ URL:

http://4.bp.blogspot.com/_Nb8DOoLyFwk/RyIOuXn2url/AAAAAAAAAEsY/fOtKjyF3O5s/s1600/zntangle.gif [25/01/2017]

shell. For solar testing, an AM of 1.5 is often used. This corresponds to a zenith angle of 48.2° . An AM of 1.5 also corresponds with an irradiation power of 1000 W/m^2 . This is used because an AM of 1.5 is a good representation for many regions in Europe and America.

2.2 Absorption of light in a semiconductor

The next step would be to look at the absorption of light in a solid. When a photon hits a solid, there is a possibility that an electron receives the energy of the photon and reaches a higher state, a so-called excited state. In a metal, this excited state is in the electron gas, so there is a continuous absorption band for the energy of the photon. In contrast, the absorption in a semiconductor can only occur if the photon has a certain amount of energy. This minimum energy equals the gap between the valence band and the conduction band. If a photon with this minimum energy hits a semiconductor, then an electron from the valence band can be excited into the conduction band and leave an electron hole. If this energy is bigger than the minimum energy, then only one electron gets excited into the conduction band and the energy excess above this minimum energy gets lost as heat or as further photons. This process is called thermalisation and occurs within 10^{-14} to 10^{-12} s. As a result of the thermalisation, there is always an electron near the lowest energy of the conduction band and a hole at the upper end of the valence band. This effect can be used to count the photons.

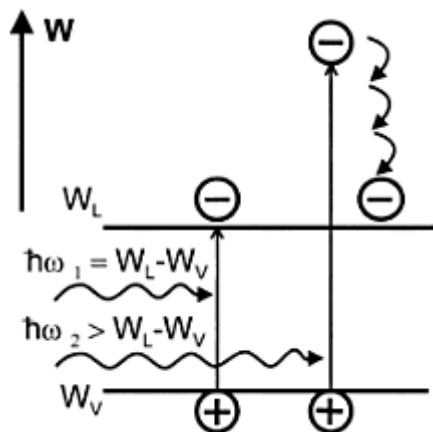


Fig. 10: Absorption of a photon⁵²

⁵² Wagemann, 2007

In an ordinary semiconductor this electron-hole pair recombines after a certain time. The minority carrier lifetime is a measure how long it takes that 63.2 % ($1-1/e$) electron-hole pairs have recombined. This lifetime depends on the material, the doping and the temperature. For a normal semiconductor this lifetime is in the range from 10^{-3} to 10^{-10} s.

2.2.1 Direct bandgap

A bandgap is called direct, if the minimum energy of the conduction band and the maximum energy of the valence band are at the same momentum. For a semiconductor with a direct bandgap a photon directly can excite an electron-hole pair, since no additional transfer of momentum is needed. The probability that a photon above a certain energy gets absorbed is high, as expressed by the steplike change of the absorption coefficient. An example of a direct bandgap would be gallium arsenide with a gap of 1.43 eV, which corresponds to a wavelength of the incident photon of ~865 nm.

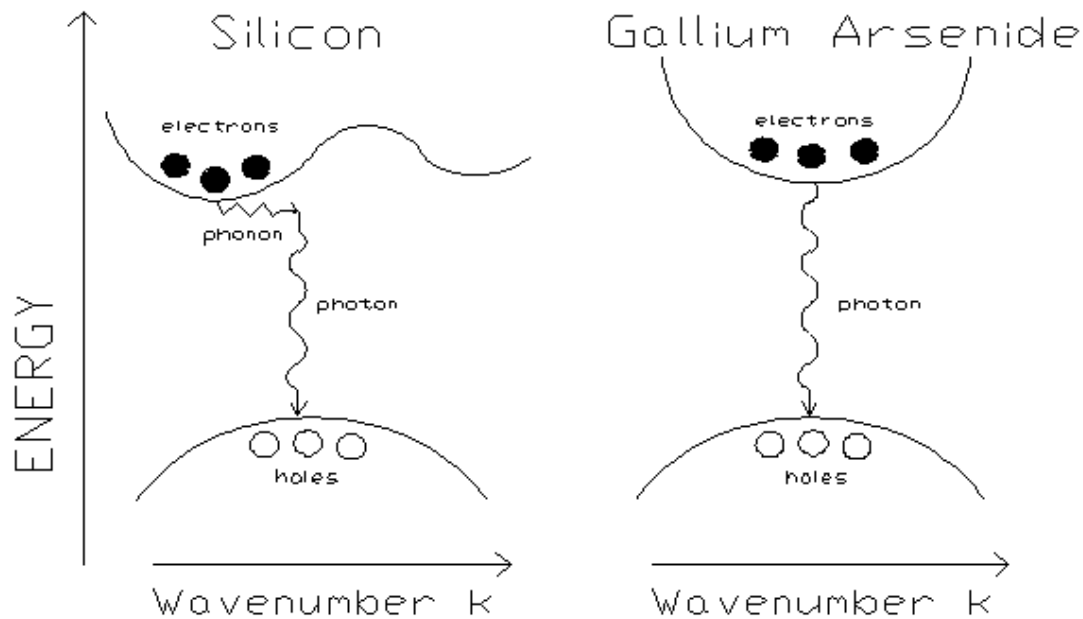


Fig. 11: Indirect (left) and direct gap (right)⁵³, at photon generation by recombination of an electron-hole pair

2.2.2 Indirect bandgap

In contrast to a direct bandgap, an indirect bandgap is there where the maximum energy of the valence band and the minimum energy of the conduction band are not at the same crystal momentum. Therefore a photon together with a phonon must be absorbed or emitted. The absorption of a photon alone would violate the law of the conservation of momentum, because the momentum of a photon is negligible in comparison to its energy. Thus, to be absorbed, a phonon needs to spend its momentum. The energy of the phonon is in the range of the thermal energy, which at room temperature is around 25 meV, and is small in comparison to the energy of the photon at around 1 eV. So we can say that the energy comes from the photon and the momentum comes from the phonon. Characteristic for an indirect band gap is that the probability of photon absorption is low, because of the need for a proper phonon. Therefore, a solar cell based on an indirect bandgap needs to have a thicker absorption layer because of the lower absorption probability. A typical example for an indirect bandgap would be silicon or germanium.

⁵³ URL: <http://www-aphys.physics.ox.ac.uk/research/groups/laser/diodes.html> [06/08/14]

2.2.3 Shockley-Queisser limit

A solar cell produces an electron with exactly or equal the energy of the band gap for every incoming photon with an energy bigger than the band gap. When using the spectrum of a black body with a temperature of 6000 K as irradiation, we can calculate a maximum efficiency of a single junction solar cell. This maximum efficiency is called the Shockley-Queisser limit.⁵⁴ We can also look at an irradiation with the spectrum of an AM of 1.5. Then we get slightly different values for the maximum efficiency for a single junction solar cell. In this case, the maximum efficiency is around 33 % at a band gap of around 1.15 eV, which can be seen in Fig. 12.

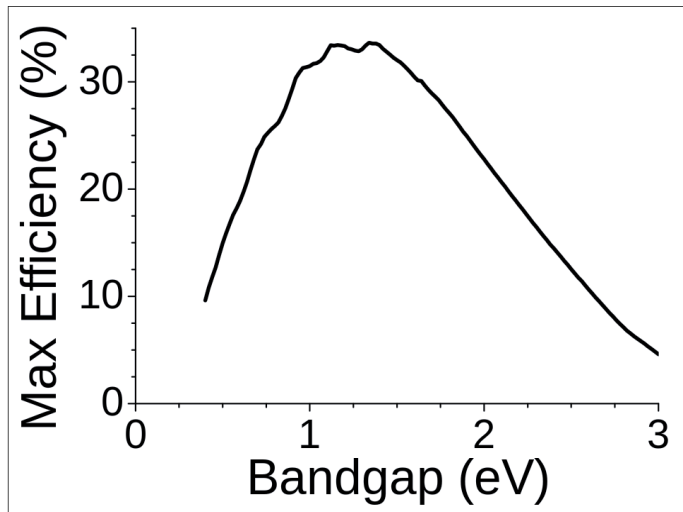


Fig. 12: Efficiency at AM=1.5⁵⁵

⁵⁴ Shockley, 1961

⁵⁵ URL: <http://upload.wikimedia.org/wikipedia/commons/4/4c/ShockleyQueisserFullCurve.svg>
[14/08/14]

2.3 Antireflection coating

According to the Fresnel equation, there is always reflection if the refractive index changes. In the case of a solar cell there is a change from the refractive index of air (which is $n=1$) to, for example, silicon ($n\approx 4$). So according to the Fresnel equation for orthogonal incident light, there is a loss of around 1/3 of the incoming light due to reflection or, in other words only around 2/3 of the light reaches the solar cell.

$$R(\lambda) = \left| \frac{n_0(\lambda) - n_I(\lambda)}{n_0(\lambda) + n_I(\lambda)} \right|^2 \quad (2.2)$$

If it is possible to eliminate the reflection, the efficiency of the solar cell would increase around 50 %. A possible way to reduce the reflection is by attaching a transparent antireflective coating. The idea behind this coating is that now two reflected waves interact in a destructive way so that in sum there is no reflection. There are, therefore, two conditions that need to be fulfilled: first, the two reflected beams need to have the same amplitude; and second, the two beams need to have a phase difference of 180° . To achieve the first condition the antireflective coating needs to have a refractive index of the geometric mean of the two other refractive indices.

$$n_1 = \sqrt{n_0 \cdot n_s} \quad (2.3)$$

The other recommendation is fulfilled if the path length in the coating is a quarter of the wavelength.

$$n_1 \cdot d = \frac{\lambda}{4} \quad (2.4)$$

One can imagine that it is only possible for a single wavelength to have absolutely no reflection. In practice there is another difference from this theoretical view. The refractive index of silicon is not a constant, in fact it depends on the wavelength of the light. Therefore neither a universal thickness nor a universal refractive index exists to eliminate the reflection over the whole wavelength range.

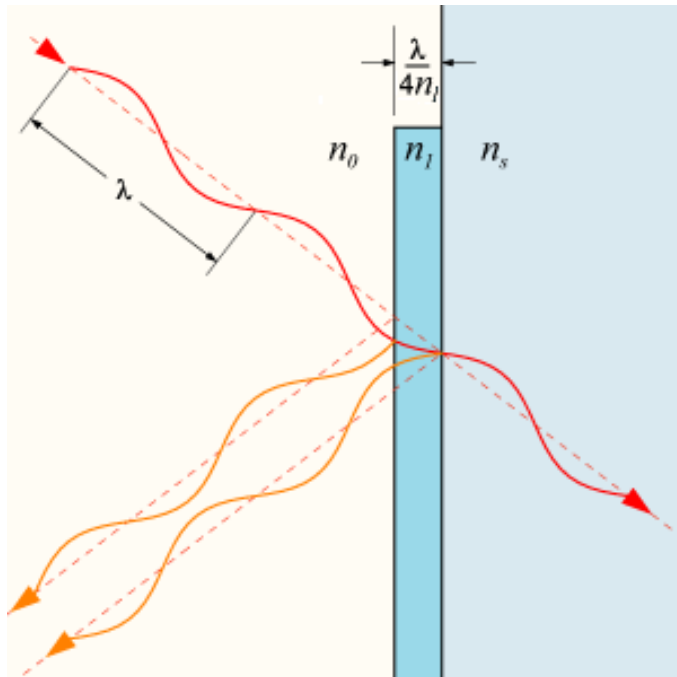


Fig. 13: Function of an antireflective coating⁵⁶

For example in Fig. 14 the effect of different coatings on uncoated silicon can be seen.

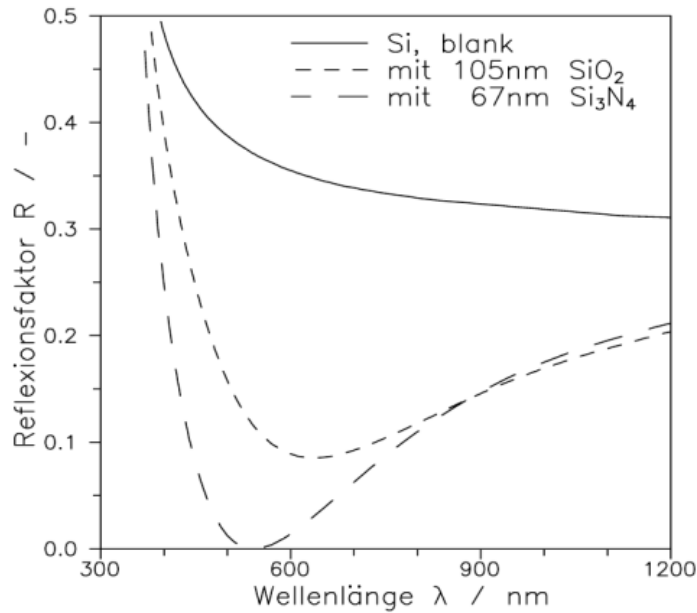


Fig. 14: Reflexion loss with and without coating⁵⁷

⁵⁶ Adapted from URL: http://en.wikipedia.org/wiki/Anti-reflective_coating#mediaviewer/File:Optical-coating-2.png [18/09/14]

⁵⁷ Wagemann, 2007

In Fig. 14 it can be seen, that even a non-optimal, but very easily to apply, antireflective coat reduces the reflections in a significant way. The refractive index of SiO_2 is $n \approx 1.4$ und for Si_3N_4 $n \approx 1.9-2.0$. A better effect can be reached by attaching more than one antireflective layer, so that the losses are reduced in the area of maximum incoming irradiation.

2.4 Separation of charge

If there is no separation after the generation of an electron-hole pair, the electron will recombine with the hole, and so there would be no photo-current. The plan is, therefore, to separate the electrons from the holes before they recombine. There are several ways to achieve this separation. For example, this could be done by an external electric or magnetic field. However, the often technically realised method is by introducing an internal electric field, most frequently by forming a p-n junction. A p-n junction produces only an electric field inside a small portion of the volume, so the electron hole pairs have to get to this region via diffusion. For the photo-current it is important that the minority carrier diffusion length is long enough for the electron-hole pairs to reach the p-n junction before they recombine. Another option is to build a pin structure where the electric field is expanded over the whole intrinsic layer. This is done for solar cells made of amorphous silicon, because of the short diffusion length due to numerous defects.

2.5 Equivalent circuit

The various equivalent circuit models differ in their complexity. The most simple equivalent circuit model can be seen in Fig. 15. In this model the equivalent circuit contains only an ideal current source and a diode. The current source corresponds to the photocurrent and the diode corresponds to the p-n junction.

A more appropriate equivalent circuit can be seen in Fig. 16. In this circuit, the current leak due to crystal defects is represented by a parallel resistor and the losses due to contact resistors and the resistance of the semiconductor are represented by a series resistor. This more appropriate model is called a one diode model. There are more detailed models of a solar cell, for example the two diode model. These models are suitable for certain problems.

As a next step I want to look at the current-voltage characteristic of these equivalent circuits.

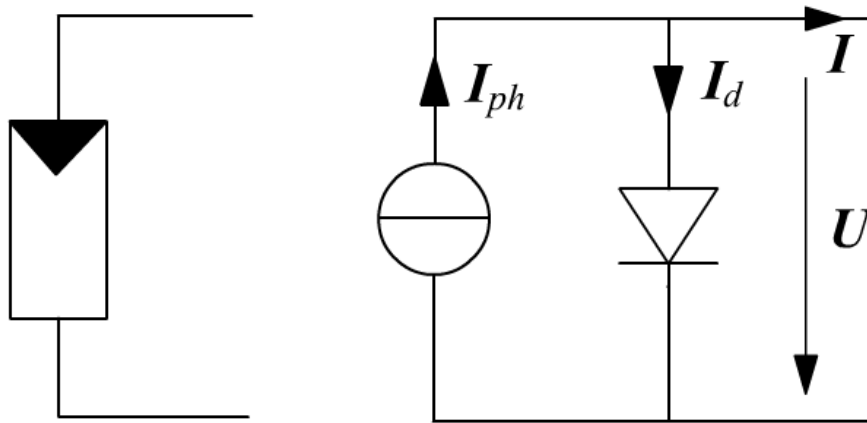


Fig. 15: Simple equivalent circuit⁵⁸, left the symbol for a PV-cell or module, right the equivalent circuit

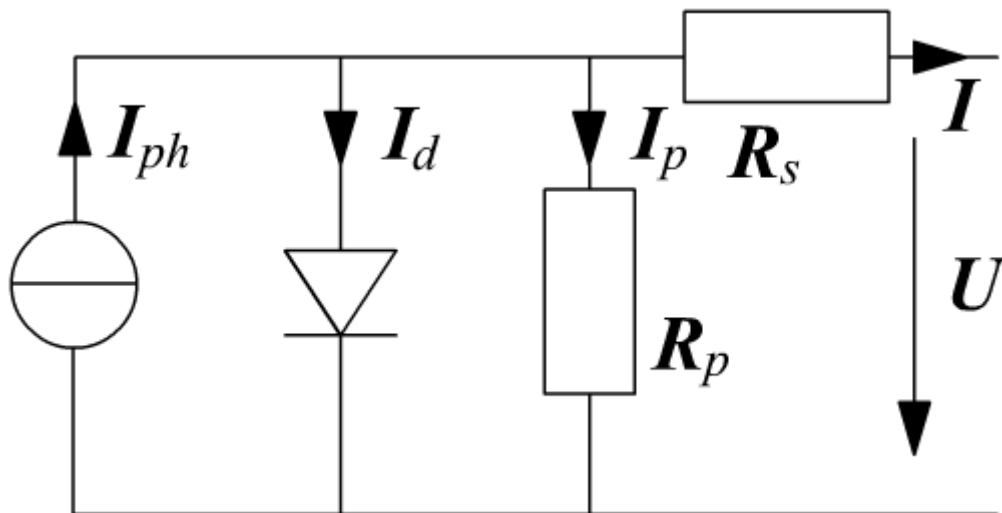


Fig. 16: One diode equivalent circuit⁵⁹

As expected, the current-voltage $I(U)$ characteristic of the simple equivalent circuit is just the current inverted characteristic of a diode shifted by a constant photocurrent, which depends on the incident light intensity only. The difference between the two equivalent circuits is that in the one diode model, parallel resistance and series resistance are introduced. The parallel resistance stands for crystal defects, non-ideal doping and other effects that cause current leakage across the pn-junction. The series resistance symbolises the resistance of the semiconductor and other objects, like the contacts and wires. The different resistances become important in different states of operation. The

⁵⁸ Adapted from URL:

http://upload.wikimedia.org/wikipedia/commons/6/6a/Solarzelle_Schaltbild.png [12/11/14]

⁵⁹ Adapted from URL:

http://upload.wikimedia.org/wikipedia/commons/1/15/Solarzelle_Schaltbild2.png [15/04/15]

parallel resistance gets visible in the $I(U)$ characteristic at a high output current and at a low output voltage. In this area, the current through the parallel resistor is visible because of the down bending current-voltage characteristic in this sector. In contrast, the series resistance field of action is at low output current and at high output voltage. There the voltage drop is visible due to the less steep current voltage characteristic in this sector. So the two resistances reduce the maximum possible output power in different sectors of the current-voltage characteristic. A visualisation of this fact is shown in Fig. 17.

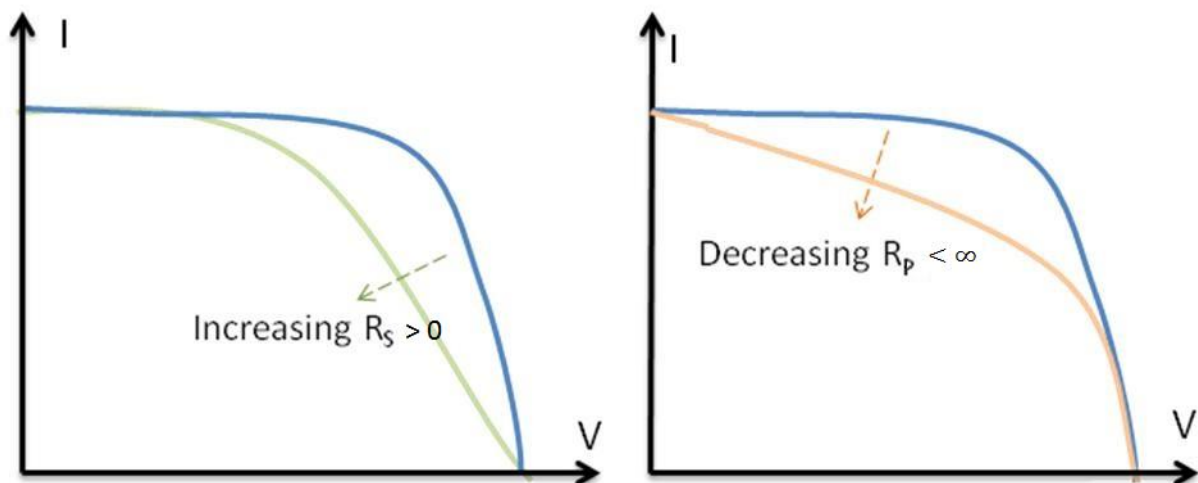


Fig. 17: Influence of series and parallel resistance⁶⁰

As it can be seen, the series resistance should ideally be zero and the parallel resistance infinity. Non ideal cells with both R_s and R_p lower the $I(U)$ curve over the whole range.

Another aspect is that the series and parallel resistance can be derived from the slope of the current voltage characteristic. This relation can be seen in Fig. 18.

⁶⁰ Adapted from URL: <http://www.ni.com/cms/images/devzone/tut/image42515.jpg> [09/02/17]

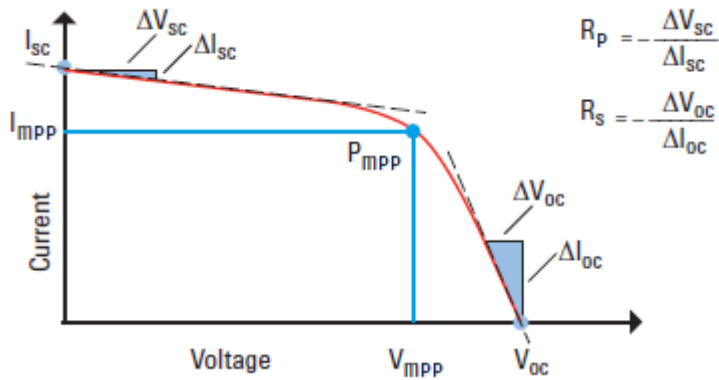


Fig. 18: Calculation of the resistances out of the I(U) characteristic⁶¹

Another thing to mention that has an influence on the current-voltage characteristic is the temperature, as the diode's behaviour depends on temperature. With increasing temperature, the open circuit's voltage decreases. Another thing that has a strong influence on the power output of a solar cell is the irradiation intensity. With increasing intensity the photo-current increases in a linear way, and likewise the open circuit's voltage increases however in a log scale. The next step takes a look at the mathematical expression for describing these current-voltage characteristics. As can be seen in Fig. 15, there must be a term that corresponds to the photo-current, and another term for the diode. For the one diode model, there is the need of resistors in the equation additionally to the photocurrent and the diode.

In the simple equivalent circuit, the output current can be written as:

$$I = I_{ph} - I_d = I_{ph} - I_s \left[e^{\frac{U_d}{n \cdot V_{th}}} - 1 \right] \quad (2.5)$$

In this equation the photo-current is noted with I_{ph} and the diode current is noted with I_d . The current of the diode exponentially increases with increasing voltage. For the next step, I want to look at the current-voltage characteristic of the one diode model. The equation is almost the same as that of the simple circuit. It starts with a photocurrent and this photocurrent is decreased by the current of the diode and the current of the parallel resistance. However, the voltage outside the solar cell, is not the same as the voltage inside the series resistor.

⁶¹ Adapted from

URL: <https://www.researchgate.net/file.PostFileLoader.html?id=586575cbeeae39b4f1795135&assetKey=AS%3A444734180204546%401483044299748> [30/05/17]

So, in the equation of the one diode model, all the voltages increase with the voltage drop across the series resistor.

As a result, the equation of the one diode model looks like this:

$$I = I_{ph} - I_d - \frac{U_d}{R_p} = I_{ph} - I_S \left[e^{\frac{U + R_s \cdot I}{n \cdot V_{th}}} - 1 \right] - \frac{U + R_s \cdot I}{R_p} \quad (2.6)$$

As mentioned before, the equation extracted from the one diode model has three sections. The first term is the photocurrent. The second term stands for the diode, but with an increased voltage at the voltage drop through the series resistor. The third term stands for the current through the parallel resistor, but with the increased voltage.

2.1 Transient behaviour of the equivalent circuit

In general, a process is called transient if it is not in a steady state. To specify, this means that the system's electric condition is changing with time, e.g. a switch gets opened or closed and the current begins or stops flowing. It is also a transient state when the power source is switched from one voltage to another voltage.

If we look at our one diode model of a solar cell, we find that the solar cell's behaviour can be described, by segmenting the solar cell and replacing the segments with conventional well-known parts. So we can describe a solar cell, by replacing it with a constant current source, a diode and some resistors.

The behaviour of the ideal current source in non-steady state conditions is easy to imagine. The photogenerated current depends only on the illumination intensity. When the conditions of illumination are not changing over time, its behaviour is the same as in steady state conditions, it provides a constant current.

Next I want to look at transient behaviours of an ideal resistor. For an ideal resistor Ohm's law applies for all conditions, and this includes transient conditions. So the current through an ideal resistor follows the applied voltage instantaneously.

The diode now shows an examinable characteristic under transient conditions. To describe this manner more clearly I start with a figure of the structure of a p-n diode.

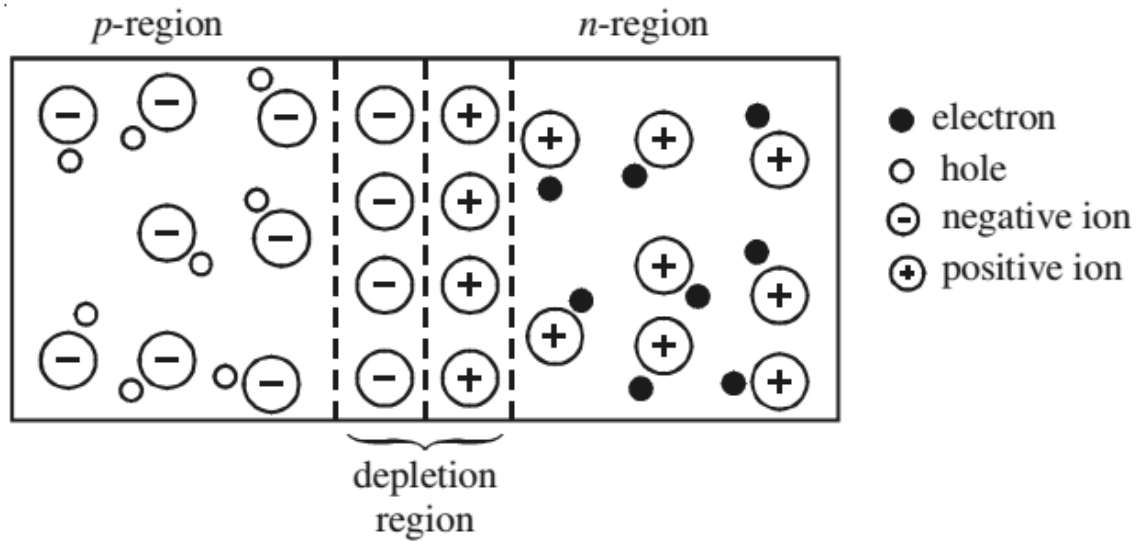


Fig. 19: Model of a p-n diode⁶²

As it can be seen in Fig. 19, a p-n diode is a combination of a positively-doped crystal and a negatively-doped crystal. At the junction, the electrons and the electron holes will combine to establish a region depleted of mobile charge carriers, the so-called depletion layer. This situation can be compared with a plate capacitor: two conductive regions separated by a nonconductive split. A diode acts like a plate capacitor. This is, for example, used in varicap diodes. These types of diodes are used wherever there is the need for a small variable capacity, for example in an adjustable oscillator. The capacity is variable, because the thickness of the depletion layer is a function of the bias voltage. The higher the reverse voltage, the wider the depletion layer gets and as a result the lower the capacity is.

For a parallel plate capacitor $C \propto \frac{A}{d}$, (2.7)

and therefore for a diode $d \rightarrow f(V) \Rightarrow C \rightarrow f(V)$

In a more formally way, the thickness of the depletion layer is a function of the square root of the applied voltage. The capacity of a plate capacitor is an inverse function of the distance of the plates. Altogether the capacity of a reverse biased diode is inversely proportionally to the square root of the applied voltage.

$$C_{dep} = CJO \left(1 - \frac{U_d}{VJ} \right)^{-m} \quad (2.8)$$

⁶² URL: <https://www.studypage.in/images/physics/ec/pn-junction.png> [06/02/17]

As mentioned in the passage above, the grading coefficient for an ideal diode would be 0.5. Since in reality there is no ideal diode, the grading coefficient is often measured as 0.3. This is because in a real diode there is no abrupt change from the p to the n region; it is a more or less steep gradient of the doping concentration.

In a forward biased diode there is also another capacitance, the so-called diffusion capacitance. A short explanation of the diffusion capacitance is that, when a diode is forward biased, there is a diffusion current from the anode to the cathode. With this diffusion current there is a specific amount of charge. If the applied voltage changes, there must be a change in the amount of diffusion current, and therefore of the charge in the diffusion process. Thus with a voltage change there is a change of the stored charge. This is, by definition, the behaviour of a capacitor.

The corresponding equation for this is:

$$C_{diff} = \frac{dQ_{excess}}{dU_d} \quad (2.9)$$

To find Q_{excess} there has to be made an integral of the charge over the neutral area. As a result, this integral over Q_{excess} can be seen as the product of the current through the diode multiplied by the lifetime of the carriers. So with this result, the diffusion capacitance can be written very clearly as:

$$C_{diff} \approx \frac{\tau}{V_{th}} I_d \quad (2.10)$$

The thermal voltage is another aspect of the thermal energy of an electron. In other words, the thermal voltage is the voltage needed to get an electron to the same energy as its thermal energy. A more formal way of looking at V_{th} would be:

$$V_{th} = \frac{k_B T}{q} \quad (2.11)$$

To give an example, at 300 K the thermal voltage is 25.85 mV.

discharging rate of the capacitor should be slow enough that the system still remains under quasi-steady state condition. In the paper it is written, that a discharge rate of 100 V/s is still considered as quasi-steady state. Fig. 21 shows such an agreement of a quasi-steady state measurement with a steady state measurement performed with an Ampere- and Voltmeter and a variable resistor.

Fig. 21 is an original from Recard⁶⁵ and in his paper the current is labelled in (A/cm²) which is a unit for the current density.

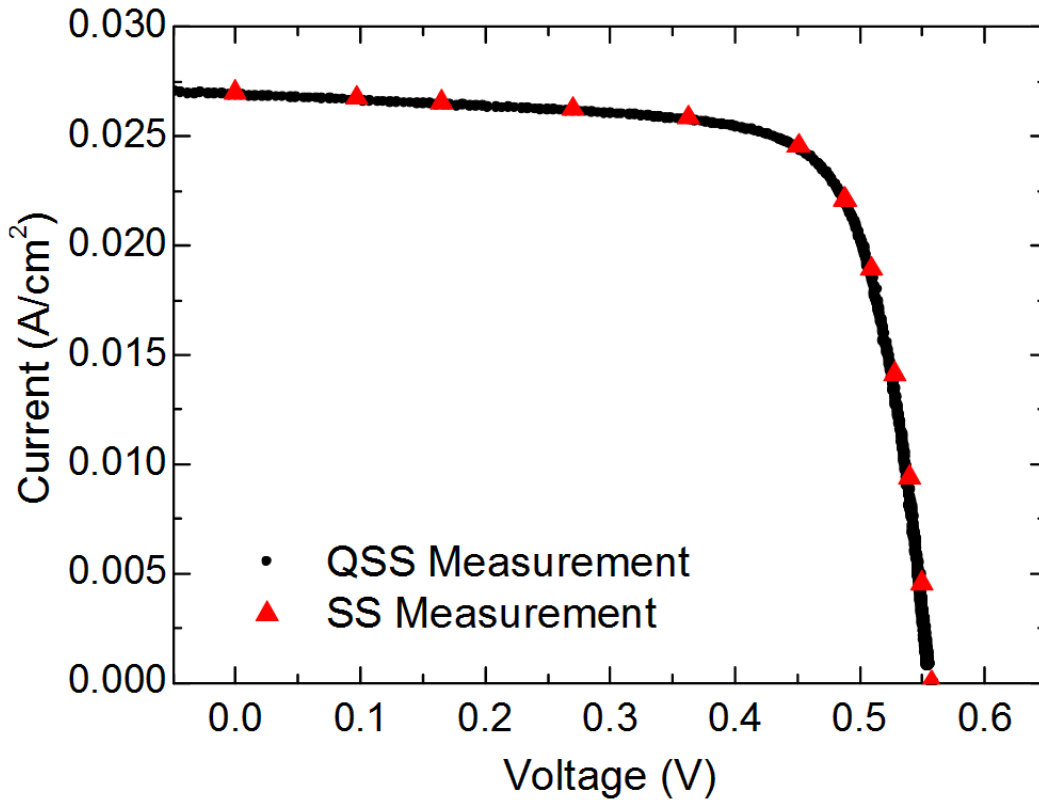


Fig. 21: Agreement of QSS and SS Measurement⁶⁶

In the paper it is recommended to use a resistor as shunt so that the voltage drop is in the range of 1 V when measuring the short-circuit current.

⁶⁵ Recard, 2006

⁶⁶ Recard, 2006

3.1.1 Solar Cell

For my experimental set-up I am using a solar cell of monocrystallin silicon at the size of 5.2cm x 1cm with an cut off edge. This solar cell is not encapsulated and mounted on a copper plate. The copper plate acts as the back contact of the cell, the front contact is achieved by a needle, pressed onto the busbar of the front contact grid. In Fig. 22 the solar cell can be seen. Also the fixed temperature sensor can be seen on the copper plate.

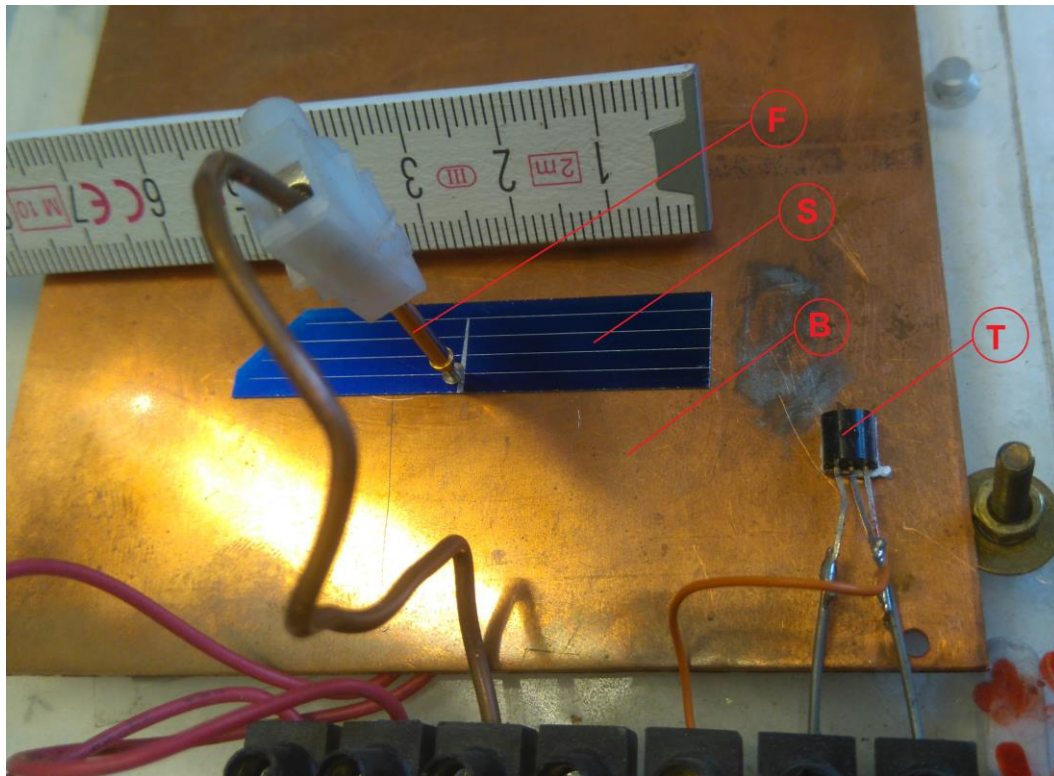


Fig. 22: Mounted solar cell

The front contact is labelled with F, the solar cell with S, the back contact with B and the temperature sensor is labelled with T.

In Fig. 23 a first current-voltage diagram of the solarcell measured with a potentiometer and two digital multimeters can be seen. As light source I used the same as described in 3.1.2.

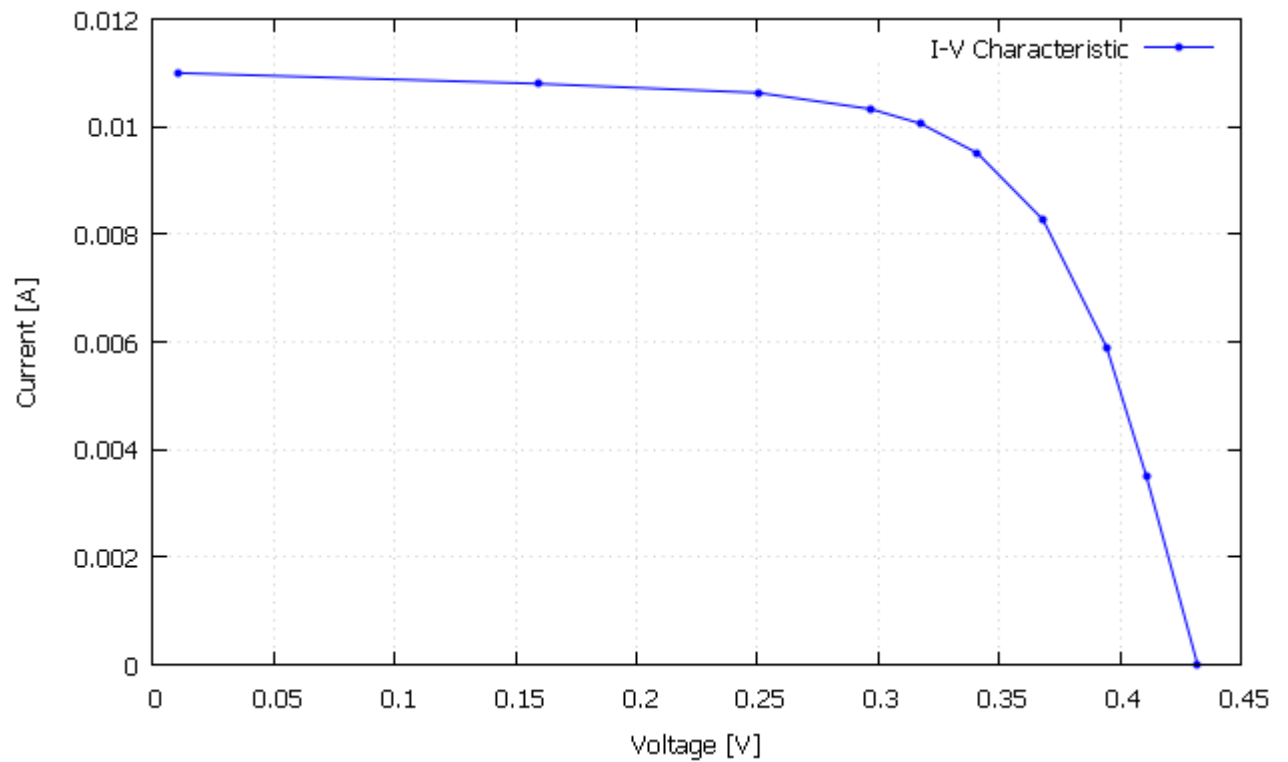


Fig. 23: Current-voltage diagram of the solar cell

From the current-voltage diagram it can be seen that the open circuit voltage with an illumination of 4 IR LEDs is 0.43 V and the short circuit current is 11 mA.

3.1.2 Light source

As illumination I am using 4 infrared diodes of type ELJ-870-629 from Roither LaserTechnik. The advantage of using an illumination built with LEDs is that the light output power can easily be read from its technical data. For these LEDs the output power is typically 90 mW at a current of 350 mA. As well there exists a chart that visualises the output power as a function of the current.

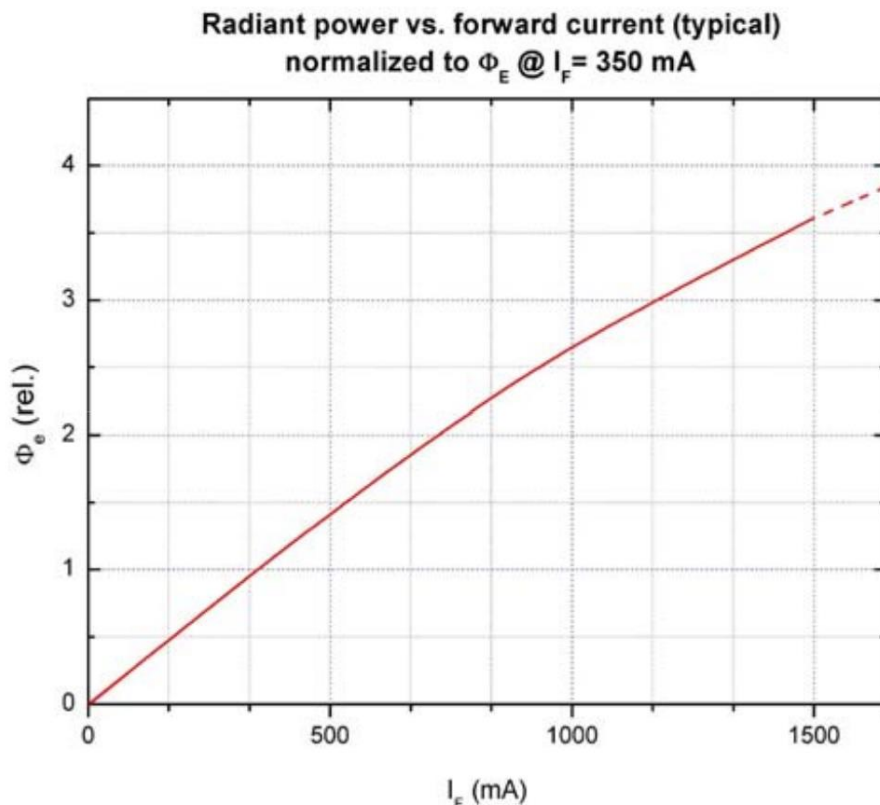


Fig. 24: Radiant power as a function of forward current⁶⁷

During the measurement the LED current was 347.6 mA, so the output power was very close to 90 mW per LED, hence in sum 360 mW.

3.1.3 Temperature sensor

For the temperature measurement and therefore the thermal voltage, I am using a LM35 precision centigrade temperature sensor from National Semiconductor. The temperature sensor is mounted on the same copper plate as the solar cell. The advantage of this temperature sensor is that the output voltage raises linear

⁶⁷ URL: http://www.roithner-laser.com/datasheets/led_highsingle/elj-870-629.pdf [20/06/2016]

with the measured temperature. For this type of temperature sensor the output voltage is $0 \text{ mV} + 10 \text{ mV/}^{\circ}\text{C}$. Thus for a Temperature of $+25 \text{ }^{\circ}\text{C}$ the output voltage will be $+250 \text{ mV}$. The typical accuracy of this temperature sensor is $\pm 0.2 \text{ }^{\circ}\text{C}$ with a guaranteed maximum tolerance of $\pm 0.5 \text{ }^{\circ}\text{C}$.

At the measurement the temperature of the copper plate was $28.6 \text{ }^{\circ}\text{C}$

3.1.4 Capacitor

The capacitors I am using are common electrolytic capacitors. It is worth mentioning that these capacitors are not unipolar, so they have a defined positive and negative side. For the measurement it is necessary to reverse the voltage of these capacitors. I decided to initially pre-charge the capacitors with a positive voltage and connect the solar cell. In this way, that the capacitors are charged at the end of the measurement with a reverse voltage, in the amount of the open circuit voltage of the solar cell. Thus, as I am using a single cell, this open circuit voltage is about 0.5 V . This little reverse voltage is a tolerable voltage for the capacitors. This can be seen from capacitors technical data. For capacitors of the manufacturer Vishay; they allow a reverse voltage of up to 1 V . I am using $220 \text{ }\mu\text{F}$ and $470 \text{ }\mu\text{F}$ capacitors of this type. The rest of the capacitors are from Philips, Panasonic, Nippon Cemi-Con and Rubycon. A list of the capacitors and their datasheets can be found in the Appendix. The capacitors are arranged into groups of differing capacities in order to be able to switch to different discharging rates. The circuit diagram of my capacitor bank can be seen in Fig. 25. The values of the various capacitors are:

C1: 5 mF	C8: 5 mF
C2: 2.5 mF	C9: 0.5 mF
C3: 0.5 mF	C10: $50 \text{ }\mu\text{F}$
C4: 0.25 mF	C11: $5 \text{ }\mu\text{F}$
C5: $50 \text{ }\mu\text{F}$	C12: $2.5 \text{ }\mu\text{F}$
C6: $25 \text{ }\mu\text{F}$	C13: $1 \text{ }\mu\text{F}$
C7: $5 \text{ }\mu\text{F}$	

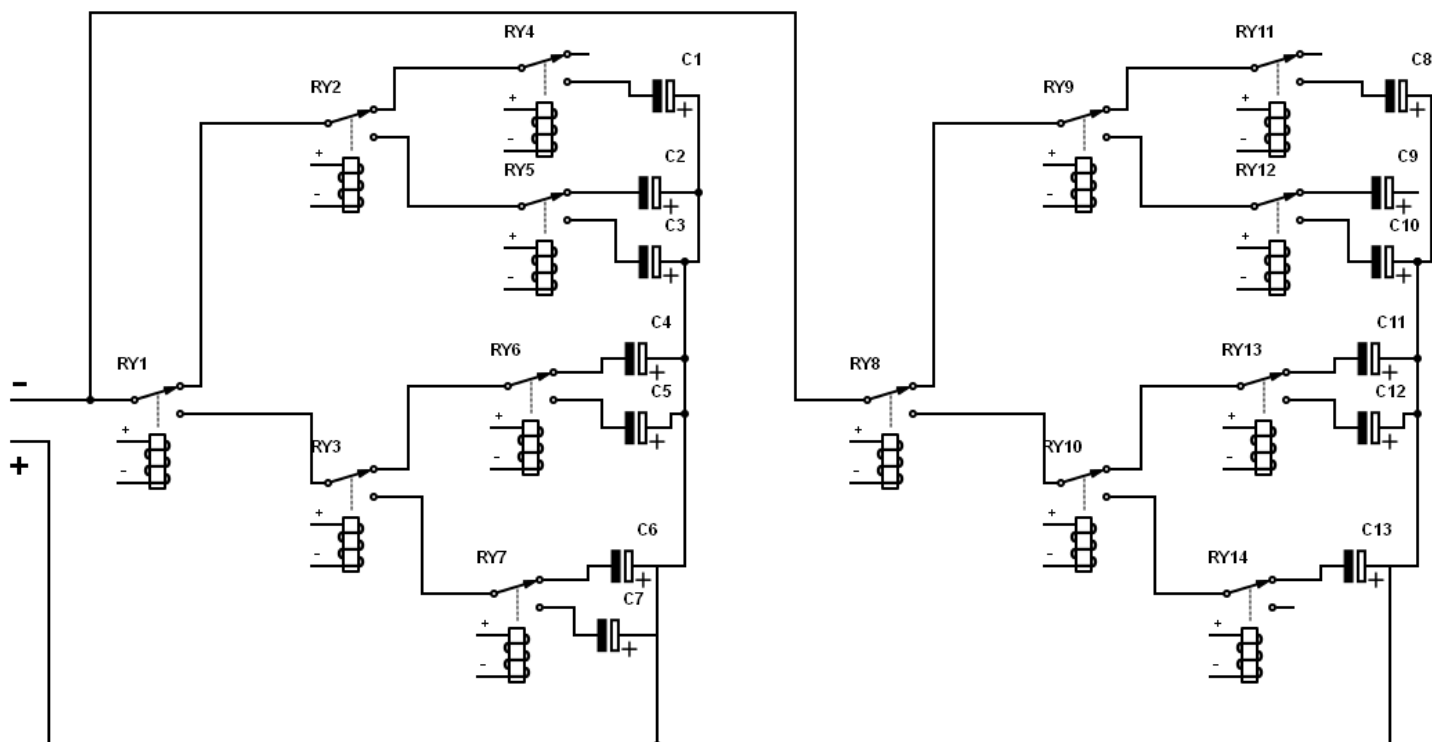


Fig. 25: Circuit diagram of the capacitor bank

These capacitance values are achieved by combining different capacitors in parallel. The technical data sheets of the capacitors can be found in the Appendix.

For 5 mF capacitance a single 4700 μF capacitor is used. The 4700 μF capacitor is from Panasonic with a capacitance tolerance of $\pm 20\%$, so 5 mF is in the tolerance range.

For 2.5 mF a capacitor of 2.2 mF from Panasonic in parallel with a capacitor of 330 μF from Panasonic is used.

For 0.5 mF a capacitor of 470 μF from Vishay is used, due to tolerances 0.5 mF can be achieved.

For 0.2 5mF a capacitor of 220 μF from Vishay and a capacitor of 33 μF from Panasonic is used.

For 50 μF a capacitor of 47 μF from Nippon Chemi-Con with a capacitance tolerance of 20 % is used.

For 25 μF a capacitor of 22 μF from Panasonic and a capacitor of 3.3 μF from Rubycon is used.

For 5 μF a capacitor of 4.7 μF from Panasonic and a 0.33 μF capacitor from Panasonic is used.

For 2.5 μF a capacitor of 2.2 μF from Panasonic and a capacitor of 0.33 μF from Panasonic is used.

For 1 μF a 1 μF capacitor from Philips is used. The capacitor is rated at a voltage of 63 V. Unfortunately, there is no additional technical data available for this capacitor.

3.1.5 Relay

DR-5V SDS relays (from Nais) were used. The complete technical data can be found in Appendix.

The advantage of using reed relays is the low contact bounce time: the typical contact bounce time for this type of relay is 1ms. I have used this type of relay not only for the capacitor bank, but also as the switch to trigger the measurement (see Fig. 20). As a consequence of the bounce time, I pre-charged the capacitors with a voltage of -1.9 V from point of view of the solar cell. The motivation of pre-charging only with -1.9 V can be found in the documentation of my measuring instrument. For measuring the fast quasi-steady state current-voltage characteristic, I used a NI USB-6251 (National Instruments). This measuring device has for different measurement ranges a different accuracy: by choosing a lower range the accuracy increases (see Fig. 26).

According to the data sheet the contact bounce time is 1 ms, so when using a capacitor as low as 1 μF with a solar cell with a short circuit current of 10 mA, the voltage increase in this initial 1ms would be 10 V. A negative voltage of 1.9 V is not enough as the measurements will all be in the contact bounce time. This is not a good condition for measurements. Therefore, I started to measure the real contact bounce time for the relay. The experimental set-up for this measurement can be seen in Fig. 27. To trigger the relay I used a switch in combination with a BC547 NPN transistor and a resistor of 12 k Ω . As a voltage source for the coil of the relay I used a Heinzinger LNG 32-3 adjusted to 5 V. As a voltage source for the bounce time measurement, I used a 9 V battery. In parallel to the oscilloscope I used a 100 Ω resistor. The resistor is needed to measure a voltage drop during bounce; without this resistor the voltage drop is not so clearly visible due to the oscilloscope's high input resistance of 1 M Ω and input capacitance of 13 pF. The oscilloscope I used for this measurement was a DSO3062A (Agilent Technologies). The influence of this additional 100 Ω resistor can be seen in Fig. 28 and Fig. 29.

AI Absolute Accuracy



Note Accuracies listed are valid for up to two years from the device external calibration.

Table 2. AI Absolute Accuracy

Nominal Range Positive Full Scale	Nominal Range Negative Full Scale	Residual Gain Error (ppm of Reading)	Residual Offset Error (ppm of Range)	Offset Tempco (ppm of Range/°C)	Random Noise, σ (μVrms)	Absolute Accuracy at Full Scale (μV)	Sensitivity (μV)
10	-10	60	20	21	280	1,920	112.0
5	-5	70	20	21	140	1,010	56.0
2	-2	70	20	24	57	410	22.8
1	-1	80	20	27	32	220	12.8
0.5	-0.5	90	40	34	21	130	8.4
0.2	-0.2	130	80	55	16	74	6.4
0.1	-0.1	150	150	90	15	52	6.0

Fig. 26: Absolute accuracy of NI USB-6251 for different ranges⁶⁸, the used range is highlighted

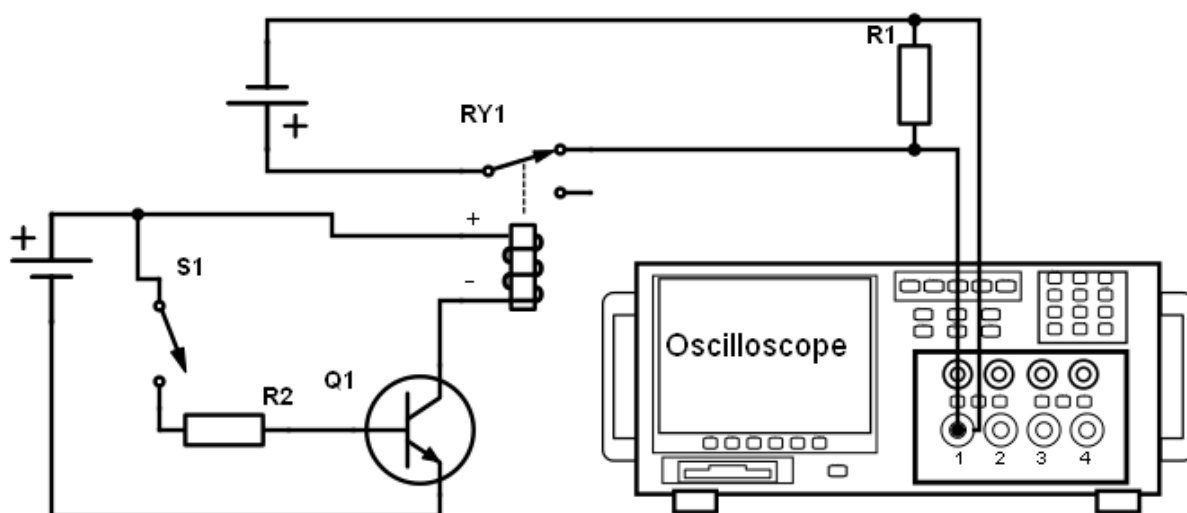


Fig. 27: Experimental set-up for bounce time measurement

⁶⁸ URL: <http://www.ni.com/pdf/manuals/375213b.pdf> [23/06/2016]

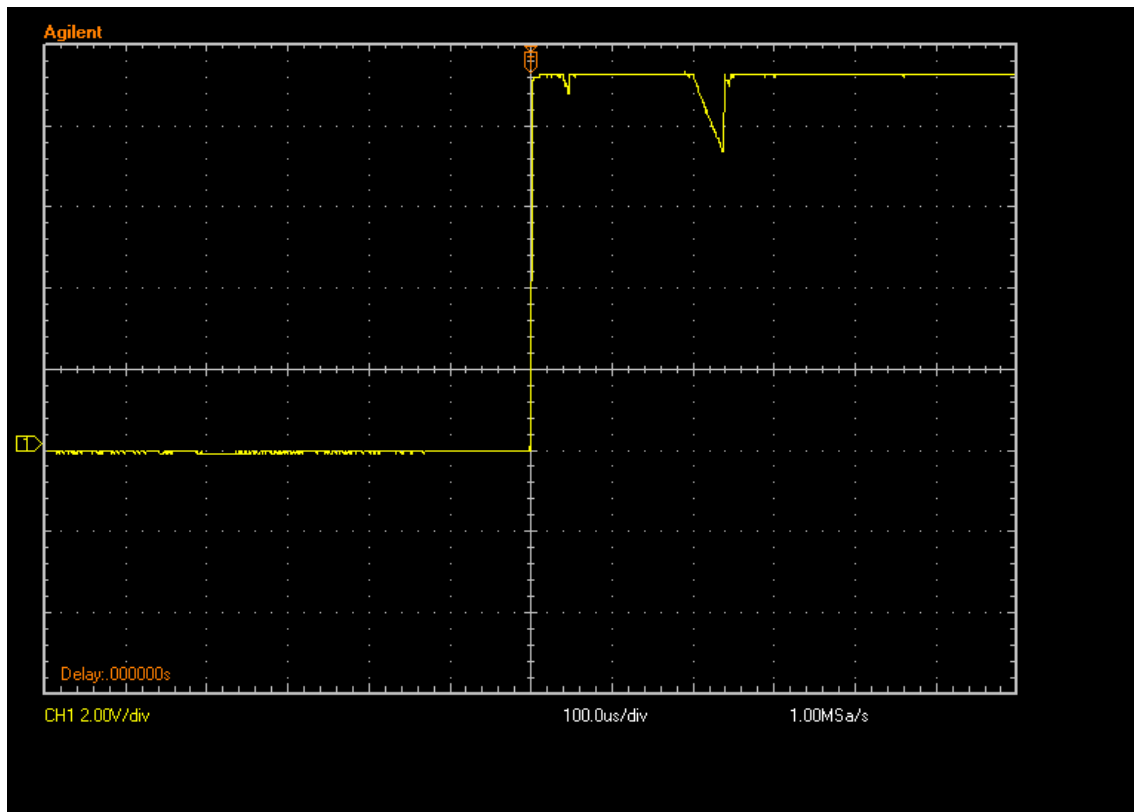


Fig. 28: Contact bounce without 100 Ω resistor switched off

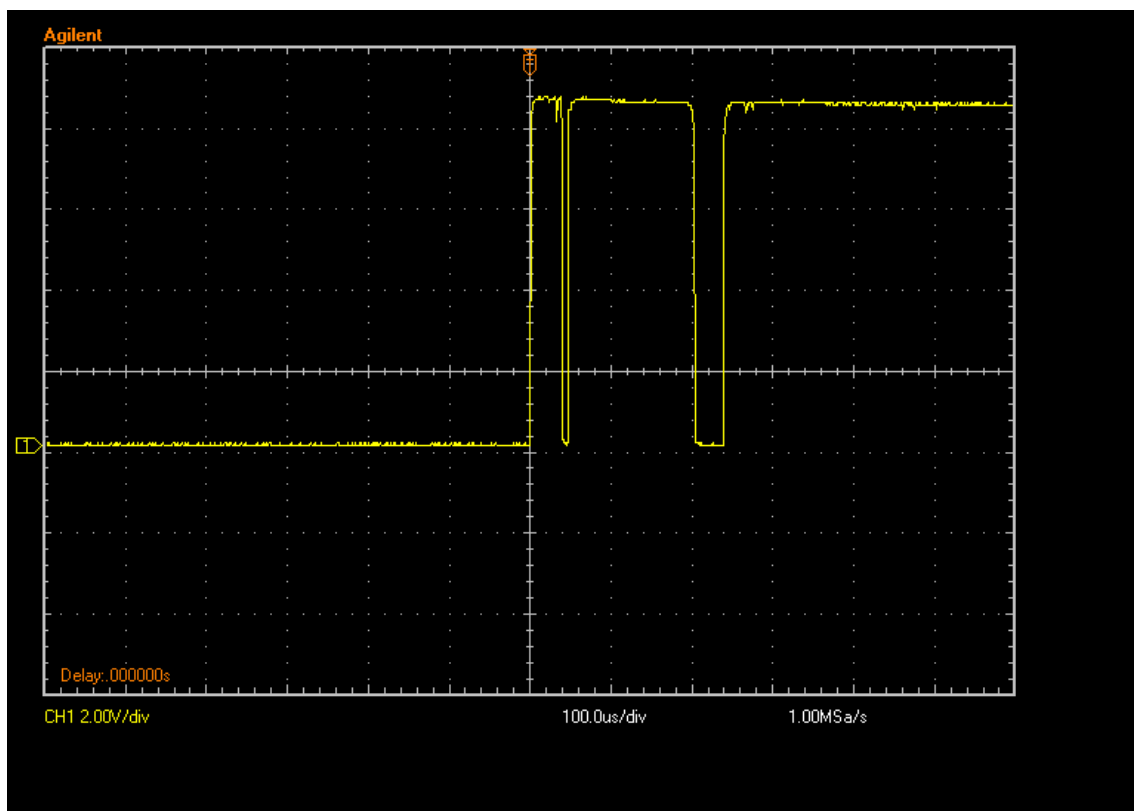


Fig. 29: Contact bounce with 100 Ω resistor switched off

These measurements were made when the current is switched off at the coil. From the contact bounce measurements it can be seen that the relay bounces for the first time after around 50 μs for a very short period and a second time after 200 μs with a longer contact loss of about 50 μs . So, after around 250 μs the contact is established. In comparison to the technical data sheet, the relay doesn't need a full 1 ms to establish a closed contact.

These 250 μs are still too long for measurements with a 1 μF capacitor with only a negative pre-charge of -1.9 V. In this time period a 1 μF capacitor will raise its voltage by 2.5 V when charged with 10 mA.

The next question is to measure the contact bounce time at the other contact of the switch, i.e. when the current at the coil is switched on. This behaviour can be seen in Fig. 30.

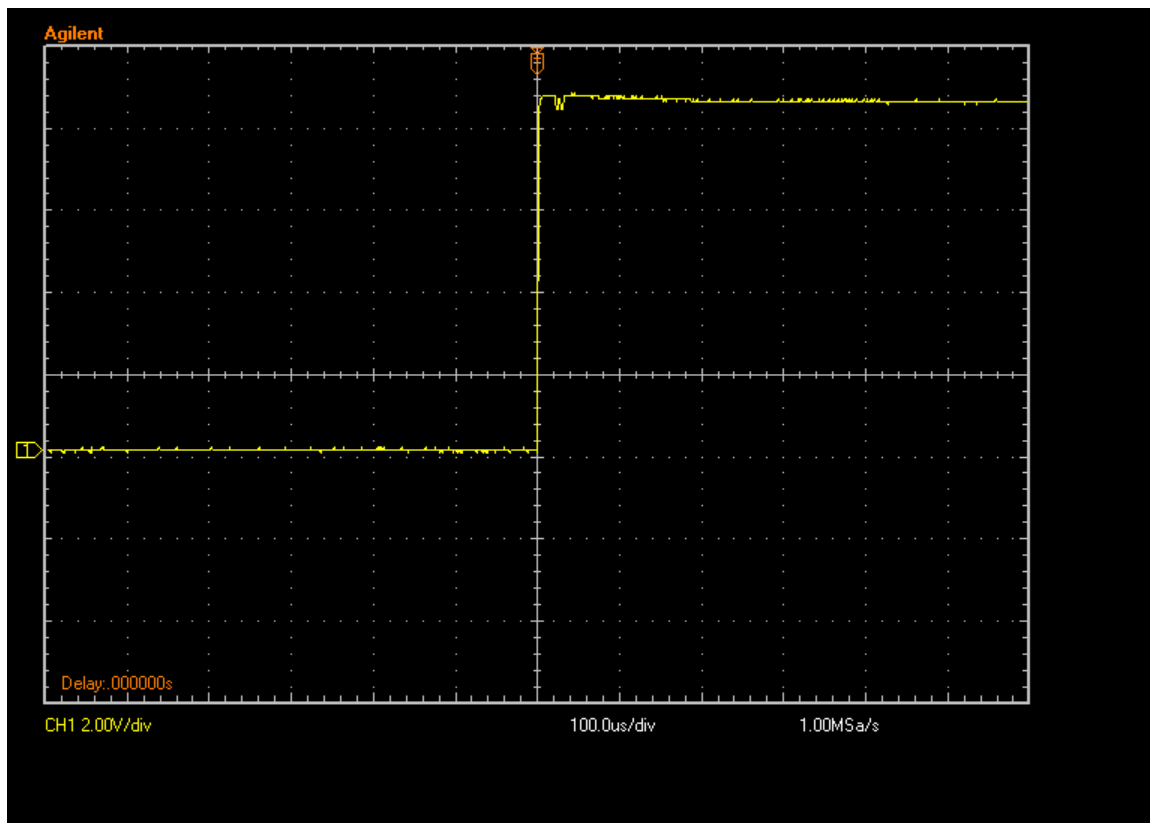


Fig. 30: Contact bounce with the coil current switched on

The behaviour is completely different from the first case. In this case the relay only bounces once and it isn't even a full contact loss. The bounce occurs after around 20 μs and only lasts for another 20 μs , so after only around 50 μs the contact is established. This means that the smallest capacitor I used only got charged around 0.5 V, so a negative pre-charge of 1.9 V is more than sufficient.

3.1.6 Data acquisition

As mentioned in section 3.1.5, for data acquisition I used a NI USB-6251 (National Instruments). This NI USB-6251 is connected with a NI ELVIS. The NI ELVIS provides a pin board where the single modules are placed. The NI ELVIS also provides connectors for the solar cell, external power supply, the temperature sensor and for current measurement of the light source. The NI ELVIS provides an output voltage for the relay coils and digital outputs for triggering the relays. A picture of the NI ELVIS can be seen in Fig. 31.

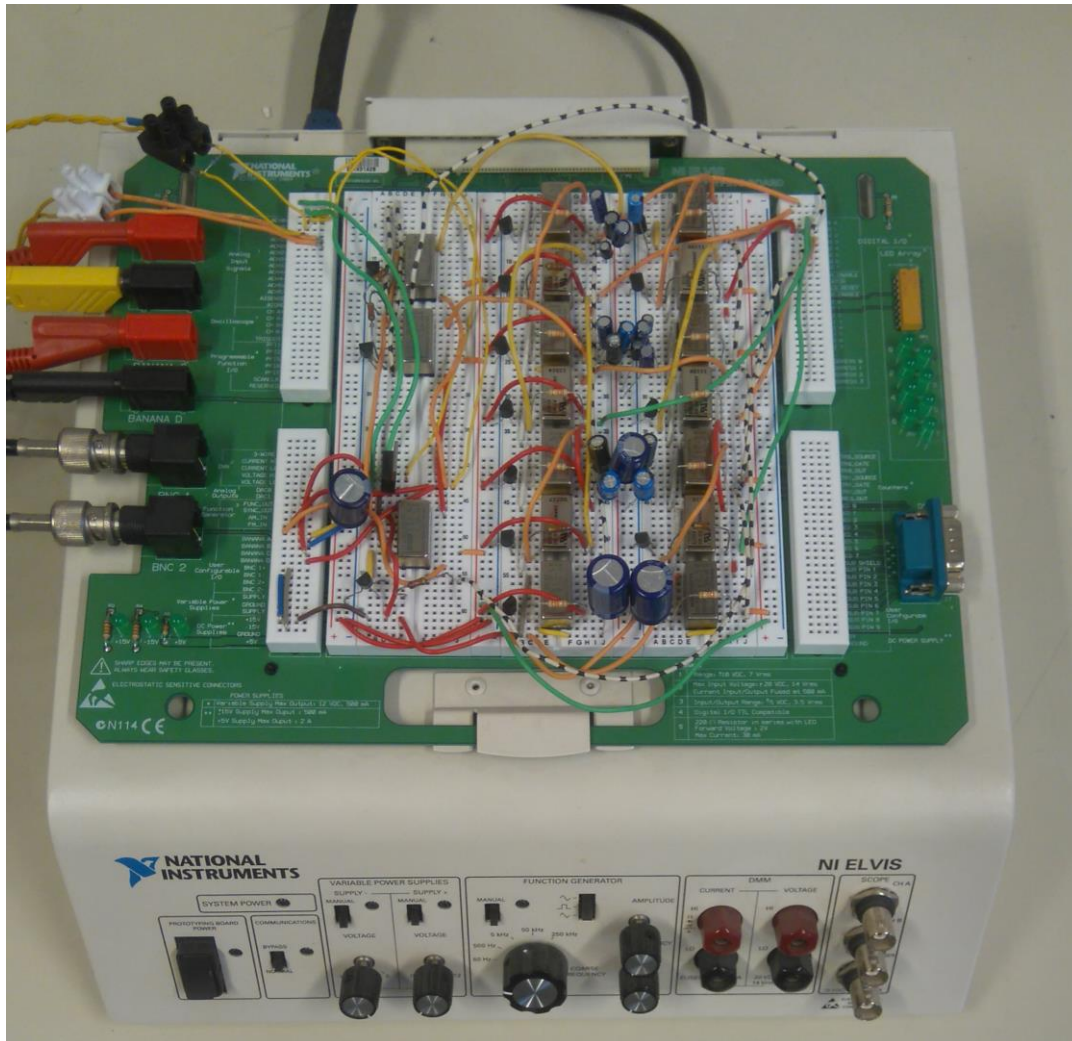


Fig. 31: NI ELVIS with experimental setup

My experimental set-up can be seen. The only parts not visible is the solar cell, the light source and the regulated power supply.

Actual the measurement is done using the NI USB-6251, which communicates with the NI ELVIS over a bus. The NI USB-6251 is able to capture a maximum of 16 analogue inputs with a maximum rate of 1 Msamples/s in multichannel

mode, or 1.25 Msamples/s for a single channel. The full technical data can be found in the Appendix. In other words, it can be said that the NI ELVIS provides the input and output connectors and a pin board, and the measurement is done by the NI USB-6251.

3.2 Measurement

3.2.1 Quasi-steady state measurement

The first measurement is testing the thesis that a quasi-steady state measurement leads to the same results as a steady-state measurement as mentioned by Recart, Mäckel, Cuevas and Sinton. Therefore I used a 5 mF capacitor for this measurement to be certain not to exceed the 100 V/s charging rate of the capacitor. Using a 5 mF capacitor is more than sufficient; this leads to a charging rate of 2 V/s when calculated with 10 mA. For the current measurement I used a 10 Ω resistor as a shunt. The used 10 Ω resistor is a thick film resistor. The advantage of a film transistor over a wire wound resistor is an almost lack of inductance. The resistor I used has an inductance lower than 0.1 μ H according to the data sheet. Therefore the influence of the inductance is negligible. In the worst case scenario, when the 1 μ F capacitor is used, the voltage drop due to the inductance is still 250 times lower than the voltage drop due to the resistance.

The result of the first measurement with a 5 mF capacitor can be seen in Fig. 32. The measurement was done five times and an average was calculated.

The electrical properties of the solar cell can also be calculated. According to equation (3.1), the relation for the simple equivalent circuit, the parameters that can be fitted out of the data are:

$$I_{ph}=0.0109326 \text{ A} \pm 0.0000087 \text{ A}$$

$$I_s=1.034 \text{ } \mu\text{A} \pm 0.032 \text{ } \mu\text{A}$$

$$n=1.7904 \pm 0.0061$$

$V_{th}=26.0 \text{ mV}$ due to the temperature of the solar cell being 28.65 °C.
The rms of residuals is 6.4753 e-5.

A visualisation of the fitted curve can be seen in Fig. 33.

The plots and the fits are done with gnuplot.

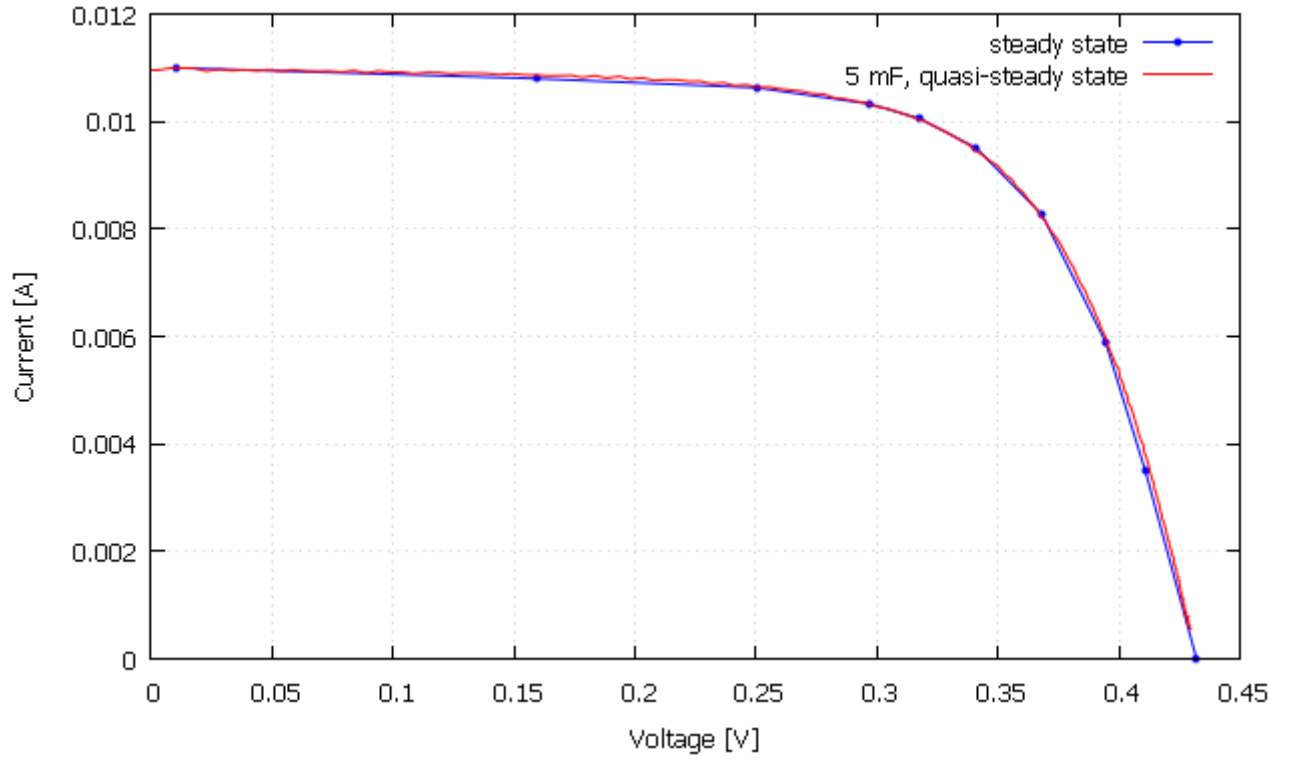


Fig. 32: Agreement of quasi-steady state and steady state measurements

The plotted equation for Fig. 33 is:

$$I = I_{ph} - I_s \left(e^{\frac{U_d}{n \cdot V_{th}}} - 1 \right) \quad (3.1)$$

U_d corresponds to the voltage at the diode. This voltage, in the model of the simple equivalent circuit, is the same as the measured voltage of the solar cell, due to the absence of resistors.

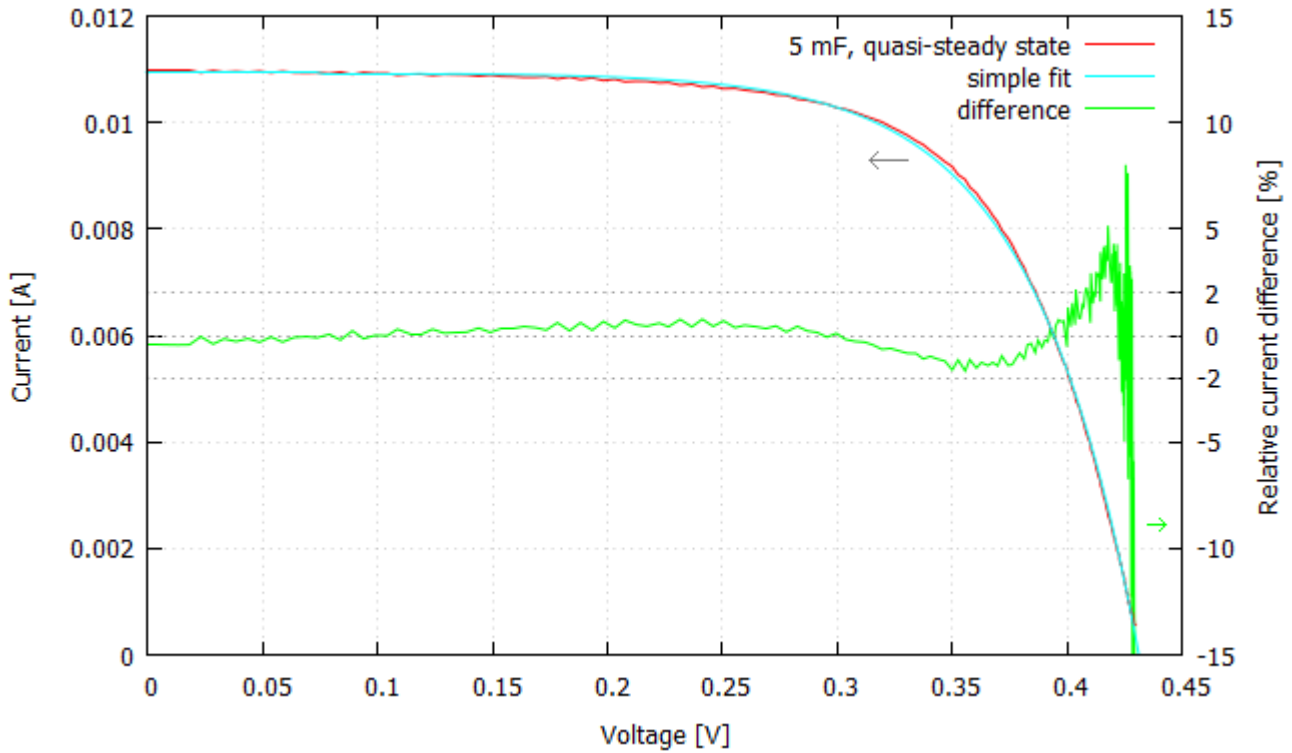


Fig. 33: Visualisation of the fit and measured curve

Also the relative difference between the measurement and the fit can be seen as the green line with the right axis scale. It can also be seen, that the difference between the measured and the fitted curve is over a wide range within a relative current difference of $\pm 2\%$.

Next I want to look at the one diode model of a solar cell. In that kind of model a parallel and a series resistor are introduced. As a result, the equation to describe a solar cell gets extended. The circuit diagram of this approximation can be seen in Fig. 16. According to the circuit diagram, the characteristic can be described with:

$$I = I_{ph} - I_d - \frac{U_d}{R_p} = I_{ph} - I_s \left[e^{\frac{U + R_s \cdot I}{n \cdot V_{th}}} - 1 \right] - \frac{U + R_s \cdot I}{R_p} \quad (3.2)$$

A difference when interpreting this equation is that it is an implicit function. The result of fitting the measured curve with this model can be seen in Fig. 34.

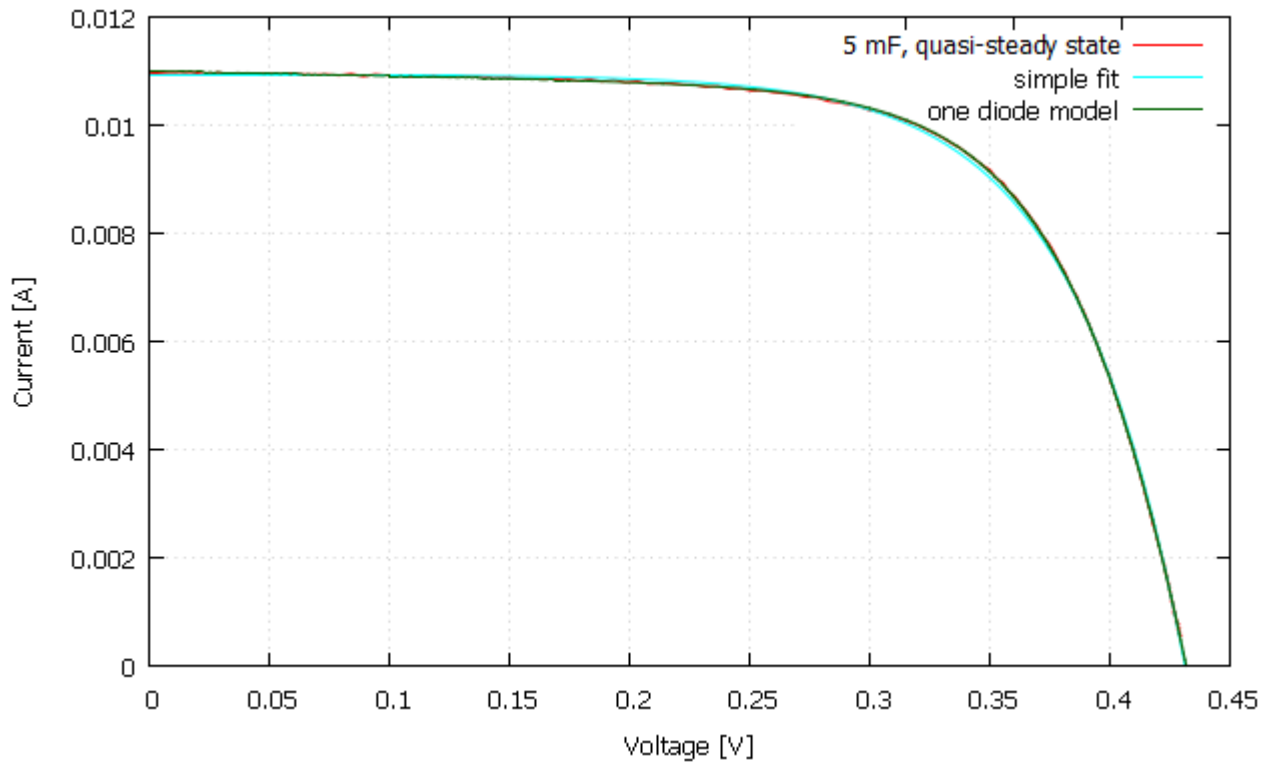


Fig. 34: Comparison of the one diode model and simple equivalent circuit

The fit with the simple equivalent circuit is named simple fit and in light blue, and the fit with the one diode model is in dark green. The fit results are:

$I_{ph} = 0.011017 \text{ A} \pm 0.000012 \text{ A}$

$I_s = 77 \text{ nA} \pm 11 \text{ nA}$

$n = 1.405 \pm 0.018$

$R_s = 1.250 \text{ } \Omega \pm 0.056 \text{ } \Omega$

$R_p = 1076 \text{ } \Omega \pm 87 \text{ } \Omega$

The thermal voltage is still 26 mV due to the cell being at the same temperature.

The rms of residuals is $1.60989 \text{ e-}9$, which is over 4 orders of magnitude less than for the simple circuit.

3.2.2 Transient measurement

In the next step I want to describe the behaviour when measured with smaller capacitors, which in fact means a faster pass of the current-voltage characteristic. The voltage change per time also increases when smaller capacitors are used. As a first measurement I want to compare the measurements with a 5 mF capacitor and with a 50 μF capacitor. In this case the charging rate of the capacitor is around 200 V/s.

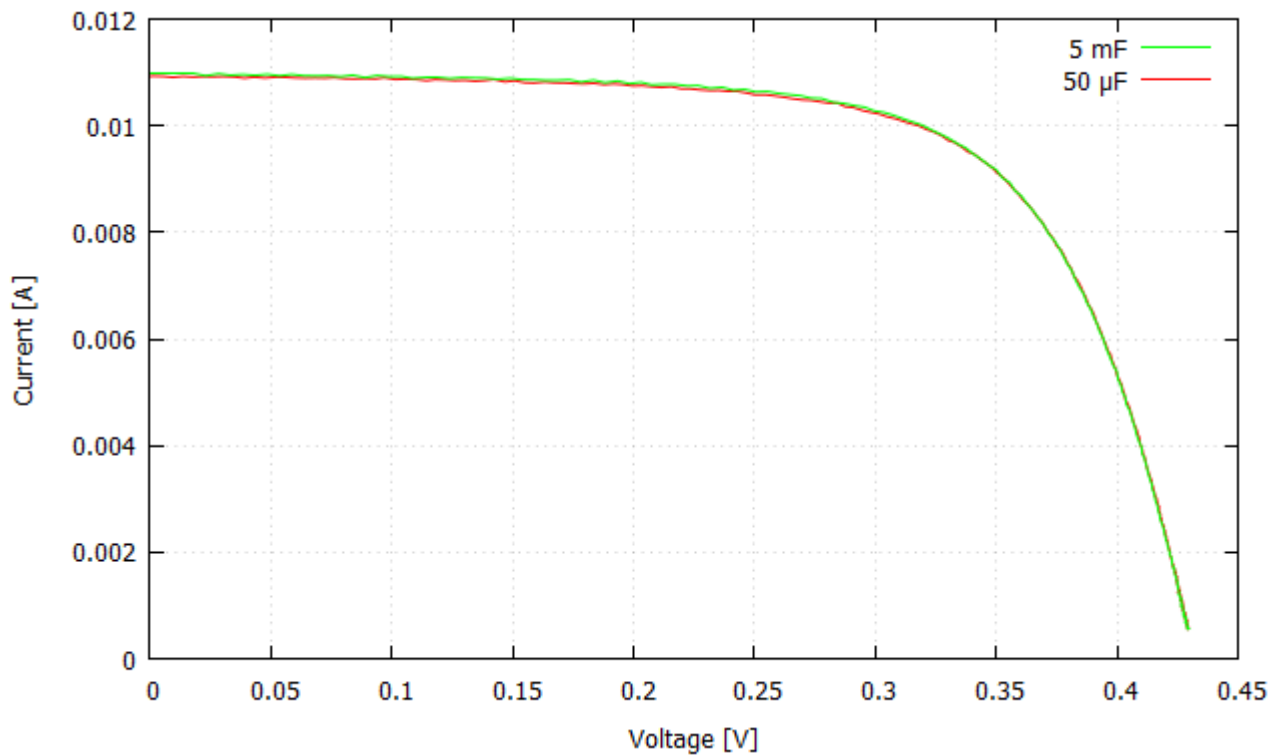


Fig. 35: Measurement with 5 mF and 50 μ F

The 5 mF measurement is done at a measure rate of 400 samples per second, or 1 sample every 2.5 ms. For the measurement with the 50 μ F capacitor the sample rate is set to 50,000 samples/s, or a sample every 20 μ s.

As it can be seen in Fig. 35, there is almost no difference in the measurement results. This means that a charging rate of 200 V/s is still in the quasi-steady state range of the solar cell.

Next I want to look at the measurement with a 25 μ F capacitor. In this case the voltage change is 400 V/s when calculated with a charging rate of 10 mA. The measurements with the 25 μ F capacitor are done at 100,000 samples/s, or a sample every 10 μ s.

At this voltage change rates a leaving of the quasi-steady state condition can be seen. The difference from the quasi-steady state measurement is not big, but it is visible.

Before discussing the effects that lead to this discrepancy when entering higher voltage change rates, I want to look at the results with even smaller capacitors. This can be seen in Fig. 37.

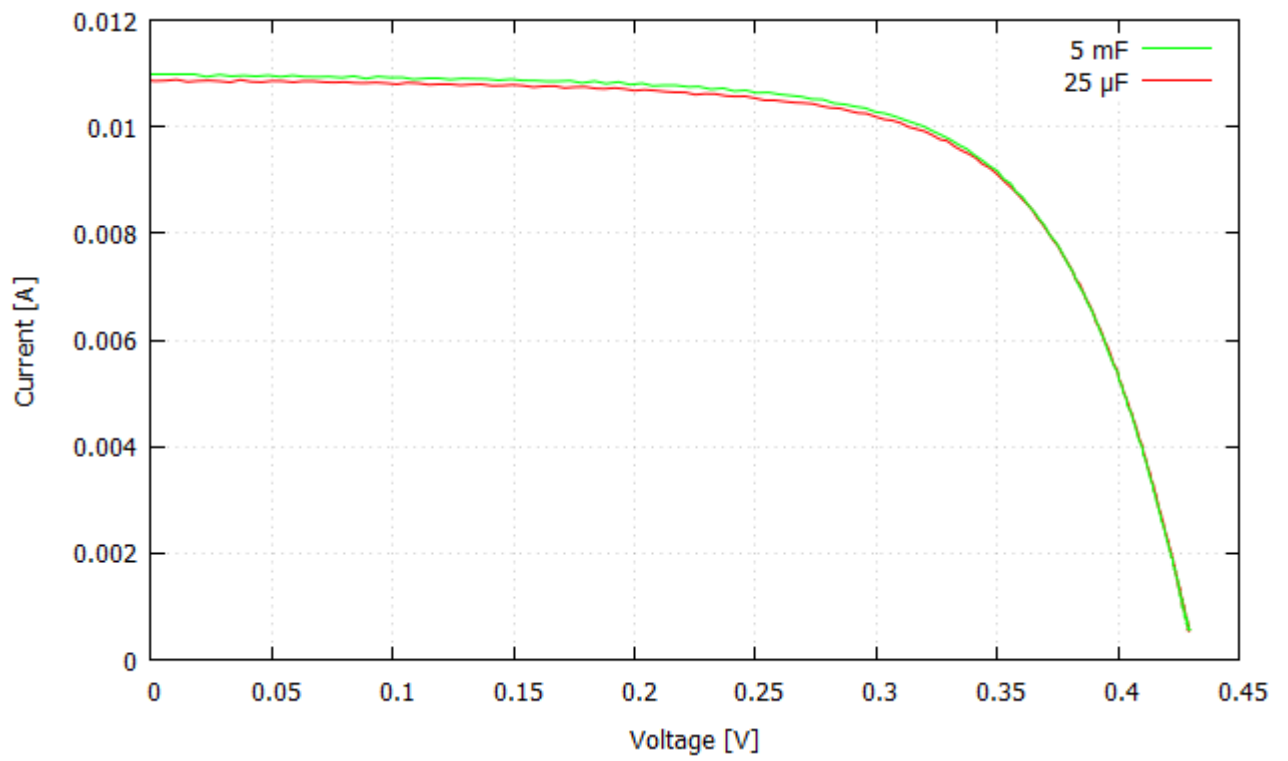


Fig. 36: Measurements with 5 mF and 25 μ F

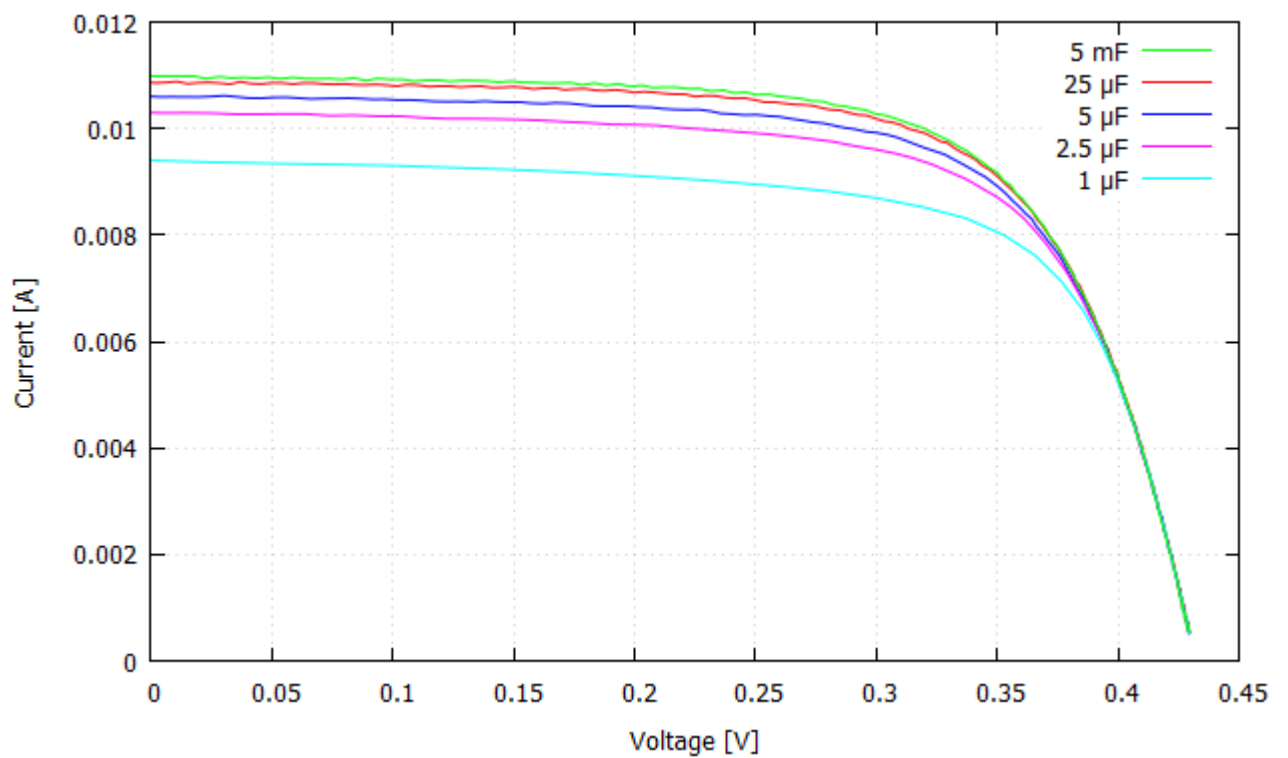


Fig. 37: Measurements with smaller capacitors

The measure rates for the smaller capacitors are:

When using a 5 μF capacitor the sample rate was set to 400,000 samples/s, or a sample every 2.5 μs

The sample rate when the 2.5 μF capacitor got used was the same as before, 400,000 samples/s.

The 1 μF capacitor was also measured at 400,000 samples/s. The reason for the 400,000 samples/s limit can be found in the NI USB-6251 data sheet. This measuring device is capable of capturing 1.25 Msamples/s for 1 channel, but is only able to capture 1 Msample/s in aggregate when recording more than one channel. So with an aggregate of 800,000 samples/s I can ensure that this limit is not exceeded.

From Fig. 37 one can assume that with a higher voltage change rate, the short circuit current decreases while the open circuit voltage stays the same. A closer look at the actual voltage change rates shows why there might be a decrease in maximum current but not in maximum voltage.

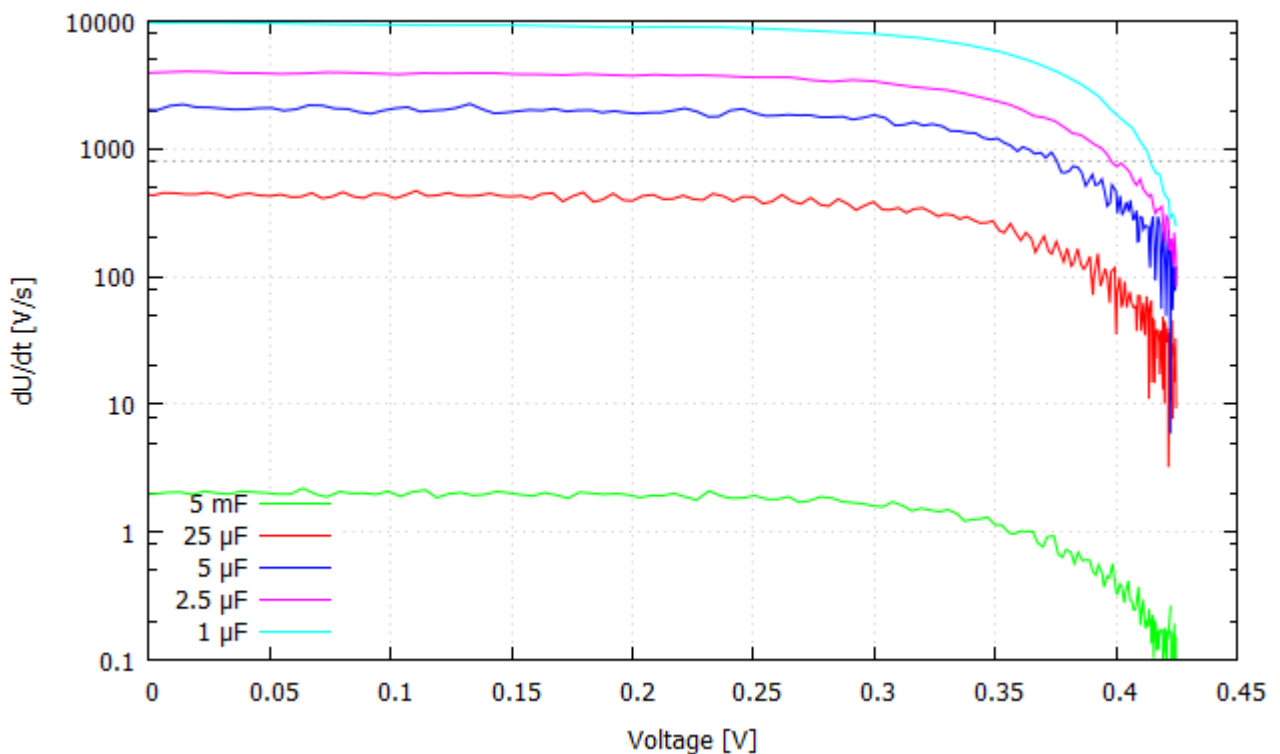


Fig. 38: Comparison of voltage change rates for different capacitors

A certain agreement of the drop in the current and the voltage change rate can be assumed. This behaviour leads to the assumption that the solar cell has an internal capacitance that needs to be charged with even higher currents, with increasing voltage change rates. Another thing to mention is the grey dotted line in Fig. 38 at 800 V/s, this line represents the limit, until where the error is within

$\pm 2\%$, as seen in Fig. 49. As it can be seen towards V_{OC} all transients decrease below this limit.

As a reminder, the equation when charging a capacitor with a fixed current is:

$$I = \frac{dQ}{dt} = C \frac{dU}{dt} \quad (3.3)$$

In this equation it can be seen that the current needed to charge an internal capacitor increases with the voltage change rate. This current to charge an internal capacitor is the current drop that is measured at high voltage change rates.

When looking at the equivalent circuit of a solar cell, one can see that a simplified solar cell is just a current source and a diode. From a diode, the internal capacitance is known.

The internal capacitance of a diode is the depletion capacitance and the diffusion capacitance.

The motivation for introducing these two capacitances can be found in section 2.1.

As a result, the equivalent circuit can be extended to:

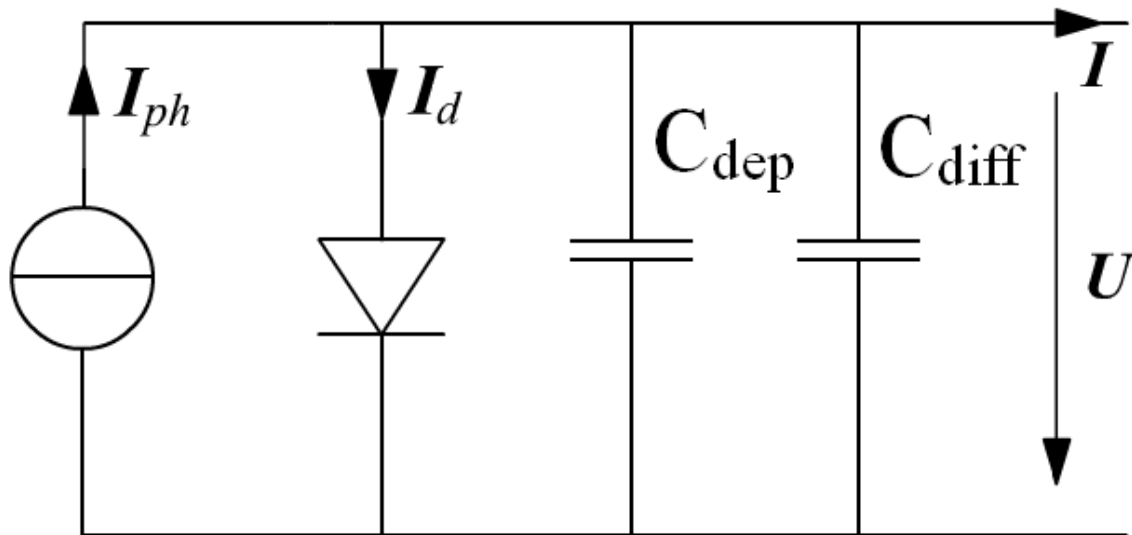


Fig. 39: Extended equivalent circuit⁶⁹

⁶⁹ Adapted from URL:

https://upload.wikimedia.org/wikipedia/commons/3/3c/Solarzelle_Schaltbild3.png [01/07/2016]

Once the depletion and the diffusion capacitance are introduced, the next step would be to measure these capacitances. There are many ways to measure capacitances. The first way would be to measure the charging or discharging curve. This way may not lead to an accurate result due to the fact that these capacitances do not have a fixed value. Another way to obtain the values is by measuring them with an AC current. In this case the value of the capacitance can be obtained from the magnitude and phase of the current. This measurement method uses the phase shifting effect of a capacitor.

The impedance of a capacitor can be written as:

$$Z_c = -i \frac{1}{\omega \cdot C} \quad (3.4)$$

The equation of the complex impedance can be derived from equation (3.3) and the assumption of a voltage curve of:

$$U(t) = U_0 \cdot e^{i \cdot \omega \cdot t} \quad (3.5)$$

As a result, when feeding a capacitor with an alternating voltage, the current is 90° before the voltage. So the phase shift of a capacitor is -90°. When adding a resistor in series to a capacitor the phase shift becomes a value between 0° and -90°, depending on the values of the elements. So when looking at a current voltage diagram in a complex plan, the values of the resistor and the capacitor can be seen.

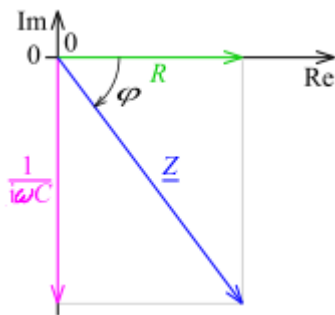


Fig. 40: Complex plane of a capacitor in series with a resistor⁷⁰

The phase shift (φ) can be obtained by comparing the alternating current and the alternating voltage. The value of the impedance (Z) can be derived using

⁷⁰ URL:

https://de.wikipedia.org/wiki/Komplexe_Wechselstromrechnung#/media/File:Widerstand_Zeiger RC.svg [01/07/2016]

Ohm's law and U_{eff} and I_{eff} . Afterwards, the results have to be split in a real and imaginary part. This imaginary part leads to the capacitance.

$$R = Z \cdot \cos(\varphi) \quad (3.6)$$

$$\frac{1}{\omega C} = Z \cdot \sin(\varphi) \quad (3.7)$$

This is the way I have obtained the solar cell's capacitance. I used a built-up experimental set-up from Prof. Schlosser. The circuit diagram can be seen in Fig. 41.

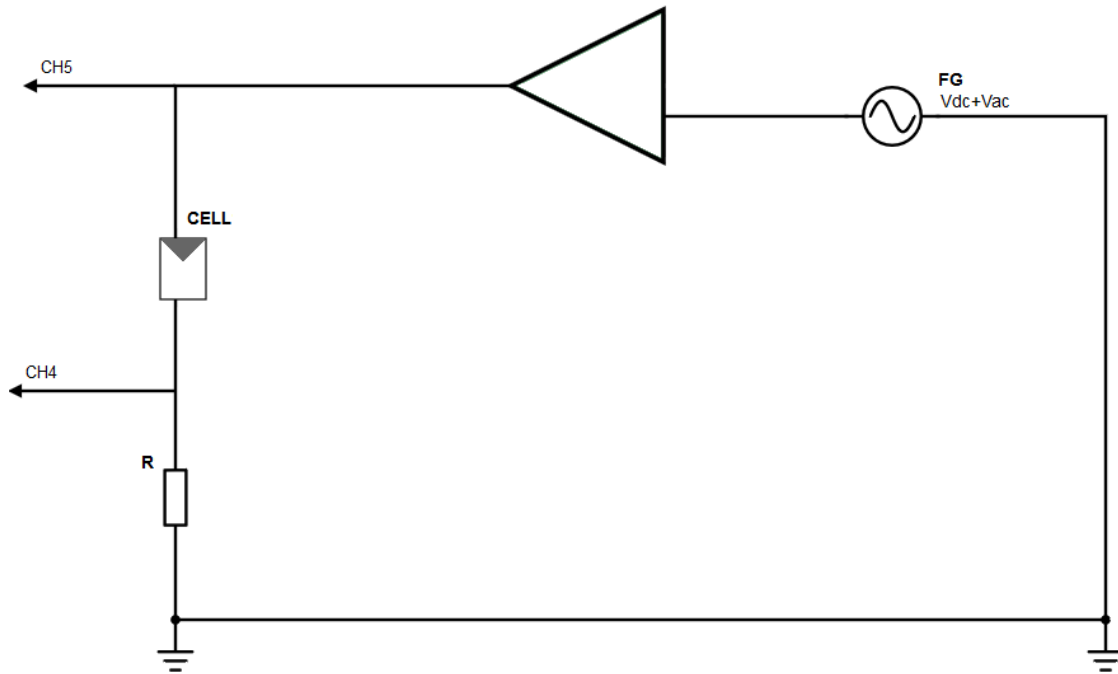


Fig. 41: Circuit diagram for capacity measurement

The measurement is done with a function generator, which produces a DC and an AC voltage, and a shunt resistor of $50 \, \Omega$ for the current measurement. The analysis of the measured curve is done by a lock-in amplifier. The DC voltage is raised in discrete steps with a constant AC voltage overlaid. As a result I obtained the capacity of the solar cell as a function of the DC voltage. The measurement is done as well illuminated with the IR LEDs, as in dark. It was also done at different AC frequencies. As an example I want to show in Fig. 42 the curve measured in the dark with an AC frequency of $9547.0 \, \text{Hz}$ and an AC amplitude of $0.05 \, \text{V}$. Also in the plot there is a fitted curve for the capacitance.

The fit is done according to:

$$C = C_{dep} + C_{diff} = CJO \left(1 - \frac{U_d}{VJ} \right)^{-0.5} + \frac{\tau}{V_{th}} I_d \quad (3.8)$$

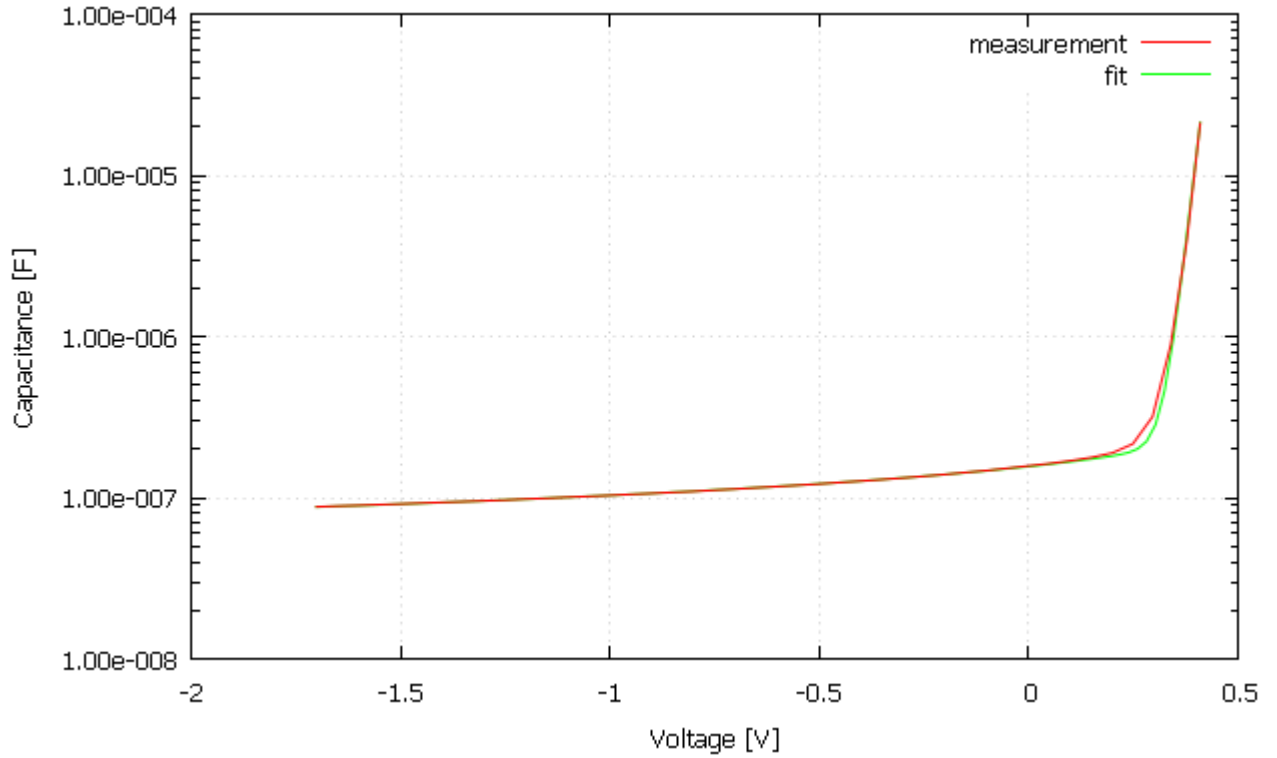


Fig. 42: Measured and fitted capacitance of the solar cell

The fit results are:

$CJO = 0.15618 \mu F \pm 0.00011 \mu F$

$VJ = 0.7794 V \pm 0.0023 V$

$\tau = 1.99 ns \pm 0.23 ns$

$n = 0.7176 \pm 0.0039$

$V_{th} = 26mV$ due to a temperature of $28.68 ^\circ C$
according to the one diode model:

$I_S = 77 nA$

The rms of residuals is $3.74709 e-7$

The lower ideality factor can be understood when looking at the two diode-model of a solar cell.

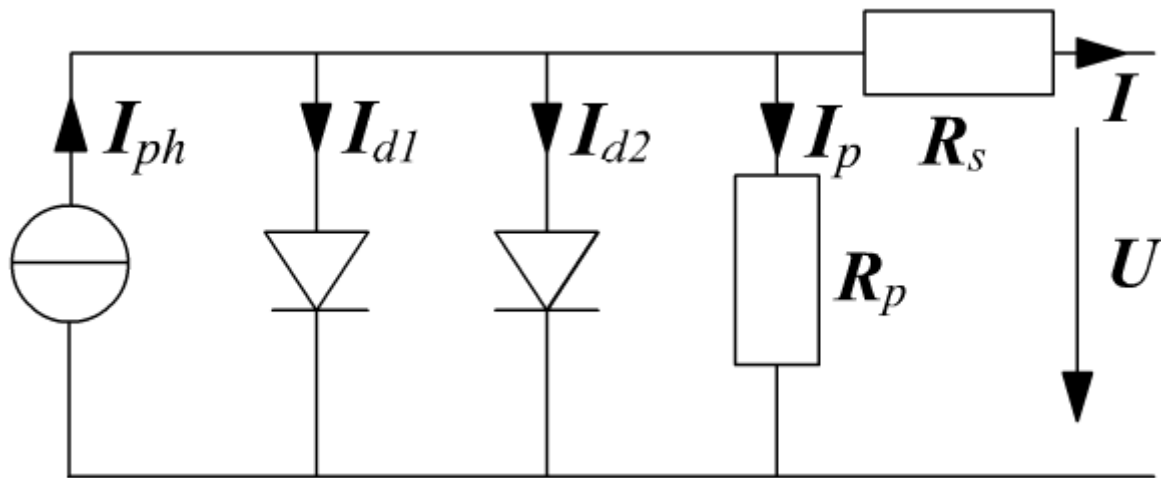


Fig. 43: Two diode model of a solar cell⁷¹

In this model the behaviour of the solar cell is described with two diodes with different ideality factors. One diode for the diffusion current has an ideality factor of one and the second diode for the recombination in the depletion area has an ideality factor often fixed at two. So when calculating the diffusion capacitance, the corresponding diode in this model is the first, and therefore the ideality factor in the fit of the diffusion capacitance is expected to be close to one. In contrast when fitting the current-voltage characteristic with the one diode model the ideality factor, n , usually accounts for the superposition of the individual diode currents and will be in between of one and two as derived in section 3.2.1.

⁷¹ Adapted from URL:

https://upload.wikimedia.org/wikipedia/commons/3/3c/Solarzelle_Schaltbild3.png [27/07/2016]

IV. Results and Discussion

To analyse if the measured current drop is caused by the internal capacitance, I added the current that leaks into the internal capacitance.

The corresponding equation is:

$$I_{corr} = I_{measured} + (C_{dep} + C_{diff}) \frac{dU}{dt} \quad (4.1)$$

To describe the current through the diode for the diffusion capacitance I used the values from the one diode model. If calculating the diode current with the low ideality factor of the capacity fit, the resulting current through the diode would be overestimated by several orders magnitude.

The result of the sum of these two currents can be seen in Fig. 44.

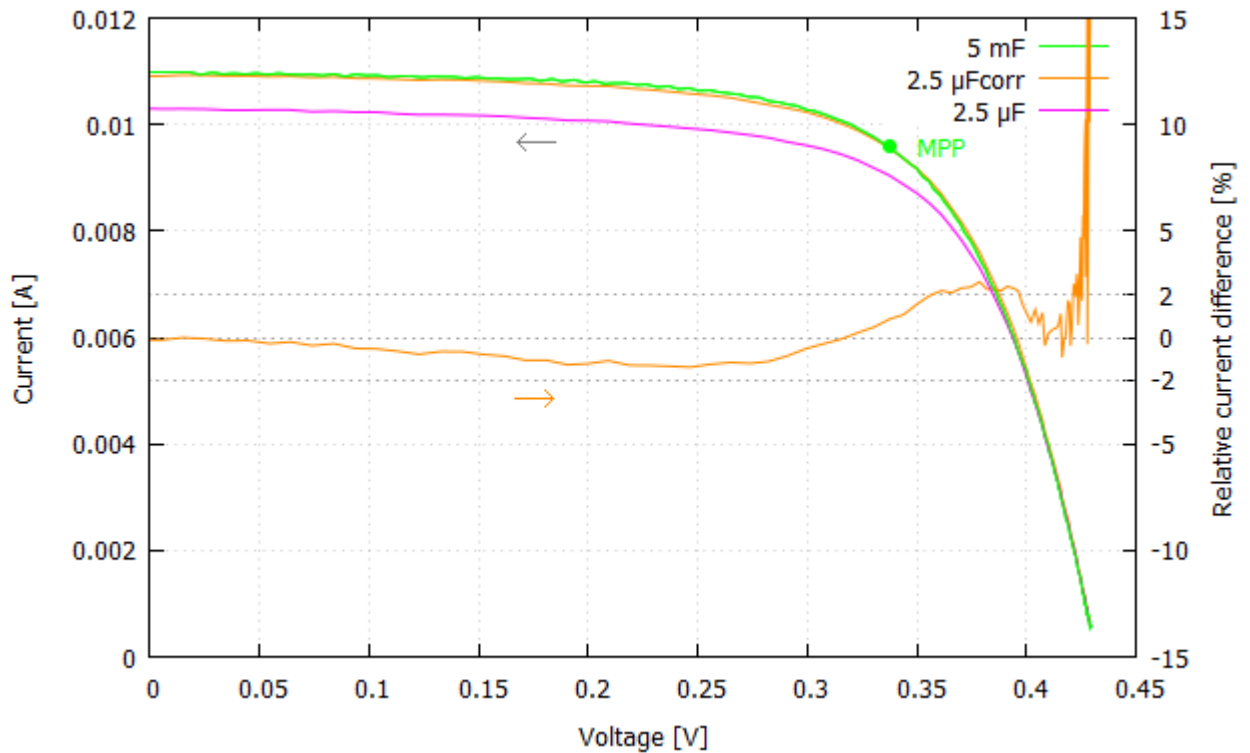


Fig. 44: Added current through capacitances

The agreement in current between the corrected curve and the steady state curve is very good. The relative error is over a wide range within $\pm 2\%$. So it can be said that the errors in the current-voltage characteristic, when measured at high voltage change rates, arise from the internal capacitance of the diode. A thing to mention is, that the value of the short circuit current and the MPP are in

the range, where the correction is possible within $\pm 2\%$. Another noticeable aspect about Fig. 44 is, that the relative agreement appears worse for voltages above 0.43 V. This is a result of the low current value at these voltages. The relative error is calculated according to equation (4.2). So small differences at these low current values are blown up because of the division by the low current.

$$\frac{I_{corr} - I_{QSS}}{I_{QSS}} \quad (4.2)$$

The absolute error remains within ± 0.2 mA over the whole range as it can be seen in Fig. 45.

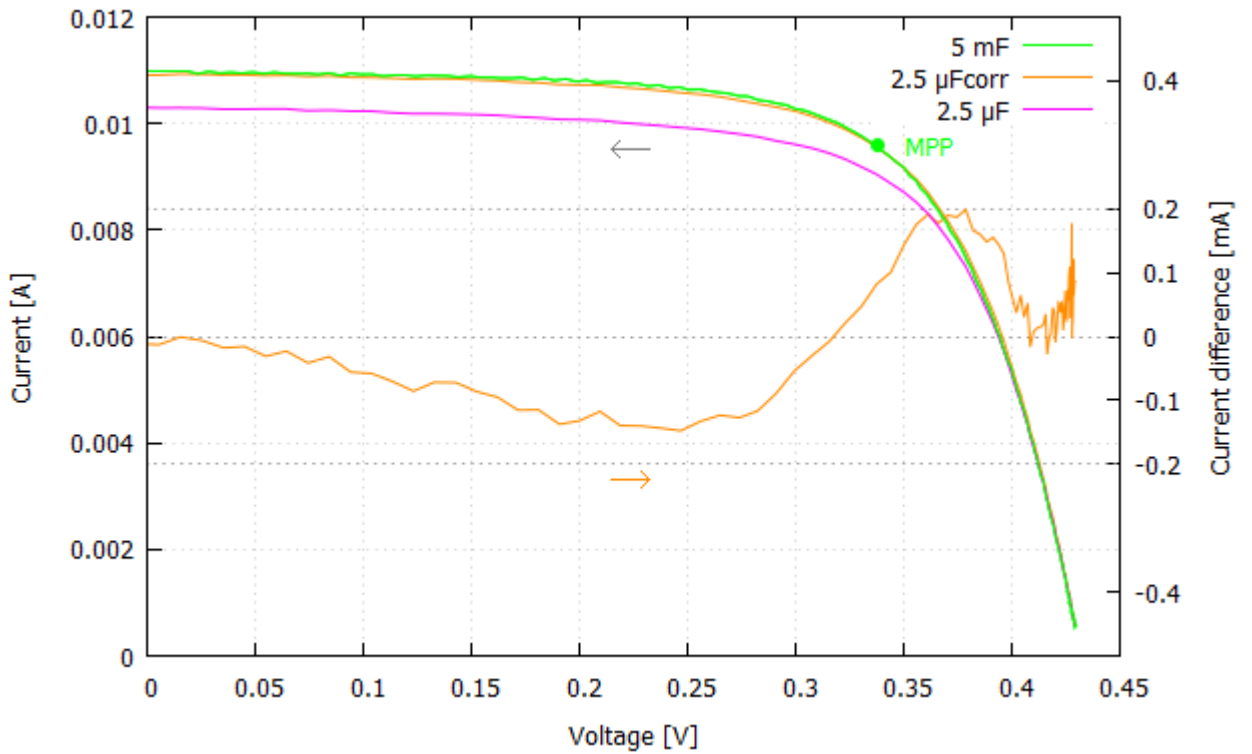


Fig. 45: Absolute error after correction

Also, the agreement with the measurement with the 1 μ F capacitor is still good. This agreement can be seen in Fig. 46. The reason for worse agreement can be found on the one hand in the low number of measured points, and on the other hand in the underlying model. For a correct description, the evaluation has to be done with the two diode model. A complication of evaluating with the two diode model is the fact that the measured voltage is not the same voltage as that at the diode, due to the series resistor. This fact has to be taken into account when calculating the derivation of the voltage.

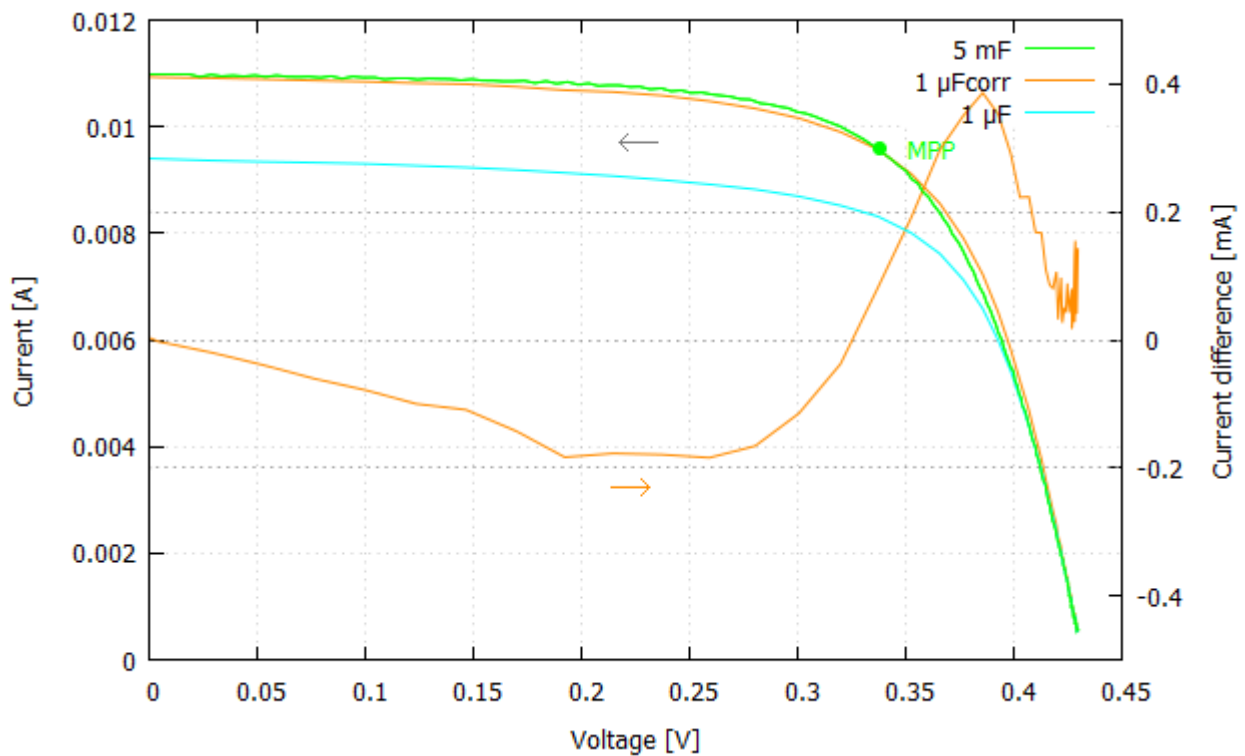


Fig. 46: Agreement for the 1 μ F capacitor

A thing to mention is, that at all important points of the current-voltage characteristic, the short circuit current, the MPP and the open circuit voltage are in a range, where the correction is possible within an error of ± 0.2 mA.

An application when a fast acquisition of the current-voltage characteristic of a solar cell is needed is the determination of the MPP from a solar inverter. In particular in the case of partially shading an array of solar cells, a measurement along the whole curve is needed to find the MPP. An example of a current-voltage characteristic of an array of partially-shaded solar cells can be seen in Fig. 47.

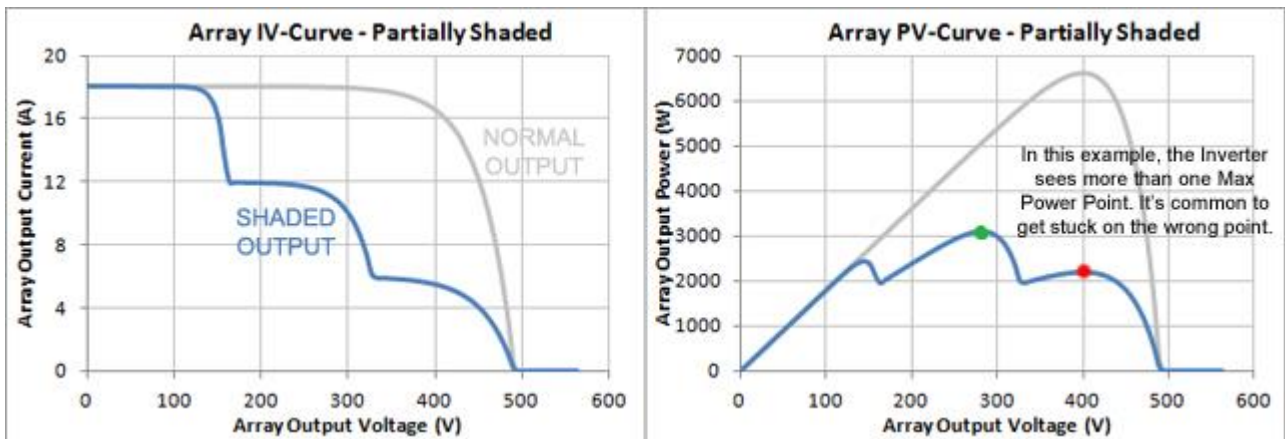


Fig. 47: Partially shaded solar cell array⁷²

When an array gets partially shaded, the solar cell inverter needs to make a full scan to find the global maximum, the green dot. When this scan is done too fast the same effects occur as with a single solar cell. As an example, I want to show the shift of the assumed MPP when the current-voltage characteristic gets acquired too fast.

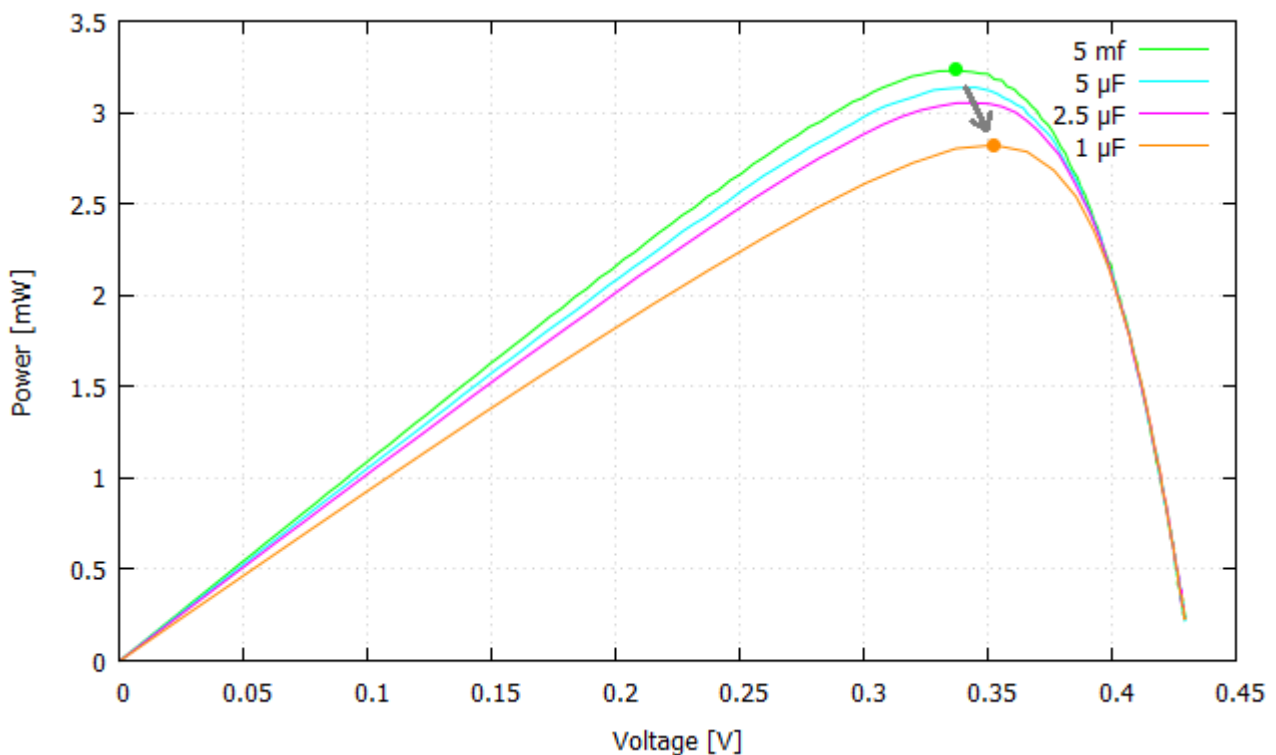


Fig. 48: Output power for different measurements

⁷² Adapted from URL: http://sargosis.com/wp-content/uploads/2015/12/inverter_mpp_curves.jpg [28/07/2016]

The global maximum output power for the measurement with an external 5mF capacitor is 3.234 mW at 0.337 V.

Another point of view is to look at the assumed maximum output power when the current-voltage measurement is done in a fast way. The MPP from the measurements in Fig. 48 as a function of dV/dt at the MPP can be seen in Fig. 49. The dotted line at 800 V/s is the limit, where the error gets bigger than 2 %.

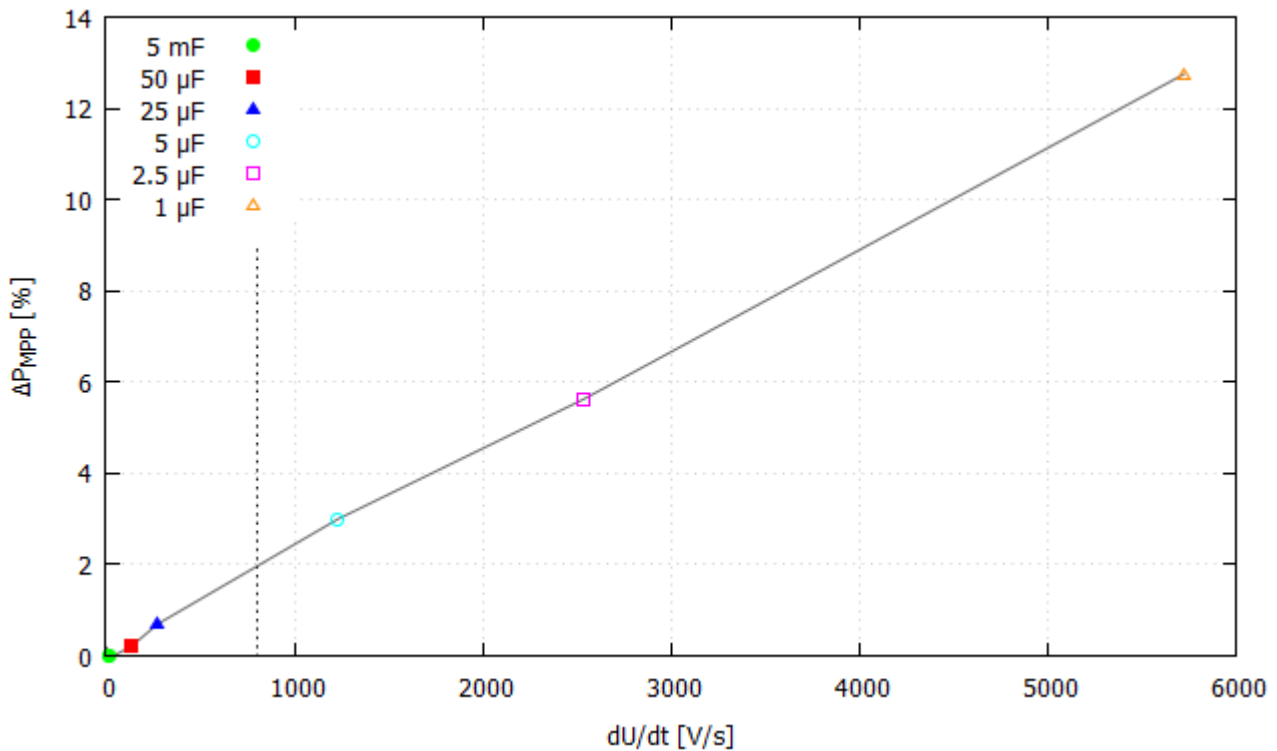


Fig. 49: Shift of the MPP for different rates of change

To be within an error of ± 2 % without correction, directly derived from $I_{meas}(U)$, the dU/dt rate must not exceed 800V/s at MPP. With correction of the internal capacitances the accuracy is maintained even with a dU/dt rate > 5000 V/s. Therefore, it is important to know that internal capacitances play a role when fast data acquisition is needed.

V. Conclusions

The measurements are done according to the paper of Recard⁷³. Recard writes, that a measurement at a discharging rate of 100 V/s can be considered as quasi-steady-state, this corresponds to Fig. 35 and the full red square in Fig. 49. One result of this thesis is that even at a discharging rate of 800 V/s the error of the measured current-voltage characteristic is within ± 2 %. Another achievement of this master thesis is the correction of even faster measurements with the internal capacitance of the solar cell. The master thesis shows, that this internal capacitance is accountable for the observed difference in the current-voltage characteristic between transient and steady-state condition. This internal capacitance relates to the p-n junction of the solar cell. To describe this capacitance the model of a capacitance of a diode is taken into account. The solar cell is modelled with the concept of a simple equivalent circuit. According to this model and the measured internal capacitance a correction of the current-voltage characteristic can be done up to a discharging rate of 2500 V/s and still will be within an error of 2 % over the whole current-voltage characteristic. This can be seen in Fig. 44 and the empty pink square in Fig. 49. At faster discharging rates, this concept of correction comes to a limit, which can be seen in Fig. 46, but even at a voltage change rate of >5000 V/s a correction of the interesting points of the characteristic, the short circuit current, the MPP and the open circuit voltage is possible within an error of ± 2 %. This voltage change rate is more than a factor of 50 larger than the suggestion of Recard.

A further improvement of this method of correction can be to model the solar cell with the two diode model. With this model the solar cell is not described with one, but rather with two diodes. The advantage of this model is that the diffusion capacitance is related to only one of these two diodes. So the influence of this capacitance can be described in a more appropriate way. Another limitation of the measurement refers to the used measuring device. The measurement is done at maximum 400,000 samples/s. This leads to the limitation in measured discharging rates of the external capacitor. For the measurement with the 1 μ F capacitor only 10 measurement points can be taken in the range of 0.3 V and 0.4 V, the range where the curvature is the highest. Thus for a measurement with smaller external capacitors, and therefore a higher dU/dt value, a faster measuring device is needed.

⁷³ Recard, 2006

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Appendix

IR LED	Roither LaserTechnik	76
Temperature Sensor	National Semiconductor	80
Thick Film Resistor	Vishay	93
SDS Relay	Nais	98
4.7mF,2,2mF,33μF,22μF,4.7μF,2.2μF Capacitor	Panasonic	100
470μF,220μF Capacitor	Vishay	105
330μF Capacitor	Panasonic	112
47μF Capacitor	Nippon	116
3.3μF Capacitor	Rubycon	120
0.33μF	Panasonic	122
NI ELVIS	National Instruments	125
NI 6251	National Instruments	135



ELJ-870-629



TECHNICAL DATA

High Power LED, Jumbo Package

AlGaAs

ELJ-870-629 is high power LED in an black anodised aluminium case, with thread socket for easy handling and heat sink mounting.
It is designed for medical appliances, remote control and optical communications, light barriers, measurement systems, etc.

Specifications

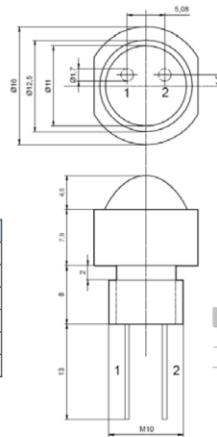
- Technology: AlGaAs/GaAlAs, 1 power LED chip
- Peak Wavelength: typ. 870 nm
- Optical Output Power: typ. 90 mW
- Package: Jumbo, metal case with plastic lens

Absolute Maximum Ratings ($T_c=25^\circ\text{C}$)

Item	Symbol	Value	Unit
Power Dissipation	P_D	4	W
Forward Current	I_F	1.5	A
Pulse Forward Current *	I_{FP}	2.0	A
Operating Temperature	T_{opr}	-25 ... +100	$^\circ\text{C}$
Storage Temperature	T_{stg}	-25 ... +100	$^\circ\text{C}$
Junction Temperature	T_j	100	$^\circ\text{C}$

on heat sink ($S \geq 200 \text{ cm}^2$)

* pulse width $\leq 10 \mu\text{s}$, $f \leq 500 \text{ Hz}$



Outline:

H = 12.4 mm (± 0.5)
D = 16 mm (± 0.5)

Thread M10

PIN	Function
1	LED Cathode
2	LED Anode

(Unit: mm)

Specifications ($T_c=20^\circ\text{C}$)

Item	Test Condition	Symbol	Min.	Typ.	Max.	Unit
Optical Specifications						
Radiant Power	$I_F = 350 \text{ mA}$	Φ_e	70	90	-	mW
Radiant Power *	$I_F = 1000 \text{ mA}$	Φ_e	-	250	-	mW
Radiant Intensity	$I_F = 350 \text{ mA}$	I_e	350	650	-	mW/sr
Radiant Intensity *	$I_F = 1000 \text{ mA}$	I_e	-	1900	-	mW/sr
Peak Wavelength	$I_F = 350 \text{ mA}$	λ_p	860	870	880	nm
Spectral Bandwidth at 50%	$I_F = 350 \text{ mA}$	$\Delta\lambda_{0.5}$	-	42	-	nm
Viewing Angle	$I_F = 350 \text{ mA}$	φ	-	17	-	deg
Electrical Specifications						
Forward Voltage	$I_F = 350 \text{ mA}$	U_F	-	1.5	1.8	V
Forward Voltage *	$I_F = 1000 \text{ mA}$	U_F	-	1.8	2.3	V
Switching Time	$I_F = 350 \text{ mA}$	t_r, t_f	-	10/20	-	ns
Reverse Voltage	$I_R = 100 \mu\text{A}$	U_R	5	-	-	
Thermal Resistance Junction-Case		R_{thJC}	-	10	-	K/W

* only recommended on optimal heat sink



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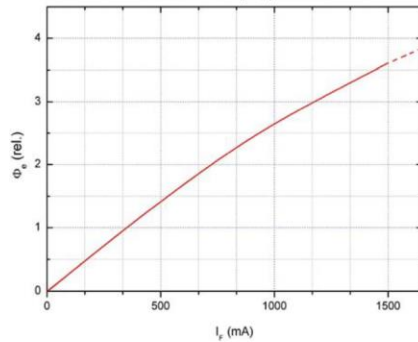
1040 VIENNA

AUSTRIA

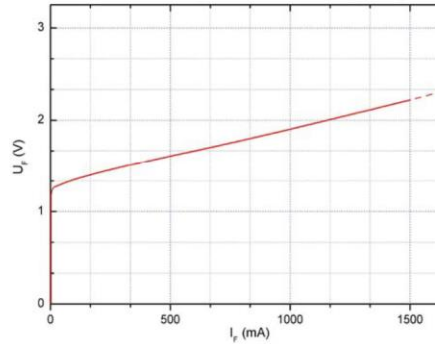


Typical Performance Curves

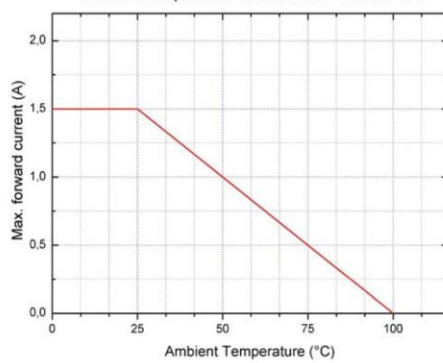
Radiant power vs. forward current (typical)
normalized to Φ_E @ $I_F = 350$ mA



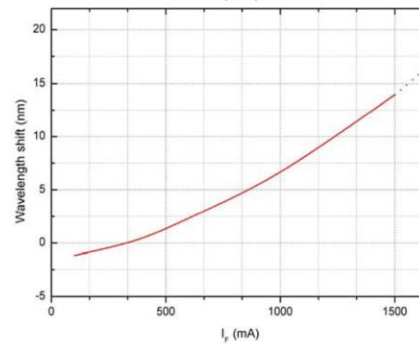
Forward voltage vs. forward current (typical)



Ambient Temperature vs. maximal forward current



Typical wavelength shift vs. forward current
(rel. to λ_p @ $I_F = 350$ mA)



Remarks concerning optical radiation safety*

At low forward current (≤ 150 mA), and continuous operation, this LED may be classified as LED product *Class 1*, according to standard IEC 60825-1:A2. *Class 1* products are safe to eyes and skin under reasonably predictable conditions. This implicates a direct observation of the light beam by means of optical instruments.

When driven with higher continuous forward current, (up to 1 A), this product should be classified as LED product *Class 1M*, according to standard IEC 60825-1:A2. *Class 1M* products are safe to eyes and skin under normal conditions, including when users view the light beam directly. *Class 1M* products produce either a highly divergent beam or a large diameter beam. Therefore only a small part of the whole light beam can enter the eye. However, such optical products can be harmful to the retina if the beam is viewed using magnifying optical instruments. Therefore, users should not incorporate optics that could concentrate the output into the eyes.

If intended to operate at very high continuous current (>1 A), this product has to be (potentially) classified as *Class 3B* LED. *Class 3B* LEDs may have sufficient power to cause an eye injury, both from the direct beam and from reflections, so these products are therefore considered hazardous to the eye. However, the extent and severity of any eye injury arising from an exposure to the light beam of a *Class 3B* product will depend upon several factors including the radiant power entering the eye and the duration of the exposure. Nonetheless, adequate precautions should be taken to avoid direct or indirect viewing into the beam.

***Note:** Safety classification of an optical component mainly depends on the intended application and the way the component is being used. Furthermore, all statements made to classification are based on calculations and are only valid for this LED "as it is", and at continuous operation. Using pulsed current or altering the light beam with additional optics may lead to different safety classifications. Therefore these remarks should be taken as recommendation and guideline only.

Notes

- The mentioned specifications are for reference purpose only and subjected to change without prior notice.
- All measurements carried out on blank aluminium heat sink, $S = 180 \text{ cm}^2$, passive cooling. Measurement results and curve characteristics obtained with other heat sinks may differ.
- Do not view directly into the emitting area of the LED during operation!
- This high power LED must be cooled!





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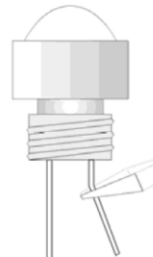
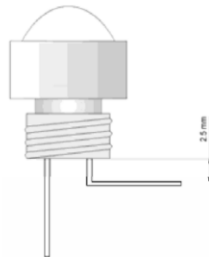
AUSTRIA



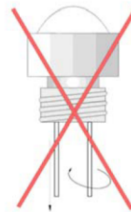
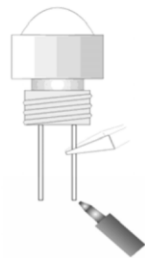
Handling precautions

To prevent damage to the LED during soldering and assembly, following precautions have to be taken into account.

- a) The bending point of the lead frame should be located at least 2.5 mm away from the body.
b) While bending, the base of the lead frame has to be fixed with radio pliers or similar.



- c) To ensure an adequate strain relief, the lead frames have to be firmly fixed during soldering.
d) Avoid any torsion or tensile loading of the lead frames, especially when they have been heated after being soldered.



- e) LEDs are static sensitive devices, so adequate handling precautions have to be taken, e.g. wearing grounding wrist straps.



LM35 Precision Centigrade Temperature Sensors

General Description

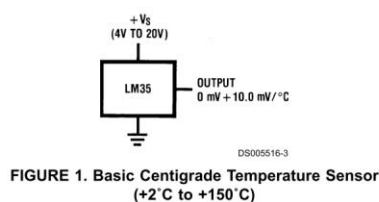
The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in $^{\circ}$ Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of $\pm 1/4^{\circ}\text{C}$ at room temperature and $\pm 3/4^{\circ}\text{C}$ over a full -55° to $+150^{\circ}\text{C}$ temperature range. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only $60\text{ }\mu\text{A}$ from its supply, it has very low self-heating, less than 0.1°C in still air. The LM35 is rated to operate over a -55° to $+150^{\circ}\text{C}$ temperature range, while the LM35C is rated for a -40° to $+110^{\circ}\text{C}$ range (-10° with improved accuracy). The LM35 series is available pack-

aged in hermetic TO-46 transistor packages, while the LM35C, LM35CA, and LM35D are also available in the plastic TO-92 transistor package. The LM35D is also available in an 8-lead surface mount small outline package and a plastic TO-220 package.

Features

- Calibrated directly in $^{\circ}$ Celsius (Centigrade)
- Linear $+10.0\text{ mV}/^{\circ}\text{C}$ scale factor
- 0.5°C accuracy guaranteeable (at $+25^{\circ}\text{C}$)
- Rated for full -55° to $+150^{\circ}\text{C}$ range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than $60\text{ }\mu\text{A}$ current drain
- Low self-heating, 0.08°C in still air
- Nonlinearity only $\pm 1/4^{\circ}\text{C}$ typical
- Low impedance output, $0.1\text{ }\Omega$ for 1 mA load

Typical Applications



**FIGURE 1. Basic Centigrade Temperature Sensor
($+2^{\circ}\text{C}$ to $+150^{\circ}\text{C}$)**

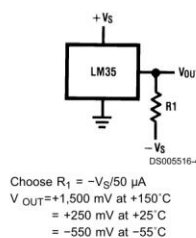
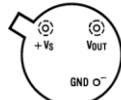


FIGURE 2. Full-Range Centigrade Temperature Sensor

Connection Diagrams

TO-46
Metal Can Package*

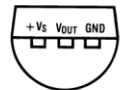


BOTTOM VIEW
DS0005516-1

*Case is connected to negative pin (GND)

Order Number LM35H, LM35AH, LM35CH, LM35CAH or LM35DH
See NS Package Number H03H

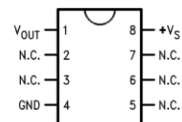
TO-92
Plastic Package



BOTTOM VIEW
DS0005516-2

Order Number LM35CZ, LM35CAZ or LM35DZ
See NS Package Number Z03A

SO-8
Small Outline Molded Package

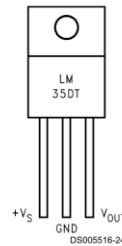


DS0005516-21

N.C. = No Connection

Top View
Order Number LM35DM
See NS Package Number M08A

TO-220
Plastic Package*



DS0005516-24

*Tab is connected to the negative pin (GND).

Note: The LM35DT pinout is different than the discontinued LM35DP.

Order Number LM35DT
See NS Package Number TA03F

Absolute Maximum Ratings (Note 10)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	+35V to -0.2V
Output Voltage	+6V to -1.0V
Output Current	10 mA
Storage Temp.:	
TO-46 Package,	-60°C to +180°C
TO-92 Package,	-60°C to +150°C
SO-8 Package,	-65°C to +150°C
TO-220 Package,	-65°C to +150°C
Lead Temp.:	
TO-46 Package,	
(Soldering, 10 seconds)	300°C

TO-92 and TO-220 Package, (Soldering, 10 seconds)	260°C
SO Package (Note 12)	
Vapor Phase (60 seconds)	215°C
Infrared (15 seconds)	220°C
ESD Susceptibility (Note 11)	2500V
Specified Operating Temperature Range: T_{MIN} to T_{MAX} (Note 2)	
LM35, LM35A	-55°C to +150°C
LM35C, LM35CA	-40°C to +110°C
LM35D	0°C to +100°C

Electrical Characteristics

(Notes 1, 6)

Parameter	Conditions	LM35A			LM35CA			Units (Max.)
		Typical	Tested Limit (Note 4)	Design Limit (Note 5)	Typical	Tested Limit (Note 4)	Design Limit (Note 5)	
Accuracy (Note 7)	$T_A = +25^\circ\text{C}$	± 0.2	± 0.5		± 0.2	± 0.5		°C
	$T_A = -10^\circ\text{C}$	± 0.3			± 0.3		± 1.0	°C
	$T_A = T_{MAX}$	± 0.4	± 1.0		± 0.4	± 1.0		°C
	$T_A = T_{MIN}$	± 0.4	± 1.0		± 0.4		± 1.5	°C
Nonlinearity (Note 8)	$T_{MIN} \leq T_A \leq T_{MAX}$	± 0.18		± 0.35	± 0.15		± 0.3	°C
Sensor Gain (Average Slope)	$T_{MIN} \leq T_A \leq T_{MAX}$	$+10.0$	$+9.9$, $+10.1$		$+10.0$		$+9.9$, $+10.1$	mV/°C
Load Regulation (Note 3) $0 \leq I_L \leq 1 \text{ mA}$	$T_A = +25^\circ\text{C}$	± 0.4	± 1.0		± 0.4	± 1.0		mV/mA
	$T_{MIN} \leq T_A \leq T_{MAX}$	± 0.5		± 3.0	± 0.5		± 3.0	mV/mA
Line Regulation (Note 3)	$T_A = +25^\circ\text{C}$	± 0.01	± 0.05		± 0.01	± 0.05		mV/V
	$4V \leq V_S \leq 30V$	± 0.02		± 0.1	± 0.02		± 0.1	mV/V
Quiescent Current (Note 9)	$V_S = +5V$, $+25^\circ\text{C}$	56	67		56	67		μA
	$V_S = +5V$	105		131	91		114	μA
	$V_S = +30V$, $+25^\circ\text{C}$	56.2	68		56.2	68		μA
	$V_S = +30V$	105.5		133	91.5		116	μA
Change of Quiescent Current (Note 3)	$4V \leq V_S \leq 30V$, $+25^\circ\text{C}$	0.2	1.0		0.2	1.0		μA
	$4V \leq V_S \leq 30V$	0.5		2.0	0.5		2.0	μA
Temperature Coefficient of Quiescent Current		$+0.39$		$+0.5$	$+0.39$		$+0.5$	μA/°C
Minimum Temperature for Rated Accuracy	In circuit of Figure 1, $I_L = 0$	+1.5		+2.0	+1.5		+2.0	°C
Long Term Stability	$T_J = T_{MAX}$, for 1000 hours	± 0.08			± 0.08			°C

Electrical Characteristics

(Notes 1, 6)

Parameter	Conditions	LM35			LM35C, LM35D			Units (Max.)
		Typical	Tested Limit (Note 4)	Design Limit (Note 5)	Typical	Tested Limit (Note 4)	Design Limit (Note 5)	
Accuracy, LM35, LM35C (Note 7)	$T_A = +25^{\circ}\text{C}$	± 0.4	± 1.0		± 0.4	± 1.0		$^{\circ}\text{C}$
	$T_A = -10^{\circ}\text{C}$	± 0.5			± 0.5		± 1.5	$^{\circ}\text{C}$
	$T_A = T_{\text{MAX}}$	± 0.8	± 1.5		± 0.8		± 1.5	$^{\circ}\text{C}$
	$T_A = T_{\text{MIN}}$	± 0.8		± 1.5	± 0.8		± 2.0	$^{\circ}\text{C}$
Accuracy, LM35D (Note 7)	$T_A = +25^{\circ}\text{C}$				± 0.6	± 1.5		$^{\circ}\text{C}$
	$T_A = T_{\text{MAX}}$				± 0.9		± 2.0	$^{\circ}\text{C}$
	$T_A = T_{\text{MIN}}$				± 0.9		± 2.0	$^{\circ}\text{C}$
Nonlinearity (Note 8)	$T_{\text{MIN}} \leq T_A \leq T_{\text{MAX}}$	± 0.3		± 0.5	± 0.2		± 0.5	$^{\circ}\text{C}$
Sensor Gain (Average Slope)	$T_{\text{MIN}} \leq T_A \leq T_{\text{MAX}}$	$+10.0$	$+9.8$, $+10.2$		$+10.0$		$+9.8$, $+10.2$	mV/ $^{\circ}\text{C}$
Load Regulation (Note 3) $0 \leq I_L \leq 1 \text{ mA}$	$T_A = +25^{\circ}\text{C}$	± 0.4	± 2.0		± 0.4	± 2.0		mV/mA
	$T_{\text{MIN}} \leq T_A \leq T_{\text{MAX}}$	± 0.5		± 5.0	± 0.5		± 5.0	mV/mA
Line Regulation (Note 3)	$T_A = +25^{\circ}\text{C}$	± 0.01	± 0.1		± 0.01	± 0.1		mV/V
	$4\text{V} \leq V_S \leq 30\text{V}$	± 0.02		± 0.2	± 0.02		± 0.2	mV/V
Quiescent Current (Note 9)	$V_S = +5\text{V}$, $+25^{\circ}\text{C}$	56	80		56	80		μA
	$V_S = +5\text{V}$	105		158	91		138	μA
	$V_S = +30\text{V}$, $+25^{\circ}\text{C}$	56.2	82		56.2	82		μA
	$V_S = +30\text{V}$	105.5		161	91.5		141	μA
Change of Quiescent Current (Note 3)	$4\text{V} \leq V_S \leq 30\text{V}$, $+25^{\circ}\text{C}$	0.2	2.0		0.2	2.0		μA
	$4\text{V} \leq V_S \leq 30\text{V}$	0.5		3.0	0.5		3.0	μA
Temperature Coefficient of Quiescent Current		$+0.39$		$+0.7$	$+0.39$		$+0.7$	$\mu\text{A}/^{\circ}\text{C}$
Minimum Temperature for Rated Accuracy	In circuit of Figure 1, $I_L = 0$	+1.5		+2.0	+1.5		+2.0	$^{\circ}\text{C}$
Long Term Stability	$T_J = T_{\text{MAX}}$, for 1000 hours	± 0.08			± 0.08			$^{\circ}\text{C}$

Note 1: Unless otherwise noted, these specifications apply: $-55^{\circ}\text{C} \leq T_J \leq +150^{\circ}\text{C}$ for the LM35 and LM35A; $-40^{\circ}\text{C} \leq T_J \leq +110^{\circ}\text{C}$ for the LM35C and LM35CA; and $0^{\circ}\text{C} \leq T_J \leq +100^{\circ}\text{C}$ for the LM35D. $V_S = +5\text{Vdc}$ and $I_{\text{LOAD}} = 50 \mu\text{A}$, in the circuit of Figure 2. These specifications also apply from $+2^{\circ}\text{C}$ to T_{MAX} in the circuit of Figure 1. Specifications in **boldface** apply over the full rated temperature range.

Note 2: Thermal resistance of the TO-46 package is 400°C/W junction to ambient, and 24°C/W junction to case. Thermal resistance of the TO-92 package is 180°C/W junction to ambient. Thermal resistance of the small outline molded package is 220°C/W junction to ambient. Thermal resistance of the TO-220 package is 90°C/W junction to ambient. For additional thermal resistance information see table in the Applications section.

Note 3: Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output due to heating effects can be computed by multiplying the internal dissipation by the thermal resistance.

Note 4: Tested Limits are guaranteed and 100% tested in production.

Note 5: Design Limits are guaranteed (but not 100% production tested) over the indicated temperature and supply voltage ranges. These limits are not used to calculate outgoing quality levels.

Note 6: Specifications in **boldface** apply over the full rated temperature range.

Note 7: Accuracy is defined as the error between the output voltage and $10\text{mV}/^{\circ}\text{C}$ times the device's case temperature, at specified conditions of voltage, current, and temperature (expressed in $^{\circ}\text{C}$).

Note 8: Nonlinearity is defined as the deviation of the output-voltage-versus-temperature curve from the best-fit straight line, over the device's rated temperature range.

Note 9: Quiescent current is defined in the circuit of Figure 1.

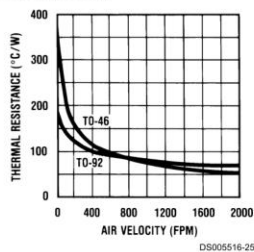
Note 10: Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions. See Note 1.

Note 11: Human body model, 100 pF discharged through a $1.5 \text{ k}\Omega$ resistor.

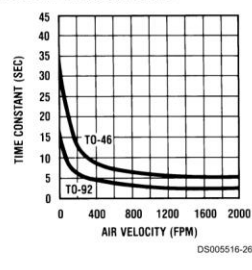
Note 12: See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" or the section titled "Surface Mount" found in a current National Semiconductor Linear Data Book for other methods of soldering surface mount devices.

Typical Performance Characteristics

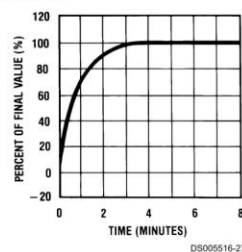
Thermal Resistance
Junction to Air



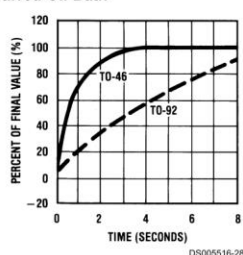
Thermal Time Constant



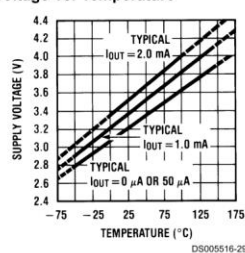
Thermal Response
in Still Air



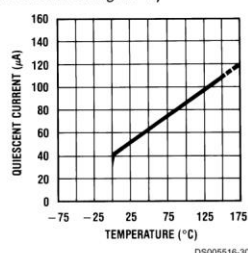
Thermal Response in
Stirred Oil Bath



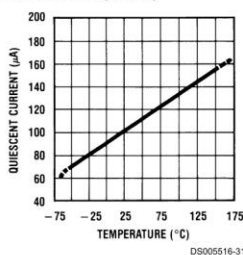
Minimum Supply
Voltage vs. Temperature



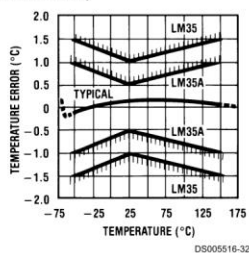
Quiescent Current
vs. Temperature
(In Circuit of Figure 1.)



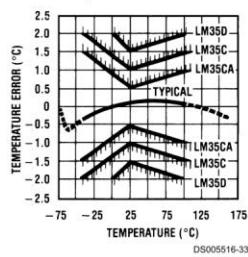
Quiescent Current
vs. Temperature
(In Circuit of Figure 2.)



Accuracy vs. Temperature
(Guaranteed)

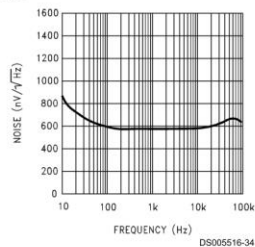


Accuracy vs. Temperature
(Guaranteed)

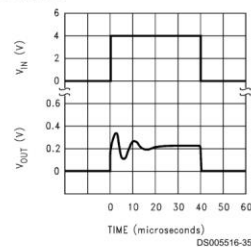


Typical Performance Characteristics (Continued)

Noise Voltage



Start-Up Response



Applications

The LM35 can be applied easily in the same way as other integrated-circuit temperature sensors. It can be glued or cemented to a surface and its temperature will be within about 0.01°C of the surface temperature.

This presumes that the ambient air temperature is almost the same as the surface temperature; if the air temperature were much higher or lower than the surface temperature, the actual temperature of the LM35 die would be at an intermediate temperature between the surface temperature and the air temperature. This is especially true for the TO-92 plastic package, where the copper leads are the principal thermal path to carry heat into the device, so its temperature might be closer to the air temperature than to the surface temperature.

To minimize this problem, be sure that the wiring to the LM35, as it leaves the device, is held at the same temperature as the surface of interest. The easiest way to do this is to cover up these wires with a bead of epoxy which will insure that the leads and wires are all at the same temperature as the surface, and that the LM35 die's temperature will not be affected by the air temperature.

The TO-46 metal package can also be soldered to a metal surface or pipe without damage. Of course, in that case the V- terminal of the circuit will be grounded to that metal. Alternatively, the LM35 can be mounted inside a sealed-end metal tube, and can then be dipped into a bath or screwed into a threaded hole in a tank. As with any IC, the LM35 and accompanying wiring and circuits must be kept insulated and dry, to avoid leakage and corrosion. This is especially true if the circuit may operate at cold temperatures where condensation can occur. Printed-circuit coatings and varnishes such as Humiseal and epoxy paints or dips are often used to insure that moisture cannot corrode the LM35 or its connections.

These devices are sometimes soldered to a small light-weight heat fin, to decrease the thermal time constant and speed up the response in slowly-moving air. On the other hand, a small thermal mass may be added to the sensor, to give the steadiest reading despite small deviations in the air temperature.

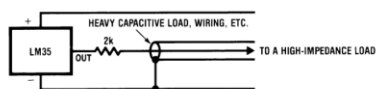
Temperature Rise of LM35 Due To Self-heating (Thermal Resistance, θ_{JA})

	TO-46, no heat sink	TO-46*, small heat fin	TO-92, no heat sink	TO-92**, small heat fin	SO-8 no heat sink	SO-8**, small heat fin	TO-220 no heat sink
Still air	400°C/W	100°C/W	180°C/W	140°C/W	220°C/W	110°C/W	90°C/W
Moving air	100°C/W	40°C/W	90°C/W	70°C/W	105°C/W	90°C/W	26°C/W
Still oil	100°C/W	40°C/W	90°C/W	70°C/W			
Stirred oil	50°C/W	30°C/W	45°C/W	40°C/W			
(Clamped to metal, Infinite heat sink)		(24°C/W)				(55°C/W)	

*Wakefield type 201, or 1" disc of 0.020" sheet brass, soldered to case, or similar.

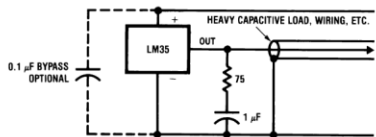
**TO-92 and SO-8 packages glued and leads soldered to 1" square of 1/16" printed circuit board with 2 oz. foil or similar.

Typical Applications



DS005516-19

FIGURE 3. LM35 with Decoupling from Capacitive Load



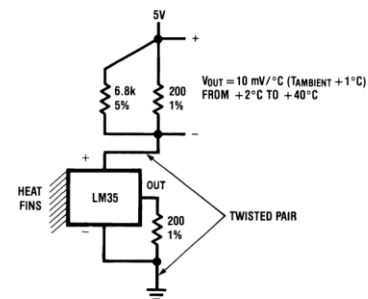
DS005516-20

FIGURE 4. LM35 with R-C Damper

CAPACITIVE LOADS

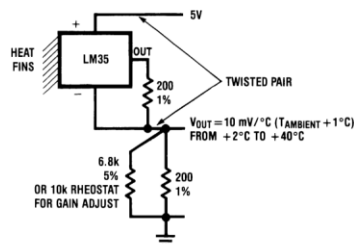
Like most micropower circuits, the LM35 has a limited ability to drive heavy capacitive loads. The LM35 by itself is able to drive 50 pF without special precautions. If heavier loads are anticipated, it is easy to isolate or decouple the load with a resistor; see Figure 3. Or you can improve the tolerance of capacitance with a series R-C damper from output to ground; see Figure 4.

When the LM35 is applied with a 200Ω load resistor as shown in Figure 5, Figure 6 or Figure 8 it is relatively immune to wiring capacitance because the capacitance forms a bypass from ground to input, not on the output. However, as with any linear circuit connected to wires in a hostile environment, its performance can be affected adversely by intense electromagnetic sources such as relays, radio transmitters, motors with arcing brushes, SCR transients, etc., as its wiring can act as a receiving antenna and its internal junctions can act as rectifiers. For best results in such cases, a bypass capacitor from V_{IN} to ground and a series R-C damper such as 75Ω in series with 0.2 or 1 μF from output to ground are often useful. These are shown in Figure 13, Figure 14, and Figure 16.



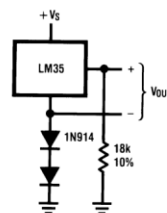
DS005516-5

FIGURE 5. Two-Wire Remote Temperature Sensor (Grounded Sensor)



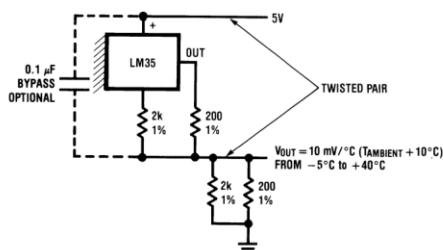
DS005516-6

FIGURE 6. Two-Wire Remote Temperature Sensor (Output Referred to Ground)



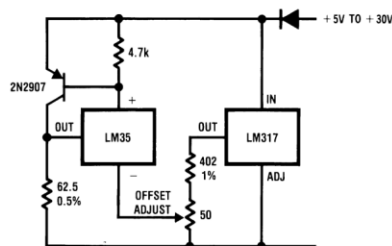
DS005516-7

FIGURE 7. Temperature Sensor, Single Supply, -55° to +150°C



DS005516-8

FIGURE 8. Two-Wire Remote Temperature Sensor (Output Referred to Ground)



DS005516-9

FIGURE 9. 4-To-20 mA Current Source (0°C to +100°C)

Typical Applications (Continued)

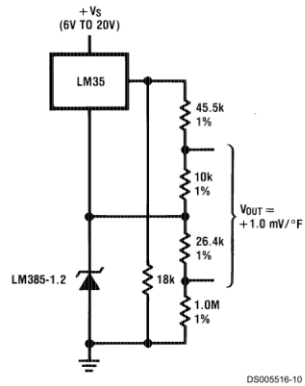


FIGURE 10. Fahrenheit Thermometer

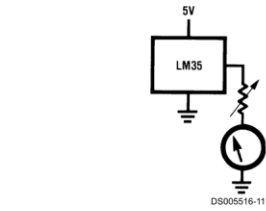


FIGURE 11. Centigrade Thermometer (Analog Meter)

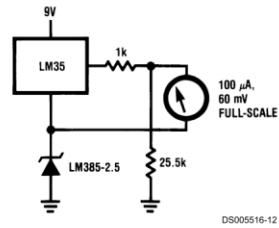


FIGURE 12. Fahrenheit Thermometer Expanded Scale Thermometer (50° to 80° Fahrenheit, for Example Shown)

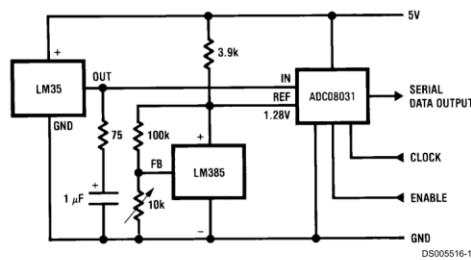


FIGURE 13. Temperature To Digital Converter (Serial Output) (+128°C Full Scale)

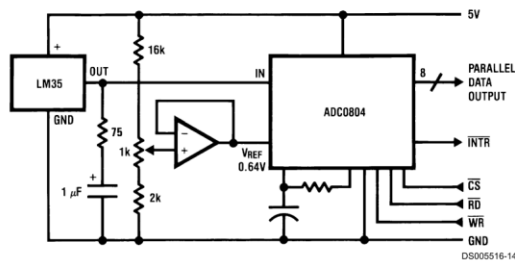
FIGURE 14. Temperature To Digital Converter (Parallel TRI-STATE™ Outputs for Standard Data Bus to μ P Interface) (128°C Full Scale)



FIGURE 15. Bar-Graph Temperature Display (Dot Mode)

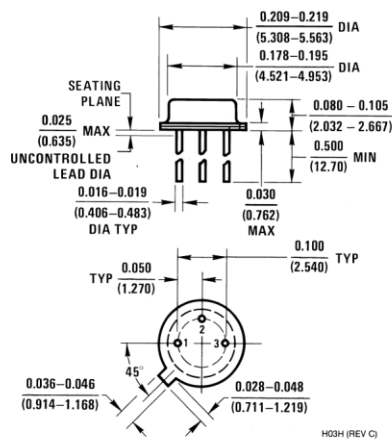


9

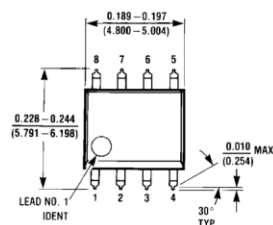


Physical Dimensions

inches (millimeters) unless otherwise noted

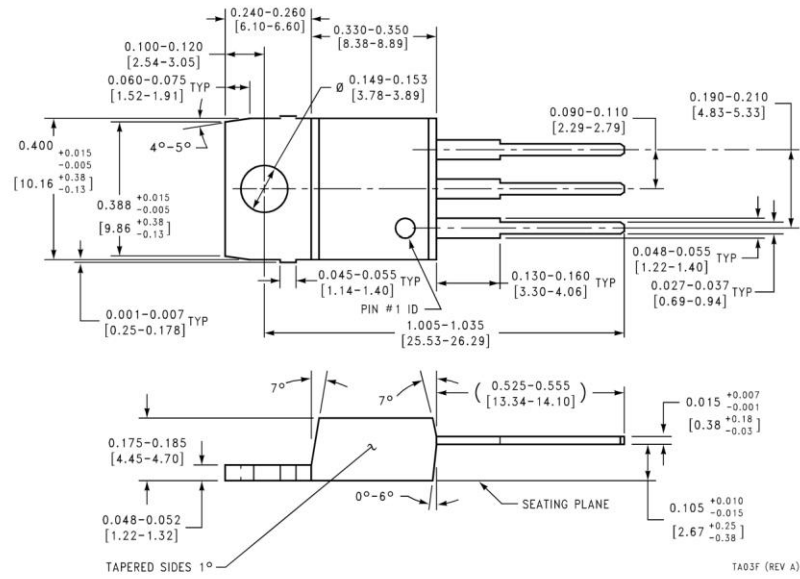


TO-46 Metal Can Package (H)
 Order Number LM35H, LM35AH, LM35CH,
 LM35CAH, or LM35DH
 NS Package Number H03H

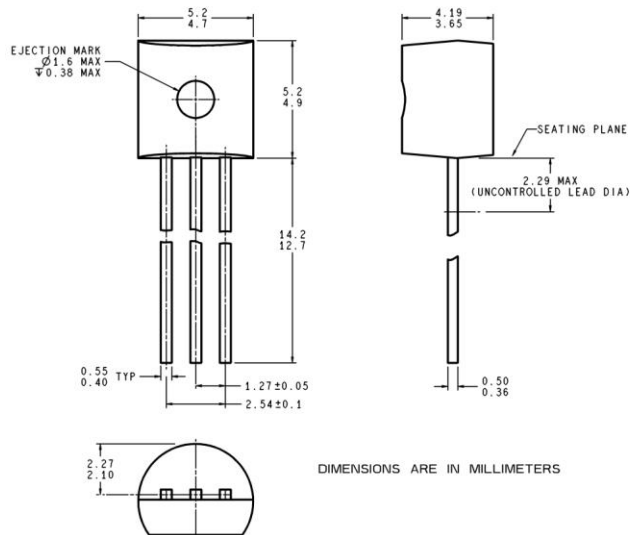


SO-8 Molded Small Outline Package (M)
 Order Number LM35DM
 NS Package Number M08A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



Power Package TO-220 (T)
Order Number LM35DT
NS Package Number TA03F

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)

Z03A (Rev. G)

TO-92 Plastic Package (Z)
Order Number LM35CZ, LM35CAZ or LM35DZ
NS Package Number Z03A

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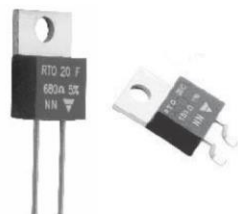


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RTO 20

Vishay Sfernice

20 W Power Resistor, Thick Film Technology, TO-220



The well known TO-220 package is compact and easy to mount.

FEATURES

- 20 W at 25 °C heatsink mounted
- High power dissipation to size ratio
- Wide resistance range from 0.01 Ω to 550 k Ω
- Negligible inductance
- Easy mounting
- TO-220 package: Compact and easy to mount
- Material categorization: For definitions of compliance please see www.vishay.com/doc?99912

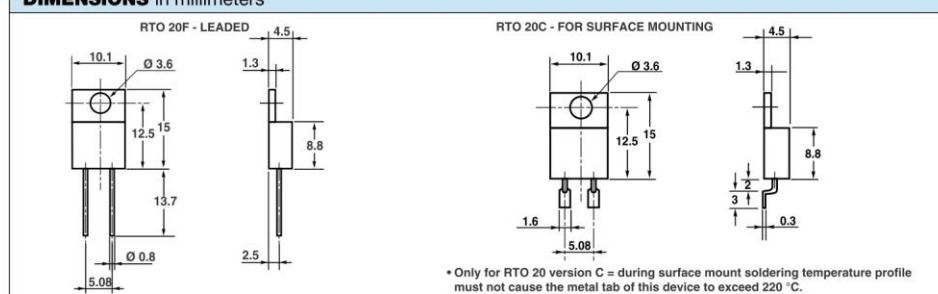


RoHS
COMPLIANT

Two versions of this thick film resistor are available:

- A radial leaded version for PCB mounting
- A flat lead version for surface mounting

DIMENSIONS in millimeters



Note

- Tolerances unless stated: ± 0.4 mm

STANDARD ELECTRICAL SPECIFICATIONS

MODEL	SIZE	RESISTANCE RANGE Ω	RATED POWER $P_{25^\circ\text{C}}$ W	LIMITING ELEMENT VOLTAGE U_L V	TOLERANCE $\pm \%$	TEMPERATURE COEFFICIENT $\pm \text{ppm}/^\circ\text{C}$	CRITICAL RESISTANCE Ω
RTO 20	TO-220	0.010 to 550K ⁽¹⁾	20	500	1, 2, 5, 10	150	3.12K

Note

⁽¹⁾ E24 series

MECHANICAL SPECIFICATIONS

Mechanical Protection	Insulated case
Resistive Element	Thick film
Substrate	Alumina onto base of nickel coated copper
Connections	Tinned copper
Weight	2.2 g max.

ENVIRONMENTAL SPECIFICATIONS

Temperature Range	- 55 °C to 155 °C
Climatic Category	55/155/56
Sealing	Sealed container, solder immersion
Flammability	IEC 60695-11-5 2 applications 30 s separated by 60 s

Note

- Not compatible with RoHS reflow profile

TECHNICAL SPECIFICATIONS

Dissipation and Associated	Onto a heatsink
Thermal Resistance and Nominal Power	20 W at + 25 °C $R_{TH \text{ (j-c)}}$: 6.5 °C/W Free air: 2 W at + 25 °C
Dielectric Strength MIL STD 202	2000 V_{RMS} - 1 min - 10 mA max. (between terminals and heatsink)
Insulation Resistance	$\geq 10^9$ M Ω
Inductance	≤ 0.1 μH

DIMENSIONS

Standard Package	TO-220 insulated case
------------------	-----------------------

Revision: 01-Aug-13

1

Document Number: 50005

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PERFORMANCE		
TESTS	CONDITIONS	REQUIREMENTS
Momentary Overload	EN 60115-1 2 Pr 5 s for $R < 2 \Omega$ 1.6 Pr 5 s for $R \geq 2 \Omega$ $U_S < 1.5 U_L$	$\pm (0.25 \% + 0.005 \Omega)$
Rapid Temperature Change	EN 60115-1/60068-2-14 5 cycles - 55 °C to + 155 °C	$\pm (0.5 \% + 0.005 \Omega)$
Load Life	EN 60115-1 1000 h Pr at + 25 °C	$\pm (1 \% + 0.005 \Omega)$
Humidity (Steady State)	EN 60115-1 56 days RH 95 %	$\pm (0.5 \% + 0.005 \Omega)$
High Temperature Exposure	NF EN 140 000 1000 h - 40 % Pr at + 100 °C	$\pm (0.5 \% + 0.005 \Omega)$
Vibration	MIL STD 202, Method 204 C Test D	$\pm (0.2 \% + 0.005 \Omega)$
Terminal Strength	MIL STD 202, Method 211 Test A1	$\pm (0.2 \% + 0.005 \Omega)$
Shock	IEC 60115-1 IEC 60068-2-27 Saw tooth: 100 g/6 ms	$\pm (0.5 \% + 0.005 \Omega)$

RESISTANCE VALUE IN RELATION TO TOLERANCE AND TCR				
Resistance Values	≥ 0.01	≥ 0.015	≥ 0.1	≥ 0.5
Tolerances	$\pm 1 \% \text{ at } \pm 10 \%$			
Typical Temperature Coefficient Range (- 55 °C to + 155 °C)	$\pm 900 \text{ ppm/}^\circ\text{C}$	$\pm 700 \text{ ppm/}^\circ\text{C}$	$\pm 250 \text{ ppm/}^\circ\text{C}$	$\pm 150 \text{ ppm/}^\circ\text{C}$

Note

- For very low ohmic values, TCR for information

CHOICE OF THE HEATSINK

The user must choose the board according to the working conditions of the component (power, room temperature). Maximum working temperature must not exceed 155 °C. The dissipated power is simply calculated by the following ratio:

$$P = \frac{\Delta T}{R_{TH(j-c)} + R_{TH(c-h)} + R_{TH(h-a)}}^{(1)}$$

P: Expressed in W

ΔT : Difference between maximum working temperature and room temperature

$R_{TH(j-c)}$: Thermal resistance value measured between resistive layer and outer side of the resistor. It is the thermal resistance of the component: Special Features table.

$R_{TH(c-h)}$: Thermal resistance value measured between outer side of the resistor and upper side of the heatsink. This is the thermal resistance of the interface (grease, thermal pad), and the quality of the fastening device.

$R_{th(h-a)}$: Thermal resistance of the heatsink.

Example:

$R_{TH(c-a)}$ for RTO 20 power rating 10 W at ambient temperature + 25 °C

Thermal resistance $R_{TH(j-c)}$: 6.5 °C/W

Considering equation ⁽¹⁾ we have:

$$\Delta T = 155 \text{ }^\circ\text{C} - 25 \text{ }^\circ\text{C} = 130 \text{ }^\circ\text{C}$$

$$R_{TH(j-c)} + R_{TH(c-h)} + R_{TH(h-a)} = \frac{\Delta T}{P} = \frac{130}{10} = 13 \text{ }^\circ\text{C/W}$$

$$R_{TH(c-h)} + R_{TH(h-a)} = 13 \text{ }^\circ\text{C/W} - 6.5 \text{ }^\circ\text{C/W} = 6.5 \text{ }^\circ\text{C/W}$$

OVERLOADS

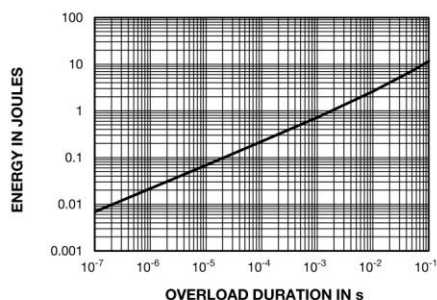
In any case the applied voltage must be lower than the maximum overload voltage of 750 V.

The values indicated on the graph below are applicable to resistors in air or mounted onto a heatsink.

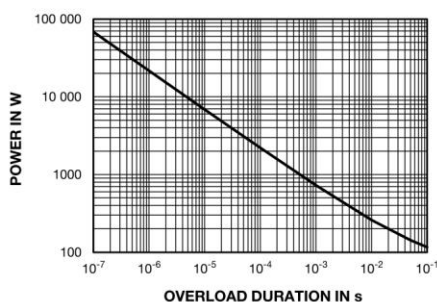
MARKING

Model, style, resistance value (in Ω), tolerance (in %), manufacturing date, Vishay Sfernice trademark.

ENERGY CURVE



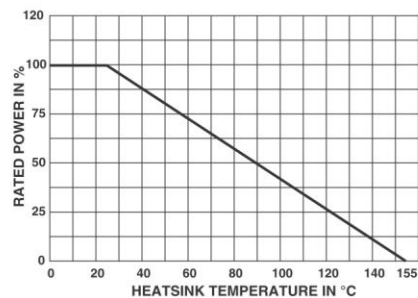
POWER CURVE



POWER RATING

The temperature of the heatsink should be maintained within the limits specified.

To improve the thermal conductivity, surfaces in contact should be coated with a silicone grease and the torque applied on the screw for tightening should be around 1 Nm. Spring clip can also be used to mount the component on an heatsink (ex: Kunze, clip KU4-498).



PACKAGING

Tube of 50 units



ORDERING INFORMATION							
RTO	20	F	U68	5 %	xxx	TU50	e3
MODEL	STYLE	CONNECTIONS	RESISTANCE VALUE	TOLERANCE	CUSTOM DESIGN	PACKAGING	LEAD (Pb)-FREE
		F: Radial leads C: Surface mount		± 1 % ± 2 % ± 5 % ± 10 %	Optional on request: Special TCR, shape etc.		

GLOBAL PART NUMBER INFORMATION															
R	T	O	0	2	0	F	R	6	8	0	0	J	T	E	3
GLOBAL MODEL		STYLE		DIELECTRIC		OHMIC VALUE				TOLERANCE		PACKAGING			
RTO		020		F = Radial leads C = Surface mount		The first four digits are significant figures and the last digit specifies the number of zeros to follow. to follow. R designates decimal point. 48R70 = 48.7 Ω 48701 = 48 700 Ω 10002 = 100 000 Ω R0100 = 0.01 Ω R6800 = 0.68 Ω 27000 = 2700 Ω = 2.7 kΩ				F = 1 % G = 2 % J = 5 % K = 10 %		T = Tube Size 30 and 50: Tube 50 pieces			



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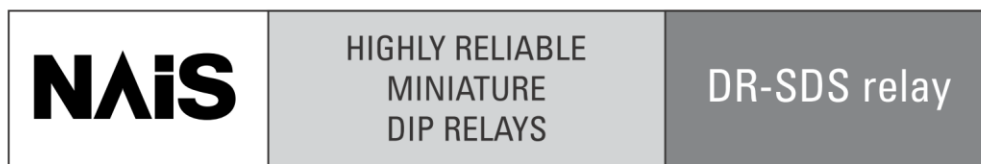
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UL File No.: E48393
CSA File No.: LR45064-2

- High breakdown (1500 V) and surge (1500 V) voltage between contacts and coil
- 1 coil and 2 coil latching types available
- High sensitivity
- High contact pressure

Specifications

Contacts

Arrangement	1 Form C
Contact material	PdNi Au layer
Initial contact resistance, (max.) (Measured by voltage drop 6 V DC 1 A)	100 mΩ
Rating (resistive)	
Max. switching power	33 VA, 20 W
Max. switching voltage	110 V AC / 30 V DC
Max. switching current	0.3 AC / 1 A DC
Min. switching capacity	10 mV / 0.1 mA
Electrical life (6 V / 100 mA)	10 ⁸
(24 V / 1 A)	10 ⁷
(0.3 A / 110 V AC)	10 ⁶
Mechanical life	10 ⁸

Coil

Nominal / minimum		
monostable	5 – 24 V DC	65 ... 130 mW
1 coil latching	5 – 24 V DC	35 ... 100 mW
2 coil latching	5 – 24 V DC	80 ... 200 mW

Characteristics

Max. operating speed	100 cpm (mechanical)
Operate time	approx. 2 ms
Release time (w/o diode)	approx. 0.6 ms
Contact bounce	1 ms
Initial breakdown voltage	
Between open contacts	750 Vrms
Between contacts and coil	1500 Vrms
Between live parts and ground	1000 Vrms
Initial insulation resistance	min. 1000 MΩ at 500 V DC
Surge voltage between contacts and coil (1.2/50μs)	1500
Ambient temperature	-40 °C to +70 °C
Shock resistance	more than 100 g
Vibration resistance	40 g, 10 to 200 Hz
Unit weight	approx. 6 g

Note: All specifications are based on the condition 25°C, 50% R.H. unless otherwise noted.

TYPICAL APPLICATIONS

- Telecommunications equipment
- Machine tools
- Industrial robots
- Optical instruments
- Business machines
- Optical instruments
- Medical equipment
- Detectors
- Alarm devices

ORDERING INFORMATION

Ex. DR — L2 — 24V — SDS

Operating function	Coil voltage*
Nil: Single side stable L: 1 coil latching L2: 2 coil latching	5, 12, 24

* other coil voltages on request

DR

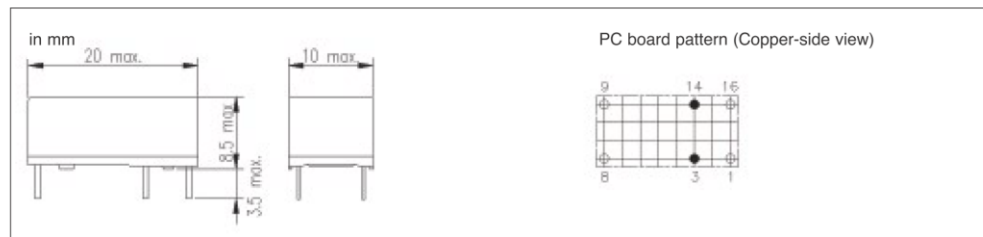
TYPES AND COIL DATA

Single side stable	Pick-up voltage, V DC (max.)	Drop-out voltage V DC (min.)	Maximum allowable voltage, V DC	Coil resistance Ω ($\pm 15\%$)	Nominal operating power, mW
DR-5V	3.75	0.5	16.5	320	78
DR-12V	9	1.2	30	1140	126
DR-24V	18	4.8	60	4370	131

1 coil latching	Pick-up voltage, V DC (max.)	Maximum allowable voltage, V DC	Coil resistance Ω ($\pm 15\%$)	Nominal operating power, mW
DR-L-5V	3.75	20	500	50
DR-L-12V	9	38	1850	78
DR-L-24V	18	67	5650	102

2 coil latching	Pick-up voltage, V DC (max.)	Maximum allowable voltage, V DC	Coil resistance Ω ($\pm 15\%$)	Nominal operating power, mW
DR-L2-5V	3.75	16	315	80
DR-L2-12V	9	30	1110	130
DR-L2-24V	18	46	2800	206

DIMENSIONS



Schematic (Bottom view)



Matsushita Electric Works

NAIS

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Radial Lead Type

Series: **M** Type: **A**

■ **Features**

- Endurance : 85 °C 2000 h
- Smaller than series SU
- RoHS directive compliant



■ **Specifications**

Category Temp. Range	-40 °C to + 85 °C		-25 °C to +85 °C
Rated W.V. Range	6.3 V.DC to 100 V.DC		160 V.DC to 450 V.DC
Nominal Cap. Range	2.2 μF to 22000 μF		1 μF to 470 μF
Capacitance Tolerance	±20 % (120 Hz/+20 °C)		
DC Leakage Current	I ≤ 0.01 CV or 3 (μA) After 2 minutes (Whichever is greater)		I ≤ 0.06 CV +10 (μA) After 2 minutes
tan δ	Please see the attached standard products list		
Endurance	After applying rated working voltage for 2000 hours at +85°C±2 °C, when the capacitors are restored to 20 °C, capacitors shall meet the following limits.		
	Capacitance change	±20 % of initial measured value	
	tan δ	≤150 % of initial specified value	
	DC leakage current	≤initial specified value	
Shelf Life	After storage for 1000 hours at +85 °C±2 °C with no voltage applied and then being stabilized at +20 °C, capacitors shall meet the limits specified in Endurance. (With voltage treatment)		

■ **Frequency correction factor for ripple current**

	Frequency (Hz)			
	50, 60	120	1 k	10 k to
Correction factor	0.70	1.00	1.30	1.70

■ **Dimensions in mm (not to scale)**

(Unit : mm)

Body Dia. ØD	5	6.3	8	10	12.5	16	18
Lead Dia. Ød	0.5	0.5	0.6	0.6	0.6	0.8	0.8
Lead space F	2.0	2.5	3.5	5.0	5.0	7.5	7.5

Design and specifications are each subject to change without notice. Ask factory for the current technical specifications before purchase and/or use.
Should a safety concern arise regarding this product, please be sure to contact us immediately.

02 May. 2014

■ Standard Products

Endurance : 85 °C 2000 h

W.V.	Cap. (±20 %)	Case size		Specification		Lead Length				Part No.	Min. Packaging Qty	
		Dia.	Length	Ripple Current (120 Hz) (+85 °C) (mA r.m.s.)	tan δ (120 Hz) (+20 °C)	Lead Dia. (mm)	Lead Space				Straight Leads (pcs)	Taping (pcs)
							Straight (mm)	Taping *B (mm)	Taping *i (mm)			
(V)	(μF)	(mm)	(mm)			(mm)	(mm)	(mm)				
6.3	220	5	11	240	0.28	0.5	2.0	5.0	2.5	ECA0JM221()	200	2000
	470	6.3	11.2	380	0.28	0.5	2.5	5.0	2.5	ECA0JM471()	200	2000
	1000	8	11.5	580	0.28	0.6	3.5	5.0		ECA0JM102()	200	1000
	2200	10	16	890	0.30	0.6	5.0	5.0		ECA0JM222()	200	500
	3300	10	20	1020	0.32	0.6	5.0	5.0		ECA0JM332()	200	500
	4700	12.5	20	1170	0.34	0.6	5.0	5.0		ECA0JM472()	200	500
	6800	12.5	25	1270	0.38	0.6	5.0	5.0		ECA0JM682()	200	500
	10000	16	25	1450	0.46	0.8	7.5	7.5		ECA0JM103()	100	250
	15000	16	31.5	1700	0.56	0.8	7.5			ECA0JM153	100	
	22000	18	35.5	1900	0.70	0.8	7.5			ECA0JM223	50	
10	330	6.3	11.2	330	0.24	0.5	2.5	5.0	2.5	ECA1AM331()	200	2000
	1000	10	12.5	630	0.24	0.6	5.0	5.0		ECA1AM102()	200	500
	2200	10	20	920	0.26	0.6	5.0	5.0		ECA1AM222()	200	500
	3300	12.5	20	1090	0.28	0.6	5.0	5.0		ECA1AM332()	200	500
	4700	12.5	25	1200	0.30	0.6	5.0	5.0		ECA1AM472()	200	500
	6800	16	25	1400	0.34	0.8	7.5	7.5		ECA1AM682()	100	250
	10000	16	31.5	1600	0.42	0.8	7.5			ECA1AM103	100	
	15000	18	35.5	1850	0.52	0.8	7.5			ECA1AM153	50	
16	10	5	11	30	0.20	0.5	2.0	5.0	2.5	ECA1CM100()	200	2000
	22	5	11	75	0.20	0.5	2.0	5.0	2.5	ECA1CM220()	200	2000
	33	5	11	110	0.20	0.5	2.0	5.0	2.5	ECA1CM330()	200	2000
	47	5	11	130	0.20	0.5	2.0	5.0	2.5	ECA1CM470()	200	2000
	100	5	11	180	0.20	0.5	2.0	5.0	2.5	ECA1CM101()	200	2000
	220	6.3	11.2	280	0.20	0.5	2.5	5.0	2.5	ECA1CM221()	200	2000
	470	8	11.5	440	0.20	0.6	3.5	5.0		ECA1CM471()	200	1000
	1000	10	16	680	0.20	0.6	5.0	5.0		ECA1CM102()	200	500
	2200	12.5	20	1000	0.22	0.6	5.0	5.0		ECA1CM222()	200	500
	3300	12.5	25	1200	0.24	0.6	5.0	5.0		ECA1CM332()	200	500
	4700	16	25	1360	0.26	0.8	7.5	7.5		ECA1CM472()	100	250
	6800	16	31.5	1600	0.30	0.8	7.5			ECA1CM682	100	
	10000	18	35.5	1800	0.38	0.8	7.5			ECA1CM103	50	
	25	100	6.3	11.2	180	0.16	0.5	2.5	5.0	2.5	ECA1EM101()	200
330		8	11.5	390	0.16	0.6	3.5	5.0		ECA1EM331()	200	1000
470		10	12.5	480	0.16	0.6	5.0	5.0		ECA1EM471()	200	500
1000		10	20	850	0.16	0.6	5.0	5.0		ECA1EM102()	200	500
2200		12.5	25	1200	0.18	0.6	5.0	5.0		ECA1EM222()	200	500
3300		16	25	1300	0.20	0.8	7.5	7.5		ECA1EM332()	100	250
4700		16	31.5	1500	0.22	0.8	7.5			ECA1EM472	100	
6800		18	35.5	1750	0.26	0.8	7.5			ECA1EM682	50	
35	47	5	11	130	0.14	0.5	2.0	5.0	2.5	ECA1VM470()	200	2000
	100	6.3	11.2	210	0.14	0.5	2.5	5.0	2.5	ECA1VM101()	200	2000
	220	8	11.5	350	0.14	0.6	3.5	5.0		ECA1VM221()	200	1000

· When requesting taped product, please put the letter "B" or "i" between the "()". Lead wire pitch *B=5 mm, 7.5 mm, i=2.5 mm.
 · Please refer to the page of "Taping Dimensions".

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02 May. 2014

■ Standard Products

Endurance : 85 °C 2000 h

W.V.	Cap. (±20 %)	Case size		Specification		Lead Length				Part No.	Min. Packaging Qty	
		Dia.	Length	Ripple Current (120 Hz (+85 °C) (mA r.m.s.)	tan δ (120 Hz (+20 °C)	Lead Dia. (mm)	Lead Space				Straight Leads (pcs)	Taping (pcs)
							Straight (mm)	Taping *B (mm)	Taping *i (mm)			
(V)	(μF)	(mm)	(mm)									
35	330	10	12.5	440	0.14	0.6	5.0	5.0		ECA1VM331()	200	500
	470	10	16	550	0.14	0.6	5.0	5.0		ECA1VM471()	200	500
	1000	12.5	20	900	0.14	0.6	5.0	5.0		ECA1VM102()	200	500
	2200	16	25	1250	0.16	0.8	7.5	7.5		ECA1VM222()	100	250
	3300	16	31.5	1400	0.18	0.8	7.5			ECA1VM332	100	
	4700	18	35.5	1600	0.20	0.8	7.5			ECA1VM472	50	
50	0.1	5	11	1.3	0.12	0.5	2.0	5.0	2.5	ECA1HM0R1()***	200	2000
	0.22	5	11	2.9	0.12	0.5	2.0	5.0	2.5	ECA1HMR22()***	200	2000
	0.33	5	11	4.4	0.12	0.5	2.0	5.0	2.5	ECA1HMR33()***	200	2000
	0.47	5	11	5	0.12	0.5	2.0	5.0	2.5	ECA1HMR47()***	200	2000
	1	5	11	10	0.12	0.5	2.0	5.0	2.5	ECA1HM010()***	200	2000
	2.2	5	11	20	0.12	0.5	2.0	5.0	2.5	ECA1HM2R2()	200	2000
	3.3	5	11	35	0.12	0.5	2.0	5.0	2.5	ECA1HM3R3()	200	2000
	4.7	5	11	45	0.12	0.5	2.0	5.0	2.5	ECA1HM4R7()	200	2000
	10	5	11	65	0.12	0.5	2.0	5.0	2.5	ECA1HM100()	200	2000
	22	5	11	100	0.12	0.5	2.0	5.0	2.5	ECA1HM220()	200	2000
	33	5	11	110	0.12	0.5	2.0	5.0	2.5	ECA1HM330()	200	2000
	47	6.3	11.2	130	0.12	0.5	2.5	5.0	2.5	ECA1HM470()	200	2000
	100	8	11.5	250	0.12	0.6	3.5	5.0		ECA1HM101()	200	1000
	220	10	12.5	400	0.12	0.6	5.0	5.0		ECA1HM221()	200	500
	330	10	16	500	0.12	0.6	5.0	5.0		ECA1HM331()	200	500
	470	10	20	650	0.12	0.6	5.0	5.0		ECA1HM471()	200	500
	1000	12.5	25	1050	0.12	0.6	5.0	5.0		ECA1HM102()	200	500
	2200	16	31.5	1300	0.14	0.8	7.5			ECA1HM222	100	
	3300	18	35.5	1500	0.16	0.8	7.5			ECA1HM332	50	
63	10	5	11	70	0.11	0.5	2.0	5.0	2.5	ECA1JM100()	200	2000
	22	5	11	105	0.11	0.5	2.0	5.0	2.5	ECA1JM220()	200	2000
	33	6.3	11.2	130	0.11	0.5	2.5	5.0	2.5	ECA1JM330()	200	2000
	47	6.3	11.2	160	0.11	0.5	2.5	5.0	2.5	ECA1JM470()	200	2000
	100	8	11.5	270	0.11	0.6	3.5	5.0		ECA1JM101()	200	1000
	220	10	16	450	0.11	0.6	5.0	5.0		ECA1JM221()	200	500
	330	10	20	550	0.11	0.6	5.0	5.0		ECA1JM331()	200	500
	470	12.5	20	750	0.11	0.6	5.0	5.0		ECA1JM471()	200	500
	1000	16	25	1100	0.11	0.8	7.5	7.5		ECA1JM102()	100	250
	2200	18	35.5	1400	0.13	0.8	7.5			ECA1JM222	50	
100	0.47	5	11	10	0.10	0.5	2.0	5.0	2.5	ECA2AMR47()***	200	2000
	1	5	11	20	0.10	0.5	2.0	5.0	2.5	ECA2AM010()***	200	2000
	2.2	5	11	30	0.10	0.5	2.0	5.0	2.5	ECA2AM2R2()	200	2000
	3.3	5	11	40	0.10	0.5	2.0	5.0	2.5	ECA2AM3R3()	200	2000
	4.7	5	11	50	0.10	0.5	2.0	5.0	2.5	ECA2AM4R7()	200	2000
	10	5	11	70	0.10	0.5	2.0	5.0	2.5	ECA2AM100()	200	2000
	22	6.3	11.2	115	0.10	0.5	2.5	5.0	2.5	ECA2AM220()	200	2000

· When requesting taped product, please put the letter "B" or "i" between the "()". Lead wire pitch *B=5 mm, 7.5 mm, i=2.5 mm.

· Please refer to the page of "Taping Dimensions".

*** Please kindly accept last shipment : 31/Mar/2015

Design and specifications are each subject to change without notice. Ask factory for the current technical specifications before purchase and/or use.
Should a safety concern arise regarding this product, please be sure to contact us immediately.

02 May. 2014

■ Standard Products

Endurance : 85 °C 2000 h

W.V.	Cap. (±20 %)	Case size		Specification		Lead Length				Part No.	Min. Packaging Qty	
		Dia.	Length	Ripple Current (120 Hz) (+85 °C) (mA r.m.s.)	tan δ (120 Hz) (+20 °C)	Lead Dia. (mm)	Lead Space				Straight Leads (pcs)	Taping (pcs)
							Straight (mm)	Taping *B (mm)	Taping *i (mm)			
(V)	(μF)	(mm)	(mm)			(mm)	(mm)	(mm)				
100	33	8	11.5	145	0.10	0.6	3.5	5.0		ECA2AM330()	200	1000
	47	8	11.5	180	0.10	0.6	3.5	5.0		ECA2AM470()	200	1000
	100	10	16	350	0.10	0.6	5.0	5.0		ECA2AM101()	200	500
	220	12.5	20	550	0.10	0.6	5.0	5.0		ECA2AM221()	200	500
	330	12.5	25	700	0.10	0.6	5.0	5.0		ECA2AM331()	200	500
	470	16	25	900	0.10	0.8	7.5	7.5		ECA2AM471()	100	250
	1000	18	35.5	1300	0.10	0.8	7.5			ECA2AM102	50	
160	1	6.3	11.2	36	0.16	0.5	2.5	5.0	2.5	ECA2CM010()	200	2000
	2.2	6.3	11.2	53	0.16	0.5	2.5	5.0	2.5	ECA2CM2R2()	200	2000
	3.3	6.3	11.2	66	0.16	0.5	2.5	5.0	2.5	ECA2CM3R3()	200	2000
	4.7	6.3	11.2	78	0.16	0.5	2.5	5.0	2.5	ECA2CM4R7()	200	2000
	10	10	12.5	105	0.16	0.6	5.0	5.0		ECA2CM100()	200	500
	22	10	16	175	0.16	0.6	5.0	5.0		ECA2CM220()	200	500
	33	10	20	235	0.16	0.6	5.0	5.0		ECA2CM330()	200	500
	47	12.5	20	320	0.16	0.6	5.0	5.0		ECA2CM470()	200	500
	100	12.5	25	515	0.16	0.6	5.0	5.0		ECA2CM101()	200	500
	220	16	31.5	830	0.16	0.8	7.5			ECA2CM221	100	
	330	18	31.5	1090	0.16	0.8	7.5			ECA2CM331	50	
	470	18	40	1440	0.16	0.8	7.5			ECA2CM471	50	
200	1	6.3	11.2	34	0.18	0.5	2.5	5.0	2.5	ECA2DM010()	200	2000
	2.2	6.3	11.2	50	0.18	0.5	2.5	5.0	2.5	ECA2DM2R2()	200	2000
	3.3	6.3	11.2	62	0.18	0.5	2.5	5.0	2.5	ECA2DM3R3()	200	2000
	4.7	8	11.5	86	0.18	0.6	3.5	5.0		ECA2DM4R7()	200	1000
	10	10	12.5	100	0.18	0.6	5.0	5.0		ECA2DM100()	200	500
	22	10	20	180	0.18	0.6	5.0	5.0		ECA2DM220()	200	500
	33	10	20	220	0.18	0.6	5.0	5.0		ECA2DM330()	200	500
	47	12.5	20	300	0.18	0.6	5.0	5.0		ECA2DM470()	200	500
	100	16	25	475	0.18	0.8	7.5	7.5		ECA2DM101()	100	250
	220	18	31.5	835	0.18	0.8	7.5			ECA2DM221	50	
	330	18	40	1140	0.18	0.8	7.5			ECA2DM331	50	
	250	1	6.3	11.2	34	0.18	0.5	2.5	5.0	2.5	ECA2EM010()	200
2.2		6.3	11.2	50	0.18	0.5	2.5	5.0	2.5	ECA2EM2R2()	200	2000
3.3		8	11.5	72	0.18	0.6	3.5	5.0		ECA2EM3R3()	200	1000
4.7		8	11.5	86	0.18	0.6	3.5	5.0		ECA2EM4R7()	200	1000
10		10	16	110	0.18	0.6	5.0	5.0		ECA2EM100()	200	500
22		10	20	180	0.18	0.6	5.0	5.0		ECA2EM220()	200	500
33		12.5	20	250	0.18	0.6	5.0	5.0		ECA2EM330()	200	500
47		12.5	25	330	0.18	0.6	5.0	5.0		ECA2EM470()	200	500
100		16	31.5	530	0.18	0.8	7.5			ECA2EM101	100	
220		18	40	930	0.18	0.8	7.5			ECA2EM221	50	
350	1	6.3	11.2	32	0.20	0.5	2.5	5.0	2.5	ECA2VM010()	200	2000
	2.2	8	11.5	55	0.20	0.6	3.5	5.0		ECA2VM2R2()	200	1000

· When requesting taped product, please put the letter "B" or "i" between the "()". Lead wire pitch *B=5 mm, 7.5 mm, i=2.5 mm.
 · Please refer to the page of "Taping Dimensions".

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02 May. 2014

■ Standard Products

Endurance : 85 °C 2000 h

W.V.	Cap. (±20 %)	Case size		Specification		Lead Length				Part No.	Min. Packaging Q'ty	
		Dia.	Length	Ripple Current (120 Hz) (+85 °C) (mA r.m.s.)	tan δ (120 Hz) (+20 °C)	Lead Dia. (mm)	Lead Space				Straight Leads (pcs)	Taping (pcs)
							Straight (mm)	Taping *B (mm)	Taping *i (mm)			
(V)	(μF)	(mm)	(mm)									
350	3.3	8	11.5	60	0.20	0.6	3.5	5.0		ECA2VM3R3()	200	1000
	4.7	10	12.5	65	0.20	0.6	5.0	5.0		ECA2VM4R7()	200	500
	10	10	20	115	0.20	0.6	5.0	5.0		ECA2VM100()	200	500
	22	12.5	20	195	0.20	0.6	5.0	5.0		ECA2VM220()	200	500
	33	16	25	300	0.20	0.8	7.5	7.5		ECA2VM330()	100	250
	47	16	25	325	0.20	0.8	7.5	7.5		ECA2VM470()	100	250
	100	18	31.5	535	0.20	0.8	7.5			ECA2VM101	50	
400	1	6.3	11.2	32	0.20	0.5	2.5	5.0	2.5	ECA2GM010()	200	2000
	2.2	8	11.5	50	0.20	0.6	3.5	5.0		ECA2GM2R2()	200	1000
	3.3	10	12.5	54	0.20	0.6	5.0	5.0		ECA2GM3R3()	200	500
	4.7	10	16	72	0.20	0.6	5.0	5.0		ECA2GM4R7()	200	500
	10	10	20	115	0.20	0.6	5.0	5.0		ECA2GM100()	200	500
	22	12.5	25	215	0.20	0.6	5.0	5.0		ECA2GM220()	200	500
	33	16	25	275	0.20	0.8	7.5	7.5		ECA2GM330()	100	250
	47	16	31.5	350	0.20	0.8	7.5			ECA2GM470	100	
450	100	18	40	600	0.20	0.8	7.5			ECA2GM101	50	
	1	8	11.5	37	0.20	0.6	3.5	5.0		ECA2WM010()	200	1000
	2.2	10	12.5	44	0.20	0.6	5.0	5.0		ECA2WM2R2()	200	500
	3.3	10	16	60	0.20	0.6	5.0	5.0		ECA2WM3R3()	200	500
	4.7	10	20	79	0.20	0.6	5.0	5.0		ECA2WM4R7()	200	500
	10	12.5	20	130	0.20	0.6	5.0	5.0		ECA2WM100()	200	500
	22	16	25	210	0.20	0.8	7.5	7.5		ECA2WM220()	100	250
	33	16	31.5	285	0.20	0.8	7.5			ECA2WM330	100	

· When requesting taped product, please put the letter "B" or "i" between the "()". Lead wire pitch *B=5 mm, 7.5 mm, i=2.5 mm.
· Please refer to the page of "Taping Dimensions".

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02 May. 2014

Aluminum Capacitors Radial Standard Ultra Miniature

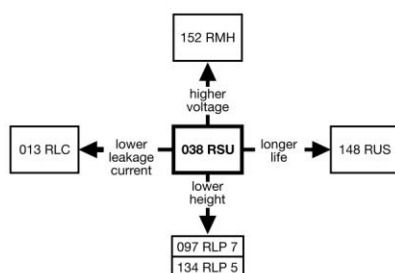


Fig. 1

QUICK REFERENCE DATA	
DESCRIPTION	VALUE
Nominal case sizes (Ø D x L in mm)	5 x 11 to 18 x 40
Rated capacitance range, C_R	2.2 µF to 22 000 µF
Tolerance on C_R	± 20 %
Rated voltage range, U_R	6.3 V to 100 V
Category temperature range	- 40 °C to + 85 °C
Endurance test at 85 °C:	
Case size Ø D ≤ 8 mm	2000 h
Case size Ø D ≥ 10 mm	3000 h
Useful life at 85 °C:	
Case size Ø D ≤ 8 mm	2500 h
Case size Ø D ≥ 10 mm	3500 h
Useful life at 40 °C, 1.4 x I_R applied:	
Case size Ø D ≤ 8 mm	60 000 h
Case size Ø D ≥ 10 mm	90 000 h
Shelf life at 0 V, 85 °C	1000 h
Based on sectional specification	IEC 60384-4/EN130300
Climatic category IEC 60068	40/085/56

FEATURES

- Polarized aluminum electrolytic capacitors, non-solid electrolyte
- Radial leads, cylindrical aluminum case, insulated with a blue sleeve
- Pressure relief for case Ø D ≥ 6.3 mm
- Charge and discharge proof
- Miniaturized, high CV-product per unit volume
- Material categorization: For definitions of compliance please see www.vishay.com/doc?99912



APPLICATIONS

- General purpose, industrial, automotive, consumer, and audio-video
- Coupling, decoupling, timing, smoothing, filtering, buffering in SMPS
- Portable and mobile equipment (small size, low mass)

MARKING

The capacitors are marked (where possible) with the following information:

- Rated capacitance (in µF)
- Tolerance on rated capacitance, code letter in accordance with IEC 60062 (M for ± 20 %)
- Rated voltage (in V)
- Date code, in accordance with IEC 60062
- Code indicating factory of origin
- Name of manufacturer
- Negative terminal identification
- Series number (038)

SELECTION CHART FOR C_R , U_R , AND RELEVANT NOMINAL CASE SIZES ($\varnothing D \times L$ in mm)								
C_R (μF)	U_R (V)							
	6.3	10	16	25	35	50	63	100
2.2	—	—	—	—	—	—	5 x 11	5 x 11
3.3	—	—	—	—	—	—	5 x 11	5 x 11
4.7	—	—	—	—	—	—	5 x 11	5 x 11
10	—	—	—	—	—	—	5 x 11	6.3 x 11
22	—	—	—	—	—	5 x 11	5 x 11	6.3 x 11
33	—	—	—	—	—	5 x 11	6.3 x 11	8 x 11.5
47	—	—	—	—	5 x 11	6.3 x 11	6.3 x 11	10 x 12
100	—	5 x 11	5 x 11	6.3 x 11	6.3 x 11	8 x 11.5	10 x 12	10 x 20
220	5 x 11	5 x 11	6.3 x 11	8 x 11.5	8 x 11.5	10 x 12	10 x 16	13 x 25
330	6.3 x 11	6.3 x 11	8 x 11.5	8 x 11.5	10 x 12	10 x 16	10 x 20	13 x 25
470	6.3 x 11	6.3 x 11	8 x 11.5	10 x 12	10 x 16	10 x 20	13 x 20	16 x 25
1000	8 x 11.5	10 x 12	10 x 16	10 x 20	13 x 20	13 x 25	16 x 25	18 x 40
2200	10 x 16	10 x 20	13 x 20	13 x 25	6 x 25	16 x 31	18 x 35	—
3300	10 x 20	13 x 20	13 x 25	16 x 25	16 x 35	18 x 35	—	—
4700	13 x 20	13 x 25	16 x 25	16 x 31	18 x 35	—	—	—
6800	13 x 25	16 x 25	16 x 31	18 x 35	—	—	—	—
10 000	16 x 25	16 x 35	18 x 35	—	—	—	—	—
22 000	18 x 40	—	—	—	—	—	—	—

DIMENSIONS in millimeters AND AVAILABLE FORMS

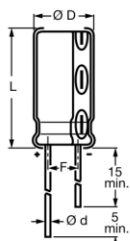


Fig. 2 - Form CA

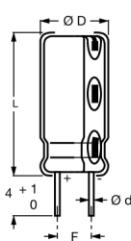
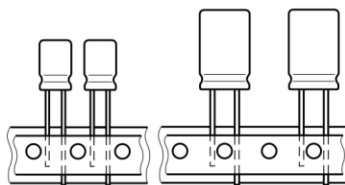
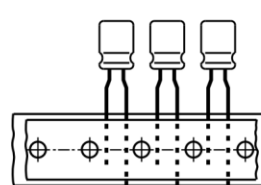

Fig. 3 - Form CB:
Cut leads

Fig. 4 - Form TNA, Form TFA:
Taped in box (ammpack), straight leads
Dimensions of pitch F see Table 1 and Table 2

Fig. 5 - Form TFA:
Taped in box (ammpack), formed leads
Case $\varnothing D = 5$ mm to 8 mm; pitch F is 5 mm

Table 1

DIMENSIONS in millimeters, MASS AND PACKAGING QUANTITIES									
NOMINAL CASE SIZE $\varnothing D \times L$	CASE CODE	$\varnothing d$	$\varnothing D_{max}$	L_{max}	F	MASS (g)	PACKAGING QUANTITIES		
							FORM CA	FORM CB	FORM TFA, TNA
5 x 11	11	0.5	5.5	12.5	2.0 ± 0.5	≈ 0.4	5000	—	2000
6.3 x 11	12	0.5	6.8	12.5	2.5 ± 0.5	≈ 0.6	5000	—	2000
8 x 11.5	13	0.6	8.5	12.5	3.5 ± 0.5	≈ 1.1	5000	—	1000
10 x 12	14	0.6	10.5	13.5	5.0 ± 0.5	≈ 1.6	3000	1000	500
10 x 16	15	0.6	10.5	17.5	5.0 ± 0.5	≈ 1.9	2500	1000	500
10 x 20	16	0.6	10.5	22.0	5.0 ± 0.5	≈ 2.2	2000	800	500
13 x 20	17	0.6	13.5	22.0	5.0 ± 0.5	≈ 4.0	1500	400	300
13 x 25	18	0.6	13.5	27.0	5.0 ± 0.5	≈ 5.0	1000	400	300
16 x 25	19	0.8	16.5	27.0	7.5 ± 0.5	≈ 8.0	750	200	200
16 x 31	20	0.8	16.5	33.5	7.5 ± 0.5	≈ 9.0	600	200	200
16 x 35	21	0.8	16.5	37.5	7.5 ± 0.5	≈ 11.0	500	200	—
18 x 35	22	0.8	18.5	37.5	7.5 ± 0.5	≈ 14.5	400	150	—
18 x 40	23	0.8	18.5	42.0	7.5 ± 0.5	≈ 16.0	400	150	—

Note

- Detailed tape dimensions see section "Packaging".



ELECTRICAL DATA	
SYMBOL	DESCRIPTION
C_R	Rated capacitance at 100 Hz, tolerance $\pm 20\%$
I_R	Rated RMS ripple current at 100 Hz, 85 °C
I_{L2}	Max. leakage current after 2 min at U_R
$\tan \delta$	Max. dissipation factor at 100 Hz

Note

- Unless otherwise specified, all electrical values in Table 2 apply at $T_{amb} = 20\text{ °C}$, $P = 86\text{ kPa}$ to 106 kPa , $RH = 45\%$ to 75% .

Table 2

ELECTRICAL DATA AND ORDERING INFORMATION													
U_R (V)	C_R 100 Hz (μF)	NOMINAL CASE SIZE $\varnothing D \times L$ (mm)	I_R 100 Hz 85 °C (mA)	I_{L2} 2 min (μA)	$\tan \delta$ 100 Hz	ORDERING CODE MAL2038							
						BULK PACKAGING				TAPED AMMOPACK			
						LONG LEADS		CUT LEADS					
						FORM CA	F (mm)	FORM CB	F (mm)	FORM TFA	F (mm)	FORM TNA	F (mm)
6.3	220	5 x 11	200	14	0.23	53221E3	2.0	-	-	33221E3	5.0	73221E3	2.5
	330	6.3 x 11	270	21	0.23	53331E3	2.5	-	-	33331E3	5.0	73331E3	2.5
	470	6.3 x 11	320	30	0.23	53471E3	2.5	-	-	33471E3	5.0	73471E3	2.5
	1000	8 x 11.5	540	63	0.23	53102E3	3.5	-	-	33102E3	5.0	73102E3	3.5
	2200	10 x 16	785	139	0.25	53222E3	5.0	63222E3	5.0	33222E3	5.0	-	-
	3300	10 x 20	1185	208	0.27	53332E3	5.0	63332E3	5.0	33332E3	5.0	-	-
	4700	13 x 20	1545	296	0.29	53472E3	5.0	63472E3	5.0	33472E3	5.0	-	-
	6800	13 x 25	1880	428	0.33	53682E3	5.0	63682E3	5.0	33682E3	5.0	-	-
	10 000	16 x 25	2330	630	0.41	53103E3	7.5	63103E3	7.5	33103E3	7.5	-	-
	22 000	18 x 40	3320	1386	0.65	53223E3	7.5	63223E3	7.5	-	-	-	-
10	100	5 x 11	145	10	0.20	54101E3	2.0	-	-	34101E3	5.0	74101E3	2.5
	220	5 x 11	160	22	0.20	54221E3	2.0	-	-	34221E3	5.0	74221E3	2.5
	330	6.3 x 11	290	33	0.20	54331E3	2.5	-	-	34331E3	5.0	74331E3	2.5
	470	6.3 x 11	350	47	0.20	54471E3	2.5	-	-	34471E3	5.0	74471E3	2.5
	1000	10 x 12	650	100	0.20	54102E3	5.0	64102E3	5.0	34102E3	5.0	-	-
	2200	10 x 20	1070	220	0.22	54222E3	5.0	64222E3	5.0	34222E3	5.0	-	-
	3300	13 x 20	1420	330	0.24	54332E3	5.0	64332E3	5.0	34332E3	5.0	-	-
	4700	13 x 25	1780	470	0.26	54472E3	5.0	64472E3	5.0	34472E3	5.0	-	-
	6800	16 x 25	2220	680	0.30	54682E3	7.5	64682E3	7.5	34682E3	7.5	-	-
	10 000	16 x 35	2760	1000	0.38	54103E3	7.5	64103E3	7.5	-	-	-	-
16	100	5 x 11	160	16	0.16	55101E3	2.0	-	-	35101E3	5.0	75101E3	2.5
	220	6.3 x 11	260	35	0.16	55221E3	2.5	-	-	35221E3	5.0	75221E3	2.5
	330	8 x 11.5	370	53	0.16	55331E3	3.5	-	-	35331E3	5.0	75331E3	3.5
	470	8 x 11.5	440	75	0.16	55471E3	3.5	-	-	35471E3	5.0	75471E3	3.5
	1000	10 x 16	785	160	0.16	55102E3	5.0	65102E3	5.0	35102E3	5.0	-	-
	2200	13 x 20	1295	352	0.18	55222E3	5.0	65222E3	5.0	35222E3	5.0	-	-
	3300	13 x 25	1655	528	0.20	55332E3	5.0	65332E3	5.0	35332E3	5.0	-	-
	4700	16 x 25	2090	752	0.22	55472E3	7.5	65472E3	7.5	35472E3	7.5	-	-
	6800	16 x 31	2520	1088	0.26	55682E3	7.5	65682E3	7.5	35682E3	7.5	-	-
	10 000	18 x 35	2920	1600	0.34	55103E3	7.5	65103E3	7.5	-	-	-	-
25	100	6.3 x 11	190	25	0.14	56101E3	2.5	-	-	36101E3	5.0	76101E3	2.5
	220	8 x 11.5	320	55	0.14	56221E3	3.5	-	-	36221E3	5.0	76221E3	3.5
	330	8 x 11.5	440	83	0.14	56331E3	3.5	-	-	36331E3	5.0	76331E3	3.5
	470	10 x 12	545	118	0.14	56471E3	5.0	66471E3	5.0	36471E3	5.0	-	-
	1000	10 x 20	955	250	0.14	56102E3	5.0	66102E3	5.0	36102E3	5.0	-	-
	2200	13 x 25	1540	550	0.16	56222E3	5.0	66222E3	5.0	36222E3	5.0	-	-
	3300	16 x 25	1975	825	0.18	56332E3	7.5	66332E3	7.5	36332E3	7.5	-	-
	4700	16 x 31	2420	1175	0.20	56472E3	7.5	66472E3	7.5	36472E3	7.5	-	-
	6800	18 x 35	2880	1700	0.24	56682E3	7.5	66682E3	7.5	-	-	-	-

Revision: 24-Apr-13

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Document Number: 28309

For technical questions, contact: aluminumcaps1@vishay.com

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ELECTRICAL DATA AND ORDERING INFORMATION													
U _R (V)	C _R 100 Hz (μF)	NOMINAL CASE SIZE Ø D x L (mm)	I _R 100 Hz 85 °C (mA)	I _{L2} 2 min (μA)	tan δ 100 Hz	ORDERING CODE MAL2038							
						BULK PACKAGING				TAPED AMMOPACK			
						LONG LEADS		CUT LEADS					
						FORM CA	F (mm)	FORM CB	F (mm)	FORM TFA	F (mm)	FORM TNA	F (mm)
35	47	5 x 11	130	17	0.12	50479E3	2.0	-	-	30479E3	5.0	70479E3	2.5
	100	6.3 x 11	210	35	0.12	50101E3	2.5	-	-	30101E3	5.0	70101E3	2.5
	220	8 x 11.5	385	77	0.12	50221E3	3.5	-	-	30221E3	5.0	70221E3	3.5
	330	10 x 12	490	116	0.12	50331E3	5.0	60331E3	5.0	30331E3	5.0	-	-
	470	10 x 16	740	165	0.12	50471E3	5.0	60471E3	5.0	30471E3	5.0	-	-
	1000	13 x 20	1145	350	0.12	50102E3	5.0	60102E3	5.0	30102E3	5.0	-	-
	2200	16 x 25	1785	770	0.14	50222E3	7.5	60222E3	7.5	30222E3	7.5	-	-
	3300	16 x 35	2275	1155	0.16	50332E3	7.5	60332E3	7.5	-	-	-	-
	4700	18 x 35	2700	1645	0.18	50472E3	7.5	60472E3	7.5	-	-	-	-
50	22	5 x 11	95	11	0.10	51229E3	2.0	-	-	31229E3	5.0	71229E3	2.5
	33	5 x 11	125	17	0.10	51339E3	2.0	-	-	31339E3	5.0	71339E3	2.5
	47	6.3 x 11	165	24	0.10	51479E3	2.5	-	-	31479E3	5.0	71479E3	2.5
	100	8 x 11.5	260	50	0.10	51101E3	3.5	-	-	31101E3	5.0	71101E3	3.5
	220	10 x 12	455	110	0.10	51221E3	5.0	61221E3	5.0	31221E3	5.0	-	-
	330	10 x 16	585	165	0.10	51331E3	5.0	61331E3	5.0	31331E3	5.0	-	-
	470	10 x 20	755	235	0.10	51471E3	5.0	61471E3	5.0	31471E3	5.0	-	-
	1000	13 x 25	1340	500	0.10	51102E3	5.0	61102E3	5.0	31102E3	5.0	-	-
	2200	16 x 31	1885	1100	0.12	51222E3	7.5	61222E3	7.5	31222E3	7.5	-	-
3300	18 x 35	2500	1650	0.14	51332E3	7.5	61332E3	7.5	-	-	-	-	
63	2.2	5 x 11	28	3.0	0.09	58228E3	2.0	-	-	38228E3	5.0	78228E3	2.5
	3.3	5 x 11	34	3.0	0.09	58338E3	2.0	-	-	38338E3	5.0	78338E3	2.5
	4.7	5 x 11	45	3.0	0.09	58478E3	2.0	-	-	38478E3	5.0	78478E3	2.5
	10	5 x 11	70	6.3	0.09	58109E3	2.0	-	-	38109E3	5.0	78109E3	2.5
	22	5 x 11	105	14	0.09	58229E3	2.0	-	-	38229E3	5.0	78229E3	2.5
	33	6.3 x 11	140	21	0.09	58339E3	2.5	-	-	38339E3	5.0	78339E3	2.5
	47	6.3 x 11	170	30	0.09	58479E3	2.5	-	-	38479E3	5.0	78479E3	2.5
	100	10 x 12	320	63	0.09	58101E3	5.0	68101E3	5.0	38101E3	5.0	-	-
	220	10 x 16	490	139	0.09	58221E3	5.0	68221E3	5.0	38221E3	5.0	-	-
330	10 x 20	710	208	0.09	58331E3	5.0	68331E3	5.0	38331E3	5.0	-	-	
100	470	13 x 20	900	296	0.09	58471E3	5.0	68471E3	5.0	38471E3	5.0	-	-
	1000	16 x 25	1560	630	0.09	58102E3	7.5	68102E3	7.5	38102E3	7.5	-	-
	2200	18 x 35	1950	1386	0.11	58222E3	7.5	68222E3	7.5	-	-	-	-
	2.2	5 x 11	33	3.0	0.08	59228E3	2.0	-	-	39228E3	5.0	79228E3	2.5
	3.3	5 x 11	40	3.3	0.08	59338E3	2.0	-	-	39338E3	5.0	79338E3	2.5
	4.7	5 x 11	48	4.7	0.08	59478E3	2.0	-	-	39478E3	5.0	79478E3	2.5
	10	6.3 x 11	80	10	0.08	59109E3	2.5	-	-	39109E3	5.0	79109E3	2.5
	22	6.3 x 11	115	22	0.08	59229E3	2.5	-	-	39229E3	5.0	79229E3	2.5
	33	8 x 11.5	145	33	0.08	59339E3	3.5	-	-	39339E3	5.0	79339E3	3.5
47	10 x 12	235	47	0.08	59479E3	5.0	69479E3	5.0	39479E3	5.0	-	-	
100	10 x 20	370	100	0.08	59101E3	5.0	69101E3	5.0	39101E3	5.0	-	-	
220	13 x 25	675	220	0.08	59221E3	5.0	69221E3	5.0	39221E3	5.0	-	-	
330	13 x 25	825	330	0.08	59331E3	5.0	69331E3	5.0	39331E3	5.0	-	-	
470	16 x 25	1070	470	0.08	59471E3	7.5	69471E3	7.5	39471E3	7.5	-	-	
1000	18 x 40	2410	1000	0.08	59102E3	7.5	69102E3	7.5	-	-	-	-	



ADDITIONAL ELECTRICAL DATA		
PARAMETER	CONDITIONS	VALUE
Voltage		
Surge voltage		$U_s \leq 1.15 \times U_R$
Reverse voltage		$U_{rev} \leq 1 \text{ V}$
Current		
Leakage current	After 2 min at U_R	$I_{L2} \leq 0.01 C_R \times U_R$ or $3 \mu\text{A}$, whichever is greater
	After 5 min at U_R	$I_{L5} \leq 0.002 C_R \times U_R + 3 \mu\text{A}$
Inductance		
Equivalent series inductance (ESL)	Case $\varnothing D \leq 8 \text{ mm}$	Typ. 13 nH
	Case $\varnothing D = 10 \text{ mm}$	Typ. 16 nH
	Case $\varnothing D \geq 12.5 \text{ mm}$	Typ. 18 nH
Resistance		
Equivalent series resistance (ESR)	Calculated from $\tan \delta_{\max}$ and C_R (see Table 2)	$\text{ESR} = \tan \delta / 2 \pi f C_R$

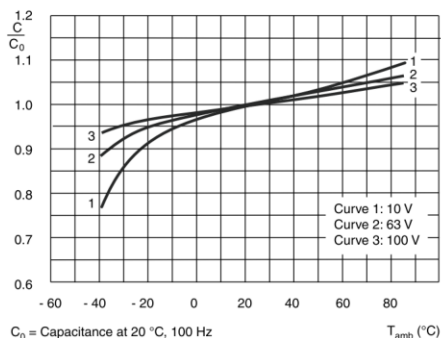
CAPACITANCE (C)

Fig. 6 - Typical multiplier of capacitance as a function of ambient temperature

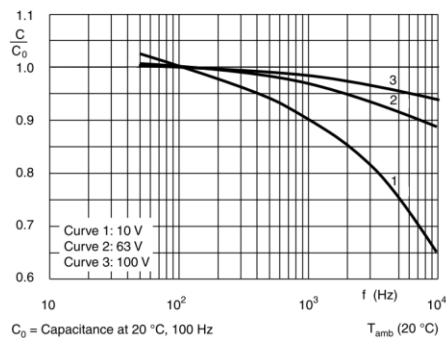


Fig. 7 - Typical multiplier of capacitance as a function of frequency

RIPPLE CURRENT AND USEFUL LIFE

I_A = Actual ripple current at 100 Hz
 I_R = Rated ripple current at 100 Hz, 85 °C
 Useful life at 85 °C and I_R applied:
 Case Ø ≤ 8 mm: 2500 h
 Case Ø ≥ 10 mm: 3500 h

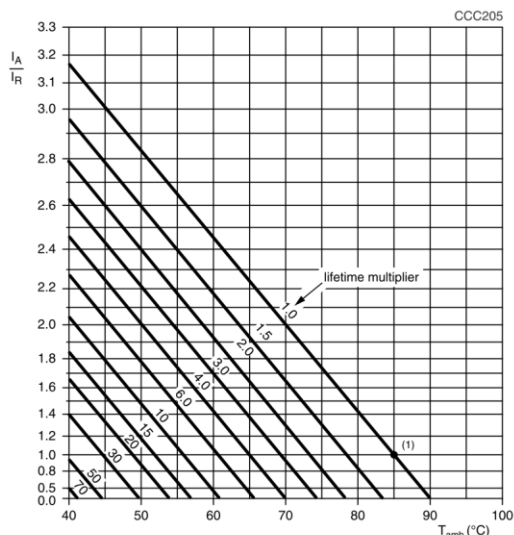


Fig. 8 - Multiplier of useful life as a function of ambient temperature and ripple current load

Table 3

MULTIPLIER OF RIPPLE CURRENT (I_R) AS A FUNCTION OF FREQUENCY			
FREQUENCY (Hz)	I_R MULTIPLIER		
	$C_R < 100 \mu F$	$C_R = 100 \mu F$ TO $1000 \mu F$	$C_R > 1000 \mu F$
50	0.70	0.75	0.80
100	1.00	1.00	1.00
500	1.30	1.20	1.10
1000	1.40	1.30	1.12
≥ 10 000	1.50	1.35	1.15

Table 4

TEST PROCEDURES AND REQUIREMENTS			
TEST		PROCEDURE (quick reference)	REQUIREMENTS
NAME OF TEST	REFERENCE		
Endurance	IEC 60384-4/ EN130300 subclause 4.13	$T_{amb} = 85 \text{ °C}$; U_R applied; Case Ø ≤ 8 mm: 2000 h Case Ø ≥ 10 mm: 3000 h	$\Delta C/C: \pm 20 \%$ $\tan \delta \leq 2 \times \text{spec. limit}$ $I_{L5} \leq \text{spec. limit}$
Useful life	CECC 30301 subclause 1.8.1	$T_{amb} = 85 \text{ °C}$; U_R and I_R applied; Case Ø ≤ 8 mm: 2500 h Case Ø ≥ 10 mm: 3500 h	$\Delta C/C: \pm 50 \%$ $\tan \delta \leq 3 \times \text{spec. limit}$ $I_{L5} \leq \text{spec. limit}$ no short or open circuit total failure percentage: ≤ 1 %
Shelf life (storage at high temperature)	IEC 60384-4/ EN130300 subclause 4.17	$T_{amb} = 85 \text{ °C}$; no voltage applied; 1000 h after test: U_R to be applied for 30 min, 24 h to 48 h before measurement	$\Delta C/C: \pm 20 \%$ $\tan \delta \leq 2 \times \text{spec. limit}$ $I_{L5} \leq 3 \times \text{spec. limit}$
Surge	IEC 60384-4/ EN130300 subclause 4.14	From source of $1.15 \times U_R$; $RC = 0.1 \text{ s} \pm 0.05 \text{ s}$; 1000 cycles of 30 s on, 330 s off, at 85 °C	$\Delta C/C: \pm 25 \%$ $\tan \delta \leq 1.5 \times \text{spec. limit}$ $I_{L5} \leq \text{spec. limit}$



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Radial Lead Type

Series: **FM** Type: **A**

■ Features

- Low impedance (40 % to 70 % less than FC Series)
- Endurance : 2000 h to 7000 h at +105 °C
- RoHS directive compliant

■ Attention

Not applicable for automotive

■ Specifications

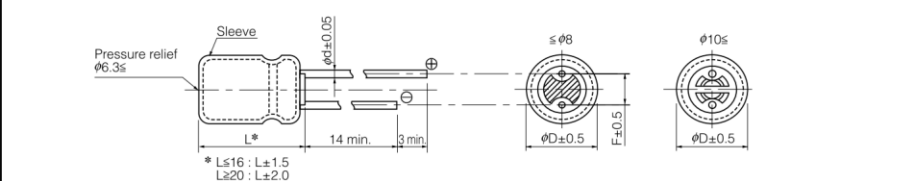
- Specifications -								
Category Temp. Range	-40 °C to +105 °C							
Rated W.V. Range	6.3 V.DC to 50 V.DC							
Nominal Cap. Range	22 µF to 6800 µF							
Capacitance Tolerance	±20 % (120 Hz/+20 °C)							
DC Leakage Current	I ≤ 0.01 CV (µA) After 2 minutes							
tan δ	W.V.	6.3	10	16	25	35	50	(max.) (120 Hz/+20 °C)
	tan δ	0.22	0.19	0.16	0.14	0.12	0.10	
	Add 0.02 per 1000 µF for products of 1000 µF or more.							
Endurance	After following life test with DC voltage and +105 °C±2 °C ripple current value applied. (The sum of DC and ripple peak voltage shall not exceed the rated working voltage) when the capacitors are restored to 20 °C, the capacitors shall meet the limits specified below. Duration φ5 to φ6.3 : 2000 hours, φ8×11.5 to φ8×15: 3000 hours φ8×20 to φ10×16 : 4000 hours, φ10×20 to φ12.5×20/ φ16×20: 5000 hours φ12.5×25 to φ12.5×35/ φ16×25 : 7000 hours							
	Capacitance change	±25 % of initial measured value (6.3 V to 10 V : ±30 %)						
	tan δ	≤ 200 % of initial specified value						
	DC leakage current	≤ initial specified value						
	Shelf Life	After storage for 1000 hours at +105 °C±2 °C with no voltage applied and then being stabilized at +20 °C, capacitors shall meet the limits specified in Endurance. (With voltage treatment)						

■ Frequency correction factor for ripple current

W.V.(V.DC)	Cap (µF)	Frequency (Hz)				
		60	120	1 k	10 k	100 k
6.3 to 50	22 to 33	0.45	0.55	0.75	0.90	1.00
	47 to 330	0.60	0.70	0.85	0.95	1.00
	390 to 1000	0.65	0.75	0.90	0.98	1.00
	1200 to 6800	0.75	0.80	0.95	1.00	1.00

■ Dimensions in mm (not to scale)

(Unit : mm)

 Pressure relief $\phi 6.3s$ Sleeve $\phi d \pm 0.05$ 14 min. 3 min. * $L \leq 16$: $L \pm 1.5$ $L \geq 20$: $L \pm 2.0$							
Body Dia. ϕD	5	6.3	8	10	12.5	16	
Body Length L	—	—	—	—	12.5 to 25	30 to 40	—
Lead Dia. ϕd	0.5	0.5	0.6	0.6	0.6	0.8	0.8
Lead space F	2.0	2.5	3.5	5.0	5.0	7.5	

Design and specifications are each subject to change without notice. Ask factory for the current technical specifications before purchase and/or use.
 Should a safety concern arise regarding this product, please be sure to contact us immediately.

01 May. 2014

■ Case size/Impedance/Ripple current

W.V.(V.DC) Case size (ϕ D×L)	6.3 V to 35 V			50 V		
	Impedance (Ω /100 kHz)		Ripple Current (mA r.m.s./100 kHz)	Impedance (Ω /100 kHz)		Ripple Current (mA r.m.s./100 kHz)
	+20 °C	−10 °C	+105 °C	+20 °C	−10 °C	+105 °C
5 × 11	0.300	1.000	280	0.340	1.130	250
6.3 × 11.2	0.130	0.430	455	0.140	0.460	405
8 × 11.5	0.056	0.168	950	0.061	0.183	870
8 × 15	0.041	0.123	1240	0.045	0.135	1140
8 × 20	0.030	0.090	1560	0.033	0.099	1430
10 × 12.5	0.038	0.114	1290	0.042	0.126	1170
10 × 16	0.026	0.078	1790	0.030	0.090	1650
10 × 20	0.019	0.057	2180	0.023	0.069	1890
10 × 25	0.018	0.054	2470	0.022	0.066	2150
12.5 × 20	0.018	0.045	2600	0.022	0.055	2260
12.5 × 25	0.015	0.038	3190	0.018	0.045	2660
12.5 × 30	0.013	0.033	3630	0.016	0.040	3160
12.5 × 35	0.012	0.030	3750	0.014	0.035	3270
16 × 20	0.017	0.043	3300	0.019	0.048	2870
16 × 25	0.014	0.035	3820	0.016	0.040	3320

Design and specifications are each subject to change without notice. Ask factory for the current technical specifications before purchase and/or use.
Should a safety concern arise regarding this product, please be sure to contact us immediately.

01 May, 2014

■ Standard Products

W.V.	Cap. (±20 %)	Case size		Specification			Lead Length				Part No.	Min. Packaging Q'ty	
		Dia.	Length	Ripple Current (100 kHz) (+105 °C) (mA r.m.s.)	Impedance (100 kHz) (+20 °C) (Ω)	Endurance (hours)	Lead Dia. (mm)	Lead Space				Long Lead (pcs)	Taping (pcs)
								Straight (mm)	Taping *B (mm)	Taping *H (mm)			
(V)	(μF)	(mm)	(mm)				(mm)	(mm)	(mm)	(mm)			
6.3	150	5	11	280	0.300	2000	0.5	2.0	5.0	2.5	EEUFM0J151()	200	2000
	330	6.3	11.2	455	0.130	2000	0.5	2.5	5.0	2.5	EEUFM0J331()	200	2000
	560	8	11.5	950	0.056	3000	0.6	3.5	5.0		EEUFM0J561()	200	1000
	820	8	15	1240	0.041	3000	0.6	3.5	5.0		EEUFM0J821L()	200	1000
	1000	10	12.5	1290	0.038	4000	0.6	5.0	5.0		EEUFM0J102()	200	500
	1200	8	20	1560	0.030	4000	0.6	3.5	5.0		EEUFM0J122L()	200	1000
		10	16	1790	0.026	4000	0.6	5.0	5.0		EEUFM0J122()	200	500
	1500	10	20	2180	0.019	5000	0.6	5.0	5.0		EEUFM0J152()	200	500
	2200	10	25	2470	0.018	5000	0.6	5.0	5.0		EEUFM0J222L()	200	500
	3300	12.5	20	2600	0.018	5000	0.6	5.0	5.0		EEUFM0J332()	200	500
	3900	12.5	25	3190	0.015	7000	0.6	5.0	5.0		EEUFM0J392()	200	500
	4700	12.5	30	3630	0.013	7000	0.8	5.0			EEUFM0J472L	100	
	5600	12.5	35	3750	0.012	7000	0.8	5.0			EEUFM0J562L	100	
		16	20	3300	0.017	5000	0.8	7.5	7.5		EEUFM0J562S()	100	250
	6800	16	25	3820	0.014	7000	0.8	7.5	7.5		EEUFM0J682()	100	250
10	100	5	11	280	0.300	2000	0.5	2.0	5.0	2.5	EEUFM1A101()	200	2000
	220	6.3	11.2	455	0.130	2000	0.5	2.5	5.0	2.5	EEUFM1A221()	200	2000
	470	8	11.5	950	0.056	3000	0.6	3.5	5.0		EEUFM1A471()	200	1000
	680	8	15	1240	0.041	3000	0.6	3.5	5.0		EEUFM1A681L()	200	1000
		10	12.5	1290	0.038	4000	0.6	5.0	5.0		EEUFM1A681()	200	500
	1000	8	20	1560	0.030	4000	0.6	3.5	5.0		EEUFM1A102L()	200	1000
		10	16	1790	0.026	4000	0.6	5.0	5.0		EEUFM1A102()	200	500
	1200	10	20	2180	0.019	5000	0.6	5.0	5.0		EEUFM1A122()	200	500
	1500	10	25	2470	0.018	5000	0.6	5.0	5.0		EEUFM1A152L()	200	500
	2200	12.5	20	2600	0.018	5000	0.6	5.0	5.0		EEUFM1A222()	200	500
	3300	12.5	25	3190	0.015	7000	0.6	5.0	5.0		EEUFM1A332()	200	500
	3900	12.5	30	3630	0.013	7000	0.8	5.0			EEUFM1A392L	100	
		16	20	3300	0.017	5000	0.8	7.5	7.5		EEUFM1A392S()	100	250
	4700	12.5	35	3750	0.012	7000	0.8	5.0			EEUFM1A472L	100	
	5600	16	25	3820	0.014	7000	0.8	7.5	7.5		EEUFM1A562()	100	250
16	68	5	11	280	0.300	2000	0.5	2.0	5.0	2.5	EEUFM1C680()	200	2000
	120	6.3	11.2	455	0.130	2000	0.5	2.5	5.0	2.5	EEUFM1C121()	200	2000
	330	8	11.5	950	0.056	3000	0.6	3.5	5.0		EEUFM1C331()	200	1000
	470	8	15	1240	0.041	3000	0.6	3.5	5.0		EEUFM1C471L()	200	1000
		10	12.5	1290	0.038	4000	0.6	5.0	5.0		EEUFM1C471()	200	500
	680	8	20	1560	0.030	4000	0.6	3.5	5.0		EEUFM1C681L()	200	1000
		10	16	1790	0.026	4000	0.6	5.0	5.0		EEUFM1C681()	200	500
	1000	10	20	2180	0.019	5000	0.6	5.0	5.0		EEUFM1C102()	200	500
	1200	10	25	2470	0.018	5000	0.6	5.0	5.0		EEUFM1C122L()	200	500
	1500	12.5	20	2600	0.018	5000	0.6	5.0	5.0		EEUFM1C152()	200	500
	2200	12.5	25	3190	0.015	7000	0.6	5.0	5.0		EEUFM1C222()	200	500
	2700	12.5	30	3630	0.013	7000	0.8	5.0			EEUFM1C272L	100	
		16	20	3300	0.017	5000	0.8	7.5	7.5		EEUFM1C272S()	100	250
	3300	12.5	35	3750	0.012	7000	0.8	5.0			EEUFM1C332L	100	
	3900	16	25	3820	0.014	7000	0.8	7.5	7.5		EEUFM1C392()	100	250

· When requesting taped product, please put the letter "B" of "H" between the "()". Lead wire pitch *B=5 mm, 7.5 mm, H=2.5 mm.
· Please refer to the page of "Taping Dimensions".

Design and specifications are each subject to change without notice. Ask factory for the current technical specifications before purchase and/or use.
Should a safety concern arise regarding this product, please be sure to contact us immediately.

01 May, 2014

■ Standard Products

W.V.	Cap. (±20 %)	Case size		Specification			Lead Length				Part No.	Min. Packaging Qty	
		Dia.	Length	Ripple Current (100 kHz) (+105 °C) (mA r.m.s.)	Imped- ance (100 kHz) (+20 °C) (Ω)	Endur- ance (hours)	Lead Dia. (mm)	Lead Space				Long Lead (pcs)	Taping (pcs)
								Straight (mm)	Taping *B (mm)	Taping *H (mm)			
(V)	(μF)	(mm)	(mm)				(mm)	(mm)	(mm)	(mm)			
25	47	5	11	280	0.300	2000	0.5	2.0	5.0	2.5	EEUFM1E470()	200	2000
	100	6.3	11.2	455	0.130	2000	0.5	2.5	5.0	2.5	EEUFM1E101()	200	2000
	220	8	11.5	950	0.056	3000	0.6	3.5	5.0		EEUFM1E221()	200	1000
	330	8	15	1240	0.041	3000	0.6	3.5	5.0		EEUFM1E331L()	200	1000
		10	12.5	1290	0.038	4000	0.6	5.0	5.0		EEUFM1E331()	200	500
	470	8	20	1560	0.030	4000	0.6	3.5	5.0		EEUFM1E471L()	200	1000
		10	16	1790	0.026	4000	0.6	5.0	5.0		EEUFM1E471()	200	500
	680	10	20	2180	0.019	5000	0.6	5.0	5.0		EEUFM1E681()	200	500
	820	10	25	2470	0.018	5000	0.6	5.0	5.0		EEUFM1E821L()	200	500
	1000	12.5	20	2600	0.018	5000	0.6	5.0	5.0		EEUFM1E102()	200	500
	1500	12.5	25	3190	0.015	7000	0.6	5.0	5.0		EEUFM1E152()	200	500
	1800	12.5	30	3630	0.013	7000	0.8	5.0			EEUFM1E182L	100	
		16	20	3300	0.017	5000	0.8	7.5	7.5		EEUFM1E182S()	100	250
	2200	12.5	35	3750	0.012	7000	0.8	5.0			EEUFM1E222L	100	
	2700	16	25	3820	0.014	7000	0.8	7.5	7.5		EEUFM1E272()	100	250
35	33	5	11	280	0.300	2000	0.5	2.0	5.0	2.5	EEUFM1V330()	200	2000
	68	6.3	11.2	455	0.130	2000	0.5	2.5	5.0	2.5	EEUFM1V680()	200	2000
	150	8	11.5	950	0.056	3000	0.6	3.5	5.0		EEUFM1V151()	200	1000
	220	8	15	1240	0.041	3000	0.6	3.5	5.0		EEUFM1V221L()	200	1000
		10	12.5	1290	0.038	4000	0.6	5.0	5.0		EEUFM1V221()	200	500
	330	8	20	1560	0.030	4000	0.6	3.5	5.0		EEUFM1V331L()	200	1000
		10	16	1790	0.026	4000	0.6	5.0	5.0		EEUFM1V331()	200	500
	470	10	20	2180	0.019	5000	0.6	5.0	5.0		EEUFM1V471()	200	500
	560	10	25	2470	0.018	5000	0.6	5.0	5.0		EEUFM1V561L()	200	500
	680	12.5	20	2600	0.018	5000	0.6	5.0	5.0		EEUFM1V681()	200	500
	1000	12.5	25	3190	0.015	7000	0.6	5.0	5.0		EEUFM1V102()	200	500
	1200	12.5	30	3630	0.013	7000	0.8	5.0			EEUFM1V122L	100	
		16	20	3300	0.017	5000	0.8	7.5	7.5		EEUFM1V122S()	100	250
	1500	12.5	35	3750	0.012	7000	0.8	5.0			EEUFM1V152L	100	
	1800	16	25	3820	0.014	7000	0.8	7.5	7.5		EEUFM1V182()	100	250
50	22	5	11	250	0.340	2000	0.5	2.0	5.0	2.5	EEUFM1H220()	200	2000
	56	6.3	11.2	405	0.140	2000	0.5	2.5	5.0	2.5	EEUFM1H560()	200	2000
	100	8	11.5	870	0.061	3000	0.6	3.5	5.0		EEUFM1H101()	200	1000
	120	8	15	1140	0.045	3000	0.6	3.5	5.0		EEUFM1H121L()	200	1000
	150	10	12.5	1170	0.042	4000	0.6	5.0	5.0		EEUFM1H151()	200	500
	180	8	20	1430	0.033	4000	0.6	3.5	5.0		EEUFM1H181L()	200	1000
	220	10	16	1650	0.030	4000	0.6	5.0	5.0		EEUFM1H221()	200	500
	270	10	20	1890	0.023	5000	0.6	5.0	5.0		EEUFM1H271()	200	500
	330	10	25	2150	0.022	5000	0.6	5.0	5.0		EEUFM1H331L()	200	500
	470	12.5	20	2260	0.022	5000	0.6	5.0	5.0		EEUFM1H471()	200	500
	560	12.5	25	2660	0.018	7000	0.6	5.0	5.0		EEUFM1H561()	200	500
	680	12.5	30	3160	0.016	7000	0.8	5.0			EEUFM1H681L	100	
	820	12.5	35	3270	0.014	7000	0.8	5.0			EEUFM1H821L	100	
		16	20	2870	0.019	5000	0.8	7.5	7.5		EEUFM1H821S()	100	250
	1000	16	25	3320	0.016	7000	0.8	7.5	7.5		EEUFM1H102()	100	250

· When requesting taped product, please put the letter "B" of "H" between the "()". Lead wire pitch *B=5 mm, 7.5 mm, H=2.5 mm.
· Please refer to the page of "Taping Dimensions".

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01 May. 2014



MINIATURE ALUMINUM ELECTROLYTIC CAPACITORS

Downsized, 85°C

SMG Series

- Downsized from SME series
- Endurance : 2,000 hours at 85°C
- Solvent-proof type except 315 to 450V_{dc}
(see PRECAUTIONS AND GUIDELINES)
- RoHS Compliant

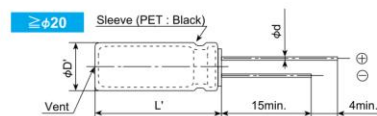
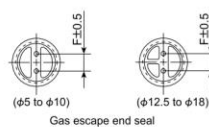
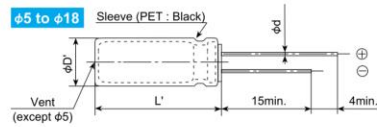


◆ SPECIFICATIONS

Items	Characteristics
Category	Temperature Range
Temperature Range	-40 to +85°C(6.3 to 400V _{dc}) -25 to +85°C(450V _{dc})
Rated Voltage Range	6.3 to 450V _{dc}
Capacitance Tolerance	±20% (M) (at 20°C, 120Hz)
Leakage Current	6.3 to 100V _{dc} 160 to 450V _{dc} ≤φ18 I=0.03CV or 4μA, whichever is greater. CV≤1,000 I=0.1CV+40 max. I=0.03CV+15 max. CV>1,000 I=0.04CV+100 max. I=0.02CV+25 max. (at 20°C after 1 minute) (at 20°C) ≥φ20 I=0.03CV (at 20°C after 3 minutes) Where, I : Max. leakage current (μA), C : Nominal capacitance (μF), V : Rated voltage (V)
Dissipation Factor (tanδ)	Rated voltage (V _{dc}) 6.3V 10V 16V 25V 35V 50V 63V 100V 160 to 250V 315 to 400V 450V tanδ (Max.) ≤φ18 0.34 0.24 0.20 0.16 0.14 0.12 0.09 0.08 0.20 0.24 0.24 ≥φ20 0.28 0.24 0.20 0.16 0.14 0.12 0.09 0.08 0.15 0.15 0.20 When nominal capacitance exceeds 1,000μF, add 0.02 to the value above for each 1,000μF increase. (at 20°C, 120Hz)
Low Temperature Characteristics (Max. Impedance Ratio)	Rated voltage (V _{dc}) 6.3V 10V 16V 25V 35V 50V 63V 100V 160 to 250V 315 to 400V 450V Z(-25°C)/Z(+20°C) ≤φ18 5 4 3 2 2 2 2 2 3 6 6 ≥φ20 5 4 3 2 2 2 2 2 4 6 6 Z(-40°C)/Z(+20°C) ≤φ18 12 10 8 5 4 3 3 3 4 6 — (at 120Hz)
Endurance	The following specifications shall be satisfied when the capacitors are restored to 20°C after the rated voltage is applied for 2,000 hours at 85°C. Capacitance change ≤±20% of the initial value D.F. (tanδ) ≤200% of the initial specified value Leakage current ≤The initial specified value
Shelf Life	The following specifications shall be satisfied when the capacitors are restored to 20°C after exposing them for 1,000 hours at 85°C without voltage applied. Rated voltage 6.3 to 100V _{dc} 160 to 450V _{dc} Capacitance change ≤±20% of the initial value ≤±20% of the initial value D.F. (tanδ) ≤200% of the initial specified value ≤200% of the initial specified value Leakage current ≤The initial specified value ≤500% of the initial specified value

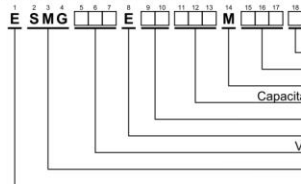
◆ DIMENSIONS [mm]

- Terminal Code : E



φD	5	6.3	8	10	12.5	16	18	20	22	25.4
φd	0.5	0.5	0.6	0.6	0.6	0.8	0.8	1.0	1.0	1.0
F	2.0	2.5	3.5	5.0	5.0	7.5	7.5	10.0	10.0	12.5
φD'	φD+0.5max.							φD+0.5max.		
L'	L+1.5max.							L+2.0max.		

◆ PART NUMBERING SYSTEM



Please refer to "A guide to global code (radial lead type)"



MINIATURE ALUMINUM ELECTROLYTIC CAPACITORS

Downsized, 85°C

SMG Series

◆STANDARD RATINGS

WV (Vdc)	Cap (μF)	Case size φDXL(mm)	tanδ	Rated ripple current (mA rms/ 85°C, 120Hz)	Part No.	WV (Vdc)	Cap (μF)	Case size φDXL(mm)	tanδ	Rated ripple current (mA rms/ 85°C, 120Hz)	Part No.
6.3	33	5X11	0.34	77	ESMG6R3E□□330ME11D	25	4.7	5X11	0.16	36	ESMG250E□□4R7ME11D
	47	5X11	0.34	92	ESMG6R3E□□470ME11D		10	5X11	0.16	53	ESMG250E□□100ME11D
	100	5X11	0.34	134	ESMG6R3E□□101ME11D		22	5X11	0.16	78	ESMG250E□□220ME11D
	220	5X11	0.34	200	ESMG6R3E□□221ME11D		33	5X11	0.16	96	ESMG250E□□330ME11D
	330	6.3X11	0.34	270	ESMG6R3E□□331MF11D		47	5X11	0.16	115	ESMG250E□□470ME11D
	470	6.3X11	0.34	320	ESMG6R3E□□471MF11D		100	6.3X11	0.16	190	ESMG250E□□101MF11D
	1,000	8X11.5	0.34	540	ESMG6R3E□□102MHB5D		220	8X11.5	0.16	330	ESMG250E□□221MHB5D
	2,200	10X20	0.36	1,000	ESMG6R3E□□222MJ20S		330	8X11.5	0.16	440	ESMG250E□□331MHB5D
	3,300	10X20	0.38	1,185	ESMG6R3E□□332MJ20S		470	10X12.5	0.16	545	ESMG250E□□471MJCS5
	4,700	12.5X20	0.40	1,545	ESMG6R3E□□472MJ20S		1,000	10X20	0.16	955	ESMG250E□□102MJ20S
	6,800	12.5X25	0.44	1,915	ESMG6R3E□□682MK25S		2,200	12.5X25	0.18	1,540	ESMG250E□□222MK25S
	10,000	16X25	0.52	2,330	ESMG6R3E□□103ML25S		3,300	16X25	0.20	1,975	ESMG250E□□332ML25S
	10,000	20X25	0.46	2,310	ESMG6R3E□□103MN25S		3,300	20X20	0.20	1,850	ESMG250E□□332MN25S
	15,000	16X35.5	0.62	2,845	ESMG6R3E□□153MLP1S		4,700	16X31.5	0.22	2,420	ESMG250E□□472MLN3S
	15,000	20X30	0.56	2,660	ESMG6R3E□□153MN30S		4,700	20X25	0.22	2,420	ESMG250E□□472MN25S
	18,000	20X35	0.62	2,890	ESMG6R3E□□183MN35S		5,600	20X30	0.24	2,430	ESMG250E□□562MN30S
	18,000	22X30	0.62	2,860	ESMG6R3E□□183MP30S		6,800	18X35.5	0.26	2,880	ESMG250E□□682MMP1S
	22,000	18X40	0.76	3,320	ESMG6R3E□□223MM40S		6,800	20X35	0.26	2,680	ESMG250E□□682MN35S
	22,000	20X40	0.70	3,130	ESMG6R3E□□223MN40S		6,800	22X30	0.26	2,510	ESMG250E□□682MP30S
	22,000	22X35	0.70	3,130	ESMG6R3E□□223MP35S		8,200	20X40	0.30	2,810	ESMG250E□□822MN40S
10	27,000	22X40	0.80	3,280	ESMG6R3E□□273MP40S		8,200	22X35	0.30	2,810	ESMG250E□□822MP35S
	39,000	25.4X40	1.04	3,560	ESMG6R3E□□393MQ40S		10,000	22X40	0.34	3,240	ESMG250E□□103MP40S
	22	5X11	0.24	66	ESMG100E□□220ME11D		12,000	22X40	0.38	3,240	ESMG250E□□123MP40S
	33	5X11	0.24	83	ESMG100E□□330ME11D		15,000	25.4X40	0.44	3,610	ESMG250E□□153MQ40S
	47	5X11	0.24	100	ESMG100E□□470ME11D	35	4.7	5X11	0.14	41	ESMG350E□□4R7ME11D
	100	5X11	0.24	146	ESMG100E□□101ME11D		10	5X11	0.14	59	ESMG350E□□100ME11D
	220	5X11	0.24	240	ESMG100E□□221ME11D		22	5X11	0.14	88	ESMG350E□□220ME11D
	330	6.3X11	0.24	290	ESMG100E□□331MF11D		33	5X11	0.14	108	ESMG350E□□330ME11D
	470	6.3X11	0.24	350	ESMG100E□□471MF11D		47	5X11	0.14	130	ESMG350E□□470ME11D
	1,000	10X12.5	0.24	650	ESMG100E□□102MJCS5		100	6.3X11	0.14	210	ESMG350E□□101MF11D
	2,200	10X20	0.26	1,070	ESMG100E□□222MJ20S		220	8X11.5	0.14	385	ESMG350E□□221MHB5D
	3,300	12.5X20	0.28	1,420	ESMG100E□□332MK20S		330	10X12.5	0.14	490	ESMG350E□□331MJCS5
	4,700	12.5X25	0.30	1,780	ESMG100E□□472MK25S		470	10X16	0.14	645	ESMG350E□□471MJ16S
	6,800	16X25	0.34	2,220	ESMG100E□□682ML25S		1,000	12.5X20	0.14	1,145	ESMG350E□□102MK20S
	6,800	20X20	0.34	2,080	ESMG100E□□682MN20S		2,200	16X25	0.16	1,785	ESMG350E□□222ML25S
	10,000	16X35.5	0.42	2,670	ESMG100E□□103MLP1S		2,200	20X20	0.16	1,670	ESMG350E□□222MN20S
	10,000	20X25	0.42	2,410	ESMG100E□□103MN25S		3,300	16X35.5	0.18	2,275	ESMG350E□□332MLP1S
	12,000	20X30	0.46	2,620	ESMG100E□□123MN30S		3,300	20X25	0.18	2,050	ESMG350E□□332MN25S
	15,000	18X35.5	0.52	3,080	ESMG100E□□153MMP1S		3,900	20X30	0.18	2,310	ESMG350E□□392MN30S
	15,000	20X35	0.52	2,870	ESMG100E□□153MN35S		4,700	18X35.5	0.20	2,700	ESMG350E□□472MMP1S
	15,000	22X30	0.52	2,660	ESMG100E□□153MP30S		4,700	20X35	0.20	2,510	ESMG350E□□472MN35S
	18,000	22X35	0.58	3,050	ESMG100E□□183MP35S		4,700	22X30	0.20	2,380	ESMG350E□□472MP30S
	22,000	22X40	0.66	3,480	ESMG100E□□223MP40S		5,600	20X40	0.22	2,690	ESMG350E□□562MN40S
16	33,000	25.4X40	0.88	3,560	ESMG100E□□333MQ40S		5,600	22X35	0.22	2,690	ESMG350E□□562MP35S
	10	5X11	0.20	50	ESMG160E□□100ME11D	50	6,800	22X40	0.24	3,090	ESMG350E□□682MP40S
	22	5X11	0.20	75	ESMG160E□□220ME11D		10,000	25.4X40	0.32	3,480	ESMG350E□□103MQ40S
	33	5X11	0.20	91	ESMG160E□□330ME11D		0.10	5X11	0.12	1.3	ESMG500E□□0R10ME11D
	47	5X11	0.20	109	ESMG160E□□470ME11D		0.22	5X11	0.12	2.9	ESMG500E□□0R22ME11D
	100	5X11	0.20	160	ESMG160E□□101ME11D		0.33	5X11	0.12	4.3	ESMG500E□□0R33ME11D
	220	6.3X11	0.20	260	ESMG160E□□221MF11D		0.47	5X11	0.12	6.2	ESMG500E□□0R47ME11D
	330	8X11.5	0.20	370	ESMG160E□□331MHB5D		1.0	5X11	0.12	17	ESMG500E□□10R3ME11D
	470	8X11.5	0.20	440	ESMG160E□□471MHB5D		2.2	5X11	0.12	28	ESMG500E□□0R22ME11D
	1,000	10X16	0.20	785	ESMG160E□□102MJ16S		3.3	5X11	0.12	35	ESMG500E□□0R33ME11D
	2,200	12.5X20	0.22	1,295	ESMG160E□□222MK20S		4.7	5X11	0.12	41	ESMG500E□□4R7ME11D
	3,300	12.5X25	0.24	1,655	ESMG160E□□332MK25S		10	5X11	0.12	60	ESMG500E□□100ME11D
	4,700	16X25	0.26	2,090	ESMG160E□□472ML25S		22	5X11	0.12	95	ESMG500E□□220ME11D
	4,700	20X20	0.26	1,960	ESMG160E□□472MN20S		33	5X11	0.12	125	ESMG500E□□330ME11D
	6,800	16X31.5	0.30	2,520	ESMG160E□□682MLN3S		47	6.3X11	0.12	155	ESMG500E□□470MF11D
	6,800	20X25	0.30	2,330	ESMG160E□□682MN25S		100	8X11.5	0.12	260	ESMG500E□□101MHB5D
	8,200	20X30	0.34	2,500	ESMG160E□□822MN30S		220	10X12.5	0.12	430	ESMG500E□□221MJCS5
	10,000	18X35.5	0.38	2,920	ESMG160E□□103MMP1S		330	10X16	0.12	585	ESMG500E□□331MJ16S
	10,000	20X35	0.38	2,720	ESMG160E□□103MN35S		470	10X20	0.12	755	ESMG500E□□471MJ20S
	10,000	22X30	0.38	2,660	ESMG160E□□103MP30S		1,000	12.5X25	0.12	1,340	ESMG500E□□102MK25S
	12,000	20X40	0.42	2,900	ESMG160E□□123MN40S		1,500	20X20	0.12	1,570	ESMG500E□□152MN20S
	12,000	22X35	0.42	2,900	ESMG160E□□123MP35S		2,200	16X35.5	0.14	2,075	ESMG500E□□222MLP1S
	15,000	22X40	0.48	3,380	ESMG160E□□153MP40S		2,200	20X25	0.14	1,880	ESMG500E□□222MN25S
	22,000	25.4X40	0.62	3,720	ESMG160E□□223MQ40S		2,700	20X30	0.14	2,150	ESMG500E□□272MN30S

□□ : Lead forming / Taping code

(2/4)

CAT. No. E1001F



MINIATURE ALUMINUM ELECTROLYTIC CAPACITORS

Downsized, 85°C

SMG Series

◆ STANDARD RATINGS

□ is non solvent-proof.

WV (Vdc)	Cap (μF)	Case size φDXL(mm)	tanδ	Rated ripple current (mA rms/ 85°C, 120Hz)	Part No.	WV (Vdc)	Cap (μF)	Case size φDXL(mm)	tanδ	Rated ripple current (mA rms/ 85°C, 120Hz)	Part No.
50	3,300	18×35.5	0.16	2,500	ESMG500E□□332MMP1S	200	22	10×20	0.20	170	ESMG201E□□220MJ20S
	3,300	20×35	0.16	2,420	ESMG500E□□332MN35S		33	10×20	0.20	205	ESMG201E□□330MJ20S
	3,300	22×30	0.16	2,420	ESMG500E□□332MP30S		47	12.5×20	0.20	270	ESMG201E□□470MK20S
	3,900	20×40	0.16	2,590	ESMG500E□□392MN40S		100	16×25	0.20	475	ESMG201E□□101ML25S
	3,900	22×35	0.16	2,590	ESMG500E□□392MP35S		100	20×20	0.15	460	ESMG201E□□101MN20S
	4,700	22×40	0.18	2,960	ESMG500E□□472MP40S		180	20×25	0.15	660	ESMG201E□□181MN25S
63	6,800	25.4×40	0.22	3,360	ESMG500E□□682MQ40S		220	18×35.5	0.20	810	ESMG201E□□221MMP1S
	10	5×11	0.09	65	ESMG630E□□100ME11D		220	20×30	0.15	750	ESMG201E□□221MN30S
	22	5×11	0.09	100	ESMG630E□□220ME11D		270	20×30	0.15	830	ESMG201E□□271MN30S
	33	6.3×11	0.09	140	ESMG630E□□330MF11D		330	20×35	0.15	1,070	ESMG201E□□331MN35S
	47	6.3×11	0.09	170	ESMG630E□□470MF11D		330	22×30	0.15	1,070	ESMG201E□□331MP30S
	100	10×12.5	0.09	300	ESMG630E□□101MJC5S		390	20×40	0.15	1,190	ESMG201E□□391MN40S
	220	10×16	0.09	490	ESMG630E□□221MJ16S		390	22×30	0.15	1,160	ESMG201E□□391MP30S
	330	10×20	0.09	710	ESMG630E□□331MJ20S		470	22×40	0.15	1,350	ESMG201E□□471MP40S
	470	12.5×20	0.09	900	ESMG630E□□471MK20S		560	22×40	0.15	1,430	ESMG201E□□561MP40S
	820	20×20	0.09	1,370	ESMG630E□□821MN20S		680	25.4×40	0.15	1,620	ESMG201E□□681MQ40S
	1,000	16×25	0.09	1,300	ESMG630E□□102ML25S	250	2.2	6.3×11	0.20	32	ESMG251E□□2R2MF11D
	1,000	20×25	0.09	1,600	ESMG630E□□102MN25S		3.3	8×11.5	0.20	46	ESMG251E□□3R3MHB5D
	1,500	20×30	0.09	1,850	ESMG630E□□152MN30S		4.7	8×11.5	0.20	55	ESMG251E□□4R7MHB5D
	2,200	20×35	0.11	2,330	ESMG630E□□222MN35S		10	10×16	0.20	105	ESMG251E□□100MJ16S
	2,200	22×30	0.11	2,190	ESMG630E□□222MP30S		22	10×20	0.20	170	ESMG251E□□220MJ20S
	2,700	20×40	0.11	2,640	ESMG630E□□272MN40S		33	12.5×20	0.20	230	ESMG251E□□330MK20S
	3,300	22×40	0.13	2,810	ESMG630E□□332MP40S		47	12.5×25	0.20	295	ESMG251E□□470MK25S
	3,900	25.4×40	0.13	3,100	ESMG630E□□392MQ40S		82	20×20	0.15	420	ESMG251E□□820MN20S
	0.10	5×11	0.08	2.1	ESMG101E□□R10ME11D		100	16×31.5	0.20	515	ESMG251E□□101MLN3S
	0.22	5×11	0.08	4.7	ESMG101E□□R22ME11D		100	20×25	0.15	490	ESMG251E□□101MN25S
	0.33	5×11	0.08	7.0	ESMG101E□□R33ME11D		120	20×25	0.15	530	ESMG251E□□121MN25S
	0.47	5×11	0.08	10	ESMG101E□□R47ME11D		180	20×30	0.15	680	ESMG251E□□181MN30S
100	1.0	5×11	0.08	21	ESMG101E□□R10ME11D		220	18×40	0.20	825	ESMG251E□□221MM40S
	2.2	5×11	0.08	30	ESMG101E□□2R2ME11D		220	20×35	0.15	780	ESMG251E□□221MN35S
	3.3	5×11	0.08	40	ESMG101E□□3R3ME11D		220	22×30	0.15	820	ESMG251E□□221MP30S
	4.7	5×11	0.08	45	ESMG101E□□4R7ME11D		270	20×40	0.15	880	ESMG251E□□271MN40S
	10	6.3×11	0.08	75	ESMG101E□□100MF11D		270	22×35	0.15	880	ESMG251E□□271MP35S
	22	8×11.5	0.08	130	ESMG101E□□220MHB5D		330	22×40	0.15	1,060	ESMG251E□□331MP40S
	33	8×11.5	0.08	180	ESMG101E□□330MHB5D		390	25.4×40	0.15	1,200	ESMG251E□□391MQ40S
	47	10×12.5	0.08	230	ESMG101E□□470MJC5S	315	47	20×20	0.15	310	ESMG315E□□470MN20S
	100	10×20	0.08	370	ESMG101E□□101MJ20S		68	20×25	0.15	400	ESMG315E□□680MN25S
	220	12.5×25	0.08	620	ESMG101E□□221MK25S		82	20×25	0.15	440	ESMG315E□□820MN25S
	330	12.5×25	0.08	760	ESMG101E□□331MK25S		100	20×30	0.15	500	ESMG315E□□101MN30S
	330	20×20	0.08	870	ESMG101E□□331MN20S		120	20×30	0.15	550	ESMG315E□□121MN30S
	470	16×25	0.08	1,000	ESMG101E□□471ML25S		180	20×40	0.15	720	ESMG315E□□181MN40S
	680	20×30	0.08	1,360	ESMG101E□□681MN30S		180	22×35	0.15	720	ESMG315E□□181MP35S
	820	22×30	0.08	1,540	ESMG101E□□821MP30S		220	22×40	0.15	810	ESMG315E□□221MP40S
	1,000	18×40	0.08	1,380	ESMG101E□□102MM40S		270	25.4×40	0.15	920	ESMG315E□□271MQ40S
	1,000	20×35	0.08	1,720	ESMG101E□□102MN35S	350	0.47	6.3×11	0.24	15	ESMG351E□□R47MF11D
	1,200	22×40	0.08	1,980	ESMG101E□□122MP40S		1.0	6.3×11	0.24	22	ESMG351E□□R10MF11D
	1,800	25.4×40	0.08	2,490	ESMG101E□□182MQ40S		2.2	8×11.5	0.24	38	ESMG351E□□2R2MHB5D
	3.3	6.3×11	0.20	40	ESMG161E□□3R3MF11D		3.3	8×11.5	0.24	46	ESMG351E□□3R3MHB5D
	4.7	6.3×11	0.20	48	ESMG161E□□4R7MF11D		4.7	10×12.5	0.24	65	ESMG351E□□4R7MJC5S
	10	10×12.5	0.20	94	ESMG161E□□100MJC5S		10	10×20	0.24	115	ESMG351E□□100MJ20S
	22	10×20	0.20	170	ESMG161E□□220MJ20S		22	12.5×20	0.24	185	ESMG351E□□220MK20S
	33	10×20	0.20	205	ESMG161E□□330MJ20S		33	16×25	0.24	275	ESMG351E□□330ML25S
	47	12.5×20	0.20	270	ESMG161E□□470MK20S		47	16×25	0.24	325	ESMG351E□□470ML25S
	100	12.5×25	0.20	430	ESMG161E□□101MLN25S		47	20×20	0.15	310	ESMG351E□□470MN20S
	220	16×31.5	0.20	760	ESMG161E□□221MLN3S		68	20×25	0.15	400	ESMG351E□□680MN25S
	220	20×25	0.15	730	ESMG161E□□221MN25S		100	18×31.5	0.24	530	ESMG351E□□101MMN3S
160	330	18×35.5	0.20	995	ESMG161E□□331MMP1S		100	20×30	0.15	500	ESMG351E□□101MN30S
	330	20×30	0.15	920	ESMG161E□□331MN30S		120	20×35	0.15	560	ESMG351E□□121MN35S
	390	20×35	0.15	1,160	ESMG161E□□391MN35S		220	25.4×40	0.15	890	ESMG351E□□221MQ40S
	390	22×30	0.15	1,160	ESMG161E□□391MP30S	400	1.0	6.3×11	0.24	22	ESMG401E□□R10MF11D
	470	20×40	0.15	1,340	ESMG161E□□471MN40S		2.2	8×11.5	0.24	38	ESMG401E□□2R2MHB5D
	470	22×35	0.15	1,340	ESMG161E□□471MP35S		3.3	10×12.5	0.24	54	ESMG401E□□3R3MJC5S
	560	22×40	0.15	1,470	ESMG161E□□561MP40S		4.7	10×16	0.24	71	ESMG401E□□4R7MJ16S
	680	25.4×40	0.15	1,570	ESMG161E□□681MQ40S		10	10×20	0.24	115	ESMG401E□□100MJ20S
	3.3	6.3×11	0.20	40	ESMG201E□□3R3MF11D		22	12.5×25	0.24	205	ESMG401E□□220MK25S
	4.7	8×11.5	0.20	55	ESMG201E□□4R7MHB5D		33	16×25	0.24	275	ESMG401E□□330ML25S
	10	10×12.5	0.20	94	ESMG201E□□100MJC5S		33	20×20	0.15	260	ESMG401E□□330MN20S

□ : Lead forming / Taping code

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CAT. No. E1001F



MINIATURE ALUMINUM ELECTROLYTIC CAPACITORS

Downsized, 85°C

SMG Series

◆STANDARD RATINGS

□ is non solvent-proof.

WV (Vdc)	Cap (μF)	Case size φDXL(mm)	tanδ	Rated ripple current (mA rms/ 85°C, 120Hz)	Part No.	WV (Vdc)	Cap (μF)	Case size φDXL(mm)	tanδ	Rated ripple current (mA rms/ 85°C, 120Hz)	Part No.
400	47	16×31.5	0.24	350	ESMG401E□□470MLN3S	450	22	16×25	0.24	165	ESMG451E□□220ML25S
	56	20×25	0.15	350	ESMG401E□□560MN25S		22	20×20	0.20	180	ESMG451E□□220MN20S
	68	20×30	0.15	420	ESMG401E□□680MN30S		33	16×31.5	0.24	215	ESMG451E□□330MLN3S
	100	20×35	0.15	520	ESMG401E□□101MN35S		33	20×25	0.20	240	ESMG451E□□330MN25S
	100	22×30	0.15	520	ESMG401E□□101MP30S		47	16×35.5	0.24	265	ESMG451E□□470MLP1S
	120	20×40	0.15	580	ESMG401E□□121MN40S		47	20×25	0.20	290	ESMG451E□□470MN25S
	120	22×35	0.15	580	ESMG401E□□121MP35S		56	20×30	0.20	320	ESMG451E□□560MN30S
	180	25.4×40	0.15	790	ESMG401E□□181MQ40S		68	20×35	0.20	370	ESMG451E□□680MN35S
450	0.47	10×12.5	0.24	13	ESMG451E□□R47MJC5S	68	22×30	0.20	370	ESMG451E□□680MP30S	
	1.0	10×12.5	0.24	19	ESMG451E□□1R0MJC5S	82	20×40	0.20	420	ESMG451E□□820MN40S	
	2.2	10×12.5	0.24	32	ESMG451E□□2R2MJC5S	82	22×35	0.20	420	ESMG451E□□820MP35S	
	3.3	10×16	0.24	44	ESMG451E□□3R3MJ16S	100	22×40	0.20	470	ESMG451E□□101MP40S	
	4.7	10×20	0.24	56	ESMG451E□□4R7MJ20S	120	25.4×40	0.20	520	ESMG451E□□121MQ40S	
	10	12.5×20	0.24	91	ESMG451E□□100MK20S						

□□ : Lead forming / Taping code

◆RATED RIPPLE CURRENT MULTIPLIERS

●Frequency Multipliers

(φ5 to φ18)

Capacitance (μF)	Frequency (Hz)	50	120	300	1k	10k	100k
0.1 to 4.7		0.65	1.00	1.35	1.75	2.30	2.50
10 to 47		0.75	1.00	1.25	1.50	1.75	1.80
100 to 1,000		0.80	1.00	1.15	1.30	1.40	1.50
2,200 to		0.85	1.00	1.03	1.05	1.08	1.08

(φ20 to φ25.4)

Rated Voltage (Vr)	Frequency (Hz)	50	120	300	1k	10k	100k
6.3 to 50		0.95	1.00	1.03	1.05	1.08	1.08
63 to 100		0.92	1.00	1.07	1.13	1.19	1.20
160 to 250		0.81	1.00	1.17	1.32	1.45	1.50
315 to 450		0.77	1.00	1.16	1.30	1.41	1.43

The endurance of capacitors is shortened with internal heating produced by ripple current at the rate of halving the lifetime with every 5°C rise. When long life performance is required in actual use, the rms ripple current has to be reduced.



MINIATURE ALUMINUM ELECTROLYTIC CAPACITORS YK

YK SERIES

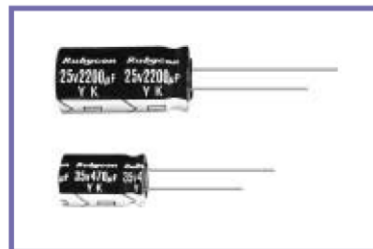
85°C Standard

◆FEATURES

- Load life : 85°C 2000 hours.

YK

105°C Version

YXA

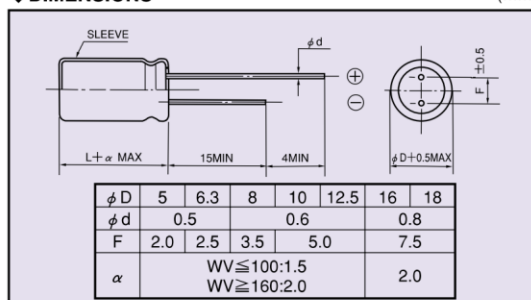
◆SPECIFICATIONS

Items	Characteristics	
Category Temperature Range	-40~+85°C	-25~+85°C
Rated Voltage Range	6.3~250V.DC	350~450V.DC
Capacitance Tolerance	±20%(20°C, 120Hz)	
Leakage Current(MAX)	6.3~100V.DC	160~450V.DC
	I=0.01CV or 3 µA whichever is greater. (After 2 minutes application of rated voltage)	CV≤1000 I=0.1CV+40 µA (1minute) I=0.03CV+15 µA (5minutes)
		CV>1000 I=0.04CV+100 µA (1minute) I=0.02CV+25 µA (5minutes)
	I=Leakage Current(µA)	C=Rated Capacitance(µF) V=Rated Voltage(V)
Dissipation Factor(MAX)	Rated Voltage(V)	6.3 10 16 25 35 50 63 100 160 200 250 350 400 450 (20°C, 120Hz)
	tan δ	0.26 0.22 0.18 0.16 0.14 0.12 0.10 0.08 0.20 0.20 0.20 0.20 0.20 0.20
	When rated capacitance is over 1000 µF, tan δ shall be added 0.02 to the listed value with increase of every 1000 µF.	
Endurance	After applying rated voltage with rated ripple current for 2000hrs at 85°C, the capacitors shall meet the following requirements.	
	Capacitance Change	Within ±25% of the initial value.
	Dissipation Factor	Not more than 200% of the specified value.
	Leakage Current	Not more than the specified value.
Low Temperature Stability Impedance Ratio(MAX)	Rated Voltage(V)	6.3 10 16 25 35 50 63 100 160 200 250 350 400 450 (120Hz)
	Z(-25°C)/Z(20°C)	4 3 2 2 2 2 2 2 3 3 3 5 5 7
	Z(-40°C)/Z(20°C)	8 6 4 4 3 3 3 3 - - - - -

◆DIMENSIONS

(mm)

◆MULTIPLIER FOR RIPPLE CURRENT



Frequency coefficient

Frequency (Hz)		60(50)	120	500	1k	10k≤
Coefficient	0.1~1 μF	0.50	1.00	1.20	1.30	1.50
	2.2~4.7 μF	0.65	1.00	1.20	1.30	1.50
	10~47 μF	0.80	1.00	1.20	1.30	1.50
	100~1000μF	0.80	1.00	1.10	1.15	1.20
	2200~22000μF	0.80	1.00	1.05	1.10	1.15

◆PART NUMBER

Rated Voltage YK Rated Capacitance Capacitance Tolerance Option Lead Forming D×L Case Size



MINIATURE ALUMINUM ELECTROLYTIC CAPACITORS YK

◆STANDARD SIZE, RATED RIPPLE CURRENT

Size ϕ D×L(mm), Ripple Current (mA r.m.s./85°C, 120Hz)

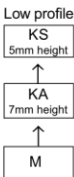
WV(V.DC) Cap(μF)	6.3 (0J)		10 (1A)		16 (1C)		25 (1E)		35 (1V)		50 (1H)		63 (1J)	
	Size	Ripple	Size	Ripple	Size	Ripple	Size	Ripple	Size	Ripple	Size	Ripple	Size	Ripple
0.1											5×11	1.1		
0.15											5×11	1.5		
0.22											5×11	2.5		
0.33											5×11	4		
0.47											5×11	7		
1											5×11	13		
2.2											5×11	23		
3.3											5×11	35		
4.7											5×11	41		
10											5×11	60	5×11	70
22									5×11	90	5×11	95	5×11	110
33							5×11	98	5×11	110	5×11	130	6.3×11	140
47					5×11	115	5×11	120	5×11	135	6.3×11	160	6.3×11	190
100	5×11	135	5×11	140	5×11	175	5×11	185	6.3×11	215	8×11.5	270	8×11.5	290
220	5×11	220	5×11	230	6.3×11	280	6.3×11	310	8×11.5	370	10×12.5	435	10×16	490
330	6.3×11	280	6.3×11	310	8×11.5	380	8×11.5	410	10×12.5	500	10×16	590	10×20	680
470	6.3×11	360	6.3×11	400	8×11.5	460	10×12.5	550	10×16	680	10×20	760	12.5×20	880
1000	8×11.5	590	10×12.5	660	10×16	800	10×20	970	12.5×20	1180	12.5×25	1350	16×25	1350
2200	10×16	920	10×20	1090	12.5×20	1320	12.5×25	1570	16×25	1810	16×35.5	2110	18×35.5	2300
3300	10×20	1200	12.5×20	1440	12.5×25	1670	16×25	2000	16×35.5	2300	18×35.5	2540		
4700	12.5×20	1550	12.5×25	1800	16×25	2120	16×31.5	2440	18×35.5	2740				
6800	12.5×25	1920	16×25	2250	16×31.5	2540	18×35.5	2900						
10000	16×25	2370	16×35.5	2710	18×35.5	2950								
15000	16×35.5	2880	18×35.5	3110										
22000	18×40	3350												

WV(V.DC) Cap(μF)	100 (2A)		160 (2C)		200 (2D)		250 (2E)		350 (2V)		400 (2G)		450 (2W)	
	Size	Ripple	Size	Ripple	Size	Ripple	Size	Ripple	Size	Ripple	Size	Ripple	Size	Ripple
0.47	5×11	8					6.3×11	8	6.3×11	8	6.3×11	8	8×11.5	8
1	5×11	16					6.3×11	16	6.3×11	16	6.3×11	16	8×11.5	16
2.2	5×11	35					6.3×11	30	8×11.5	31	10×12.5	31	10×12.5	29
3.3	5×11	45			6.3×11	36	8×11.5	45	10×12.5	45	10×12.5	43	10×16	40
4.7	5×11	50	6.3×11	45	8×11.5	51	8×11.5	54	10×12.5	56	10×16	56	10×20	56
10	5×11	75	8×11.5	83	10×12.5	85	10×16	90	10×20	100	12.5×20	90	12.5×20	84
22	6.3×11	135	10×16	133	10×20	135	12.5×20	150	12.5×25	185	12.5×25	180	16×25	140
33	8×11.5	185	10×20	180	12.5×20	205	12.5×20	205	16×25	230	16×25	230	16×31.5	180
47	10×12.5	235	12.5×20	230	12.5×20	230	12.5×25	260	16×31.5	280	16×31.5	280	16×35.5	220
100	10×20	380	12.5×25	385	16×25	400	16×31.5	450	18×40	420	18×40	420		
220	12.5×25	629	16×35.5	645	18×35.5	680								
330	12.5×25	760	18×35.5	760										
470	16×25	950												
1000	18×40	1350												

Radial Lead Type

Series: KS Type : A

- Features Endurance : 85°C 1000 h
5 mm height



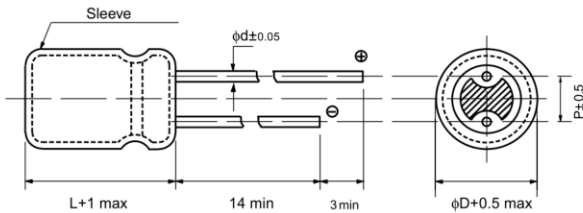
Malaysia



■ Specifications

Category temp. range	-40 to +85°C								
Rated W.V. Range	4 to 50 V .DC								
Nominal Cap. Range	0.1 to 330 μ F								
Capacitance Tolerance	±20 % (120Hz/+20°C)								
DC Leakage Current	I ≤ 0.01 CV or 3(μ A) after 2 minutes (Whichever is greater)								
tan δ	Please see the attached standard products list.								
Characteristics at Low Temperature	W.V. (V)	4	6.3	10	16	25	35	50	(Impedance ratio at 120 Hz)
	Z(-25°C)/Z(+20°C)	7	4	3	2	2	2	2	
	Z(-40°C)/Z(+20°C)	15	8	6	4	4	3	3	
Endurance	After applying rated working voltage for 1000 hours at +85°C and then being stabilized at +20°C, capacitors shall meet the following limits.								
	Capacitance change	± 20% of initial measured value (4V. : ±30%)							
	tan δ	≤200 % of initial specified value							
	DC leakage current	≤initial specified value							
Shelf Life	After storage for 1000 hours at +85±2 °C with no voltage applied and then being stabilized at +20 °C, capacitors shall meet the limits specified in Endurance.(With voltage treatment)								

■ Dimensions in mm (not to scale)



Body Dia.φD	3	4	5	6.3	8
Lead Dia.φd	0.4	0.45	0.45	0.45	0.45
Lead Space P	1.0	1.5	2.0	2.5	2.5

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■ Standard Products

W.V.	Cap. (±20%)	Case size		Specification		Lead Length				Part No.	Min.Packaging Q'ty	
		Dia.	Length	Ripple current (120Hz) (+85°C) (mA)	$\tan \delta$ (120Hz) (+20°C)	Lead Dia.	Lead Space				Straight Leads	Taping
(V)	(μF)	(mm)	(mm)			(mm)	Straight (mm)	Taping ⌀B (mm)	Taping ⌀i (mm)		(pcs)	(pcs)
4	22	3	5	19	0.35	0.40	1.0	5.0	2.5	ECEA0GKK220()	200	2000
	33	4	5	26	0.35	0.45	1.5	5.0	2.5	ECEA0GKS330()	200	2000
	47	4	5	34	0.35	0.45	1.5	5.0	2.5	ECEA0GKS470()	200	2000
	100	5	5	61	0.35	0.45	2.0	5.0	2.5	ECEA0GKS101()	200	2000
	220	6.3	5	82	0.35	0.45	2.5	5.0	2.5	ECEA0GKS221()	200	2000
6.3	22	4	5	29	0.24	0.45	1.5	5.0	2.5	ECEA0JKS220()	200	2000
	33	5	5	38	0.24	0.45	2.0	5.0	2.5	ECEA0JKS330()	200	2000
	47	5	5	46	0.24	0.45	2.0	5.0	2.5	ECEA0JKS470()	200	2000
	100	6.3	5	71	0.24	0.45	2.5	5.0	2.5	ECEA0JKS101()	200	2000
	330	8	5	130	0.24	0.45	2.5		2.5	ECEA0JKS331()	200	1000
		8	5	130	0.24	0.45		5.0		ECEA0JKS331Q		1000
10	22	5	5	35	0.20	0.45	2.0	5.0	2.5	ECEA1AKS220()	200	2000
	33	5	5	43	0.20	0.45	2.0	5.0	2.5	ECEA1AKS330()	200	2000
	47	6.3	5	65	0.20	0.45	2.5	5.0	2.5	ECEA1AKS470()	200	2000
	100	6.3	5	80	0.20	0.45	2.5	5.0	2.5	ECEA1AKS101()	200	2000
	220	8	5	120	0.20	0.45	2.5		2.5	ECEA1AKS221()	200	1000
		8	5	120	0.20	0.45		5.0		ECEA1AKS221Q		1000
16	10	3	5	20	0.16	0.40	1.0	5.0	2.5	ECEA1CKK100()	200	2000
		4	5	28	0.16	0.45	1.5	5.0	2.5	ECEA1CKS100()	200	2000
	22	5	5	39	0.16	0.45	2.0	5.0	2.5	ECEA1CKS220()	200	2000
	33	6.3	5	60	0.16	0.45	2.5	5.0	2.5	ECEA1CKS330()	200	2000
	47	6.3	5	70	0.16	0.45	2.5	5.0	2.5	ECEA1CKS470()	200	2000
	100	8	5	91	0.16	0.45	2.5		2.5	ECEA1CKS101()	200	1000
		8	5	91	0.16	0.45		5.0		ECEA1CKS101Q		1000
25	2.2	3	5	8	0.14	0.40	1.0	5.0	2.5	ECEA1EKK2R2()	200	2000
	3.3	3	5	10	0.14	0.40	1.0	5.0	2.5	ECEA1EKK3R3()	200	2000
	4.7	3	5	12	0.14	0.40	1.0	5.0	2.5	ECEA1EKK4R7()	200	2000
		4	5	22	0.14	0.45	1.5	5.0	2.5	ECEA1EKS4R7()	200	2000
	10	5	5	28	0.14	0.45	2.0	5.0	2.5	ECEA1EKS100()	200	2000
	22	6.3	5	55	0.14	0.45	2.5	5.0	2.5	ECEA1EKS220()	200	2000
	33	6.3	5	65	0.14	0.45	2.5	5.0	2.5	ECEA1EKS330()	200	2000
	100	8	5	85	0.14	0.45	2.5		2.5	ECEA1EKS101()	200	2000
	8	5	85	0.14	0.45		5.0		ECEA1EKS101Q		1000	
35	3.3	4	5	16	0.12	0.45	1.5	5.0	2.5	ECEA1VKS3R3()	200	2000
	4.7	4	5	22	0.12	0.45	1.5	5.0	2.5	ECEA1VKS4R7()	200	2000
	10	5	5	30	0.12	0.45	2.0	5.0	2.5	ECEA1VKS100()	200	2000
	22	6.3	5	60	0.12	0.45	2.5	5.0	2.5	ECEA1VKS220()	200	2000
	33	8	5	65	0.12	0.45	2.5		2.5	ECEA1VKS330()	200	1000
		8	5	65	0.12	0.45		5.0		ECEA1VKS330Q		1000
	47	8	5	85	0.12	0.45	2.5		2.5	ECEA1VKS470()	200	1000
		8	5	85	0.12	0.45		5.0		ECEA1VKS470Q		1000
50	0.1	3	5	1	0.10	0.40	1.0	5.0	2.5	ECEA1HK0R1()	200	2000
		4	5	1	0.10	0.45	1.5	5.0	2.5	ECEA1HKS0R1()	200	2000

When requesting taped product, please put the letter "B" or "i" between the "()". Lead wire pitch B=5mm, i=2.5mm.
The taping dimensions are explained on p.43 of our Catalog. Please use it as a reference guide.
Endurance : 85°C 1000h

Design, Specifications are subject to change without notice. Ask factory for technical specifications before purchase and/or use.
Whenever a doubt about safety arises from this product, please inform us immediately for technical consultation without fail.

■ Standard Products

W.V.	Cap. (±20%)	Case size		Specification		Lead Length				Part No.	Min.Packaging Q'ty	
		Dia.	Length	Ripple current (120Hz) (+85°C) (mA)	$\tan \delta$ (120Hz) (+20°C)	Lead Dia.	Lead Space				Straight Leads	Taping
(V)	(μF)	(mm)	(mm)			(mm)	Straight (mm)	Taping *B	Taping *i		(pcs)	(pcs)
50	0.22	3	5	2	0.10	0.40	1.0	5.0	2.5	ECEA1HKKR22()	200	2000
		4	5	2	0.10	0.45	1.5	5.0	2.5	ECEA1HKSR22()	200	2000
	0.33	3	5	3	0.10	0.40	1.0	5.0	2.5	ECEA1HKKR33()	200	2000
		4	5	3	0.10	0.45	1.5	5.0	2.5	ECEA1HKSR33()	200	2000
	0.47	3	5	5	0.10	0.40	1.0	5.0	2.5	ECEA1HKKR47()	200	2000
		4	5	5	0.10	0.45	1.5	5.0	2.5	ECEA1HKSR47()	200	2000
	1	3	5	8	0.10	0.40	1.0	5.0	2.5	ECEA1HKK010()	200	2000
		4	5	10	0.10	0.45	1.5	5.0	2.5	ECEA1HKS010()	200	2000
	2.2	4	5	16	0.10	0.45	1.5	5.0	2.5	ECEA1HKS2R2()	200	2000
	3.3	4	5	16	0.10	0.45	1.5	5.0	2.5	ECEA1HKS3R3()	200	2000
	4.7	5	5	23	0.10	0.45	2.0	5.0	2.5	ECEA1HKS4R7()	200	2000
	10	6.3	5	35	0.10	0.45	2.5	5.0	2.5	ECEA1HKS100()	200	2000
	22	8	5	60	0.10	0.45	2.5		2.5	ECEA1HKS220()	200	1000
		8	5	60	0.10	0.45		5.0		ECEA1HKS220Q		1000

When requesting taped product, please put the letter "B" or "i" between the "()". Lead wire pitch B=5mm, i=2.5mm.
The taping dimensions are explained on p.43 of our Catalog. Please use it as a reference guide.
Endurance : 85°C 1000h

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Design, Specifications are subject to change without notice. Ask factory for technical specifications before purchase and/or use.
Whenever a doubt about safety arises from this product, please inform us immediately for technical consultation without fail.

Specifications

This appendix lists the specifications of the NI ELVIS. These specifications are typical after a 30 minute warm-up time, at 23 °C, unless otherwise noted.



Note NI ELVIS includes a calibration utility so that you can recalibrate the circuitry for the variable power supplies and function generator.

Analog Input

Refer to the *Analog Input* section of the DAQ device specifications documentation.

Arbitrary Waveform Generator¹/Analog Output

Number of output channels	2
Maximum frequency	DC to DAQ device AO update rate/10
Full-power bandwidth	27 kHz
Output amplitude.....	±10 V
Resolution	12 bits or 16 bits, DAQ device dependent
Output drive current	25 mA
Output impedance	1 Ω
Slew rate.....	1.5 V/ μ s

¹ The Arbitrary Waveform Generator does not work with the NI 6014, NI 6024E, or NI 6036E.

Bode Analyzer

Amplitude accuracy	12 or 16 bits, DAQ device dependent
Phase accuracy	1 degree
Frequency range	5 Hz to 35 kHz

DC Power Supplies

+15 V Supply

Output current	Self-resetting circuitry, not to shut down at or below 500 mA
Output voltage	15 V at $\pm 5\%$ no load
Line regulation	0.5% max
Load regulation	1% typ, 5% max, 0 to full load ¹
Ripple and noise	1%

–15 V Supply

Output current	Self-resetting circuitry, not to shut down at or below 500 mA ²
Output voltage	–15 V at $\pm 5\%$ no load
Line regulation	0.5% max
Load regulation	1% typ, 5% max, 0 to full load ¹
Ripple and noise	1%

¹ Full load refers to the maximum current output of the power supply. Load regulation is linear over 0 to full load; therefore at 50% of full load, the output drops by 50% of the load regulation specification.

² Total current drawn from –15 V supply and variable power supplies cannot exceed 500 mA.

+5 V Supply

Output current	Self-resetting circuitry, not to shut down at or below 2 A
Output voltage	+5 V at $\pm 5\%$ no load
Line regulation	0.50% max
Load regulation	22% typ, 30% max 0 to full load ¹
Ripple and noise	1%

Digital I/O**Resolution**

Digital input channels	8 bits
Digital output channels	8 bits
Digital addressing	4 bits

Digital Input

I_I	1.0 μ A max
V_{IH}	2.0 V min
V_{IL}	0.8 V max

Digital Output

V_{OH}	3.38 V min at 6 mA 4.4 V min at 20 μ A
V_{OL}	0.86 V max at 6 mA 0.1 V max at 20 μ A

¹ Full load refers to the maximum current output of the power supply. Load regulation is linear over 0 to full load; therefore at 50% of full load, the output drops by 50% of the load regulation specification.

DMM**Capacitance Measurement**

Accuracy	1%
Range	50 pF to 500 μ F in three ranges
Test frequency	120 or 950 Hz, software-selectable
Max test frequency voltage.....	1 V _{p-p} sine wave, software-selectable

Continuity Measurement

Resistance threshold	15 Ω max, software-selectable
Test voltage.....	3.89 V, software-selectable

Current Measurement

Accuracy	
AC.....	0.25% $\pm$ 3 mA ^{1, 2}
DC.....	0.25% $\pm$ 3 mA ²
Common-mode voltage	$\pm$ 20 V max
Common-mode rejection	70 dB min
Range	$\pm$ 250 mA in two ranges, max
Resolution	12 or 16 bits, DAQ device dependent
Shunt resistance	0.5 Ω
Voltage burden	2 mV/mA

Diode Measurement³

Voltage threshold.....	1.1 V max
------------------------	-----------

¹ 25 Hz to 10 kHz

² Proper null correction when measuring on high common-mode voltage can reduce the $\pm$ 3 mA offset error to 200 μ A of noise.

³ The Two-Wire Current Voltage Analyzer SFP is the recommended instrument for diode measurement.

Inductance Measurement

Accuracy	1%
Range	100 μ H to 100 mH
Test frequency	950 Hz, software-selectable
Test frequency voltage	1 V _{p-p} sine wave, software-selectable

Resistance Measurement

Accuracy	1%
Range	5 Ω to 3 M Ω , in four ranges
Test frequency	120 Hz, software-selectable
Test frequency voltage	1 V _{p-p} sine wave, software-selectable

Voltage Measurement

AC

Accuracy	0.3% $\pm$ 0.001% full-scale ¹
Range	$\pm$ 14 V _{rms} in four ranges, max

DC

Accuracy	0.3% $\pm$ 0.001% full-scale, max
Range	$\pm$ 20 V in four ranges, max

Input impedance	1 M Ω
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Dynamic Signal Analyzer

Input range	$\pm$ 10 V in four ranges
Input resolution	12 or 16 bits, DAQ device dependant

¹ 100 Hz to 10 kHz

Function Generator

Frequency range	5 Hz to 250 kHz in five ranges
Software-controlled frequency resolution	0.8%
Frequency set point accuracy.....	3% of range, max
Frequency read back accuracy	$\pm 0.01\%$
Output amplitude	± 2.5 V
Software amplitude resolution.....	8 bits
Offset range	± 5 V
AM voltage	10 V, max
Amplitude modulation	Up to 100%
FM voltage.....	10 V, max
Amplitude flatness	
To 50 kHz	0.5 dB
To 250 kHz	3 dB
Frequency modulation	$\pm 5\%$ of full-scale, max
Output impedance.....	50 Ω guaranteed. Refer to Appendix C, <i>Theory of Operation</i> , for more information about the output impedance configuration options.

Impedance Analyzer

Measurement frequency range.....	5 Hz to 35 kHz
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Oscilloscope

Refer to the *Analog Input* section of the DAQ device specifications documentation.

Two-Wire Current-Voltage AnalyzerCurrent range..... ± 10 mAVoltage sweep range ± 10 V**Three-Wire Current-Voltage Analyzer¹**Minimum base current increment 15 μ A

Maximum collector current..... 10 mA

Maximum collector voltage 10 V

Variable Power Supplies**Positive Supply**

Output voltage..... 0 to 12 V

Ripple and noise 0.25%

Software-controlled resolution..... 7 bits

Current limiting..... 0.5 V at 160 mA,
5 V at 275 mA,
12 V at 450 mA**Negative Supply**

Output voltage..... 0 to -12 V

Ripple and noise 0.25%

Software-controlled resolution..... 7 bits

Current limiting..... 0.5 V at 130 mA,
5 V at 290 mA,
12 V at 450 mA²¹ This SFP instrument is intended for use only with NPN BJT transistors.² Total current drawn from -15 V and the negative variable power supply cannot exceed 500 mA.

Physical

Dimensions	31.75 × 30.48 × 12.7 cm (12.5 × 12.0 × 5 in.)
Weight	4.08 kg (9.0 lb)
Prototyping board Suggested field-wiring diameter.....	22 AWG, single connector

Maximum Working Voltage

Maximum working voltage refers to the signal voltage plus the common-mode voltage.

Channel-to-earth±20 V, Measurement Category I

Channel-to-channel.....±20 V, Measurement Category I



Caution Do not use for connection to signals in Categories II, III, or IV.

Environmental

Operating temperature	0 to 40 °C
Storage temperature.....	–20 to 70 °C
Humidity	10 to 90% relative humidity, noncondensing
Maximum altitude.....	2,000 m
Pollution Degree (indoor use only)	2

Safety

This product meets the requirements of the following standards of safety for electrical equipment for measurement, control, and laboratory use:

- IEC 61010-1, EN 61010-1
- UL 61010-1, CSA 61010-1



Note For UL and other safety certifications, refer to the product label or the [Online Product Certification](#) section.

Electromagnetic Compatibility

This product meets the requirements of the following EMC standards for electrical equipment for measurement, control, and laboratory use:

- EN 61326 (IEC 61326): Class A emissions; Basic immunity
- EN 55011 (CISPR 11): Group 1, Class A emissions
- AS/NZS CISPR 11: Group 1, Class A emissions
- FCC 47 CFR Part 15B: Class A emissions
- ICES-001: Class A emissions



Note For the standards applied to assess the EMC of this product, refer to the *Online Product Certification* section.



Note For EMC compliance, operate this product according to the documentation.

CE Compliance

This product meets the essential requirements of applicable European Directives as follows:

- 2006/95/EC; Low-Voltage Directive (safety)
- 2004/108/EC; Electromagnetic Compatibility Directive (EMC)

Online Product Certification

Refer to the product Declaration of Conformity (DoC) for additional regulatory compliance information. To obtain product certifications and the DoC for this product, visit ni.com/certification, search by model number or product line, and click the appropriate link in the Certification column.

Environmental Management

NI is committed to designing and manufacturing products in an environmentally responsible manner. NI recognizes that eliminating certain hazardous substances from our products is beneficial to the environment and to NI customers.

For additional environmental information, refer to the *NI and the Environment* Web page at ni.com/environment. This page contains the environmental regulations and directives with which NI complies, as well as other environmental information not included in this document.

Waste Electrical and Electronic Equipment (WEEE)



EU Customers At the end of the life cycle, all products *must* be sent to a WEEE recycling center. For more information about WEEE recycling centers and National Instruments WEEE initiatives, visit ni.com/environment/weee.

电子信息产品污染控制管理办法（中国 RoHS）



中国客户 National Instruments 符合中国电子信息产品中限制使用某些有害物质指令 (RoHS)。关于 National Instruments 中国 RoHS 合规性信息，请登录 ni.com/environment/rohs_china。(For information about China RoHS compliance, go to ni.com/environment/rohs_china.)

DEVICE SPECIFICATIONS

NI 6251

M Series Data Acquisition: 16 AI, 1.25 MS/s, 24 DIO, 2 AO

The following specifications are typical at 25 °C, unless otherwise noted. For more information about the NI 6251, refer to the *M Series User Guide* available at ni.com/manuals.

Analog Input

Number of channels	8 differential or 16 single ended
ADC resolution	16 bits
DNL	No missing codes guaranteed
INL	Refer to the <i>AI Absolute Accuracy</i> section
Sample rate	
Single channel maximum	1.25 MS/s
Multichannel maximum (aggregate)	1.00 MS/s
Minimum	No minimum
Timing resolution	50 ns
Timing accuracy	50 ppm of sample rate
Input coupling	DC
Input range	± 0.1 V, ± 0.2 V, ± 0.5 V, ± 1 V, ± 2 V, ± 5 V, ± 10 V
Maximum working voltage for analog inputs (signal + common mode)	± 11 V of AI GND
CMRR (DC to 60 Hz)	100 dB
Input impedance	
Device on	
AI+ to AI GND	>10 G Ω in parallel with 100 pF
AI- to AI GND	>10 G Ω in parallel with 100 pF



Device off	
AI+ to AI GND	820 Ω
AI- to AI GND	820 Ω
Input bias current	± 100 pA
Crosstalk (at 100 kHz)	
Adjacent channels	-75 dB
Non-adjacent channels	-95 dB
Small signal bandwidth (-3 dB)	1.7 MHz
Input FIFO size	4,095 samples
Scan list memory	4,095 entries
Data transfers	
PCI/PCI Express/PXI/PXI Express	DMA (scatter-gather), interrupts, programmed I/O
USB	USB Signal Stream, programmed I/O
Overvoltage protection for all analog input and sense channels	
Device on	± 25 V for up to four AI pins
Device off	± 15 V for up to four AI pins
Input current during overvoltage condition	± 20 mA maximum/AI pin

Settling Time for Multichannel Measurements

Table 1. Settling Time for Multichannel Measurements

Range	± 60 ppm of Step (± 4 LSB for Full-Scale Step)	± 15 ppm of Step (± 1 LSB for Full-Scale Step)
± 1 V, ± 2 V, ± 5 V, ± 10 V	1 μ s	1.5 μ s
± 0.5 V	1.5 μ s	2 μ s
± 0.1 V, ± 0.2 V	2 μ s	8 μ s

Typical Performance Graphs

Figure 1. Settling Error versus Time for Different Source Impedances

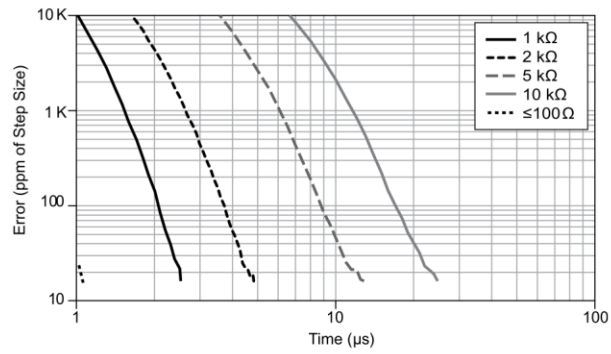


Figure 2. AI Small Signal Bandwidth

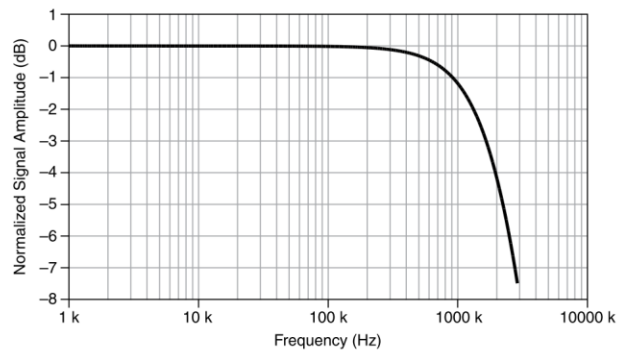
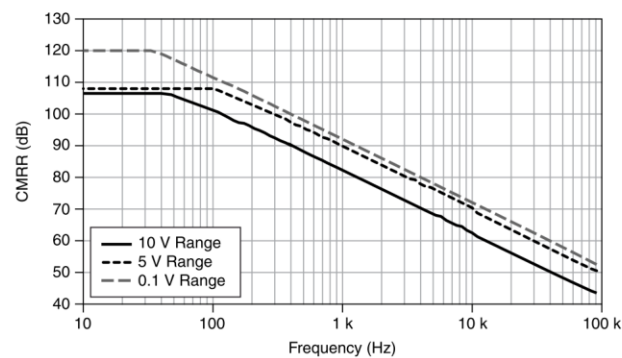


Figure 3. AI CMRR



AI Absolute Accuracy

Note Accuracies listed are valid for up to two years from the device external calibration.

Table 2. AI Absolute Accuracy

Nominal Range Positive Full Scale	Nominal Range Negative Full Scale	Residual Gain Error (ppm of Reading)	Residual Offset Error (ppm of Range)	Offset Tempco (ppm of Range/°C)	Random Noise, σ (μVrms)	Absolute Accuracy at Full Scale (μV)	Sensitivity (μV)
10	-10	60	20	21	280	1,920	112.0
5	-5	70	20	21	140	1,010	56.0
2	-2	70	20	24	57	410	22.8
1	-1	80	20	27	32	220	12.8
0.5	-0.5	90	40	34	21	130	8.4
0.2	-0.2	130	80	55	16	74	6.4
0.1	-0.1	150	150	90	15	52	6.0



Note Sensitivity is the smallest voltage change that can be detected. It is a function of noise.

Gain tempco	13 ppm/°C
Reference tempco	1 ppm/°C
INL error	60 ppm of range

AI Absolute Accuracy Equation

$$\text{AbsoluteAccuracy} = \text{Reading} \cdot (\text{GainError}) + \text{Range} \cdot (\text{OffsetError}) + \text{NoiseUncertainty}$$

$$\text{GainError} = \text{ResidualAIGainError} + \text{GainTempco} \cdot (\text{TempChangeFromLastInternalCal}) + \text{ReferenceTempco} \cdot (\text{TempChangeFromLastExternalCal})$$

$$\text{OffsetError} = \text{ResidualAIOffsetError} + \text{OffsetTempco} \cdot (\text{TempChangeFromLastInternalCal}) + \text{INLError}$$

$$\text{NoiseUncertainty} = \frac{\text{Random Noise} \cdot 3}{\sqrt{100}} \text{ for a coverage factor of } 3 \sigma \text{ and averaging } 100 \text{ points.}$$

AI Absolute Accuracy Example

Absolute accuracy at full scale on the analog input channels is determined using the following assumptions:

- TempChangeFromLastExternalCal = 10 °C
- TempChangeFromLastInternalCal = 1 °C
- number_of_readings = 100
- CoverageFactor = 3 σ

For example, on the 10 V range, the absolute accuracy at full scale is as follows:

$$\text{GainError} = 60 \text{ ppm} + 13 \text{ ppm} \cdot 1 + 1 \text{ ppm} \cdot 10 = 83 \text{ ppm}$$

$$\text{OffsetError} = 20 \text{ ppm} + 21 \text{ ppm} \cdot 1 + 60 \text{ ppm} = 101 \text{ ppm}$$

$$\text{NoiseUncertainty} = \frac{275 \mu\text{V} \cdot 3}{\sqrt{100}} = 83 \mu\text{V}$$

$$\text{AbsoluteAccuracy} = 10 \text{ V} \cdot (\text{GainError}) + 10 \text{ V} \cdot (\text{OffsetError}) + \text{NoiseUncertainty} = 1,920 \mu\text{V}$$

Analog Triggers

Number of triggers	1
Source	AI <0..15>, APFI 0
Functions	Start Trigger, Reference Trigger, Pause Trigger, Sample Clock, Convert Clock, Sample Clock Timebase

Source level	
AI <0..15>	±Full scale
APFI 0	±10 V
Resolution	10 bits, 1 in 1,024
Modes	Analog edge triggering, analog edge triggering with hysteresis, and analog window triggering
Bandwidth (-3 dB)	
AI <0..15>	3.4 MHz
APFI 0	3.9 MHz
Accuracy	±1%
APFI 0 characteristics	
Input impedance	10 kΩ
Coupling	DC
Protection, power on	±30 V
Protection, power off	±15 V

Analog Output

Number of channels	2
DAC resolution	16 bits
DNL	±1 LSB
Monotonicity	16 bit guaranteed
Accuracy	Refer to the AO Absolute Accuracy section
Maximum update rate	
1 channel	2.86 MS/s
2 channels	2.00 MS/s per channel
Timing accuracy	50 ppm of sample rate
Timing resolution	50 ns
Output range	±5 V, ±10 V, ±external reference on APFI 0
Output coupling	DC
Output impedance	0.2 Ω
Output current drive	±5 mA
Overdrive protection	±25 V
Overdrive current	20 mA

Power-on state	$\pm 5 \text{ mV}^1$
Power-on glitch	1.5 V peak for 1.5 s
Output FIFO size	8,191 samples shared among channels used
Data transfers	
PCI/PCI Express/PXI/PXI Express	DMA (scatter-gather), interrupts, programmed I/O
USB	USB Signal Stream, programmed I/O
AO waveform modes	Non-periodic waveform, periodic waveform regeneration mode from onboard FIFO, periodic waveform regeneration from host buffer including dynamic update
Settling time, full-scale step, 15 ppm (1 LSB)	2 μs
Slew rate	20 V/ μs
Glitch energy at midscale transition, $\pm 10 \text{ V}$ range	
Magnitude	10 mV
Duration	1 μs

AO Absolute Accuracy

Absolute accuracy at full-scale numbers is valid immediately following internal calibration and assumes the device is operating within 10 °C of the last external calibration.



Note Accuracies listed are valid for up to two years from the device external calibration.

Table 3. AO Absolute Accuracy

Nominal Range Positive Full Scale	Nominal Range Negative Full Scale	Residual Gain Error (ppm of Reading)	Gain Tempco (ppm/°C)	Residual Offset Error (ppm of Range)	Offset Tempco (ppm of Range/°C)	Absolute Accuracy at Full Scale (μV)
10	-10	75	17	40	2	2,080
5	-5	85	8	40	2	1,045

Reference tempco 1 ppm/°C

INL error 64 ppm of range

¹ When the USB Screw Terminal device is powered on, the analog output signal is not defined until after USB configuration is complete.

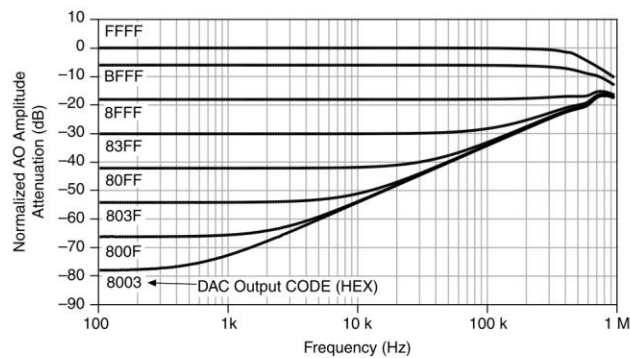
AO Absolute Accuracy Equation

$AbsoluteAccuracy = OutputValue \cdot (GainError) + Range \cdot (OffsetError)$
 $GainError = ResidualGainError + GainTempco \cdot (TempChangeFromLastInternalCal) + ReferenceTempco \cdot (TempChangeFromLastExternalCal)$
 $OffsetError = ResidualOffsetError + AOffsetTempco \cdot (TempChangeFromLastInternalCal) + INLError$

External Reference

APFI 0 characteristics	
Input impedance	10 kΩ
Coupling	DC
Protection, device on	±30 V
Protection, device off	±15 V
Range	±11 V
Slew rate	20 V/μs

Figure 4. AO External Reference Bandwidth



Digital I/O/PFI

Static Characteristics

Number of channels	24 total, 8 (P0.<0..7>), 16 (PFI <0..7>/P1, PFI <8..15>/P2)
Ground reference	D GND

Direction control	Each terminal individually programmable as input or output
Pull-down resistor	50 k Ω typical, 20 k Ω minimum
Input voltage protection	± 20 V on up to two pins ²

Waveform Characteristics (Port 0 Only)

Terminals used	Port 0 (P0.<0..7>)
Port/sample size	Up to 8 bits
Waveform generation (DO) FIFO	2,047 samples
Waveform acquisition (DI) FIFO	2,047 samples
DI Sample Clock frequency	
PCI/PCI Express/PXI/PXI Express	0 MHz to 10 MHz, system and bus activity dependent
USB	0 MHz to 1 MHz, system and bus activity dependent
DO Sample Clock frequency	
PCI/PCI Express/PXI/PXI Express	
Regenerate from FIFO	0 MHz to 10 MHz
Streaming from memory	0 to 10 MHz, system and bus activity dependent
USB	
Regenerate from FIFO	0 MHz to 10 MHz
Streaming from memory	0 MHz to 1 MHz, system and bus activity dependent
Data transfers	
PCI/PCI Express/PXI/PXI Express	DMA (scatter-gather), interrupts, programmed I/O
USB	USB Signal Stream, programmed I/O
DI or DO Sample Clock source ³	Any PFI, RTSI, AI Sample or Convert Clock, AO Sample Clock, Ctr <i>n</i> Internal Output, and many other signals

² Stresses beyond those listed under *Input voltage protection* may cause permanent damage to the device.

³ The digital subsystem does not have its own dedicated internal timing engine. Therefore, a sample clock must be provided from another subsystem on the device or an external source.

PFI/Port 1/Port 2 Functionality

Functionality	Static digital input, static digital output, timing input, timing output
Timing output sources	Many AI, AO, counter, DI, DO timing signals
Debounce filter settings	125 ns, 6.425 μ s, 2.56 ms, disable; high and low transitions; selectable per input

Recommended Operating Conditions

Level	Minimum	Maximum
Input high voltage (V_{IH})	2.2 V	5.25 V
Input low voltage (V_{IL})	0 V	0.8 V
Output high current (I_{OH}) P0.<0..7>	—	-24 mA
Output high current (I_{OH}) PFI <0..15>/P1/P2	—	-16 mA
Output low current (I_{OL}) P0.<0..7>	—	24 mA
Output low current (I_{OL}) PFI <0..15>/P1/P2	—	16 mA

Electrical Characteristics

Level	Minimum	Maximum
Positive-going threshold (V_{T+})	—	2.2 V
Negative-going threshold (V_{T-})	0.8 V	—
Delta VT hysteresis ($V_{T+} - V_{T-}$)	0.2 V	—
I_{IL} input low current ($V_{in} = 0$ V)	—	-10 μ A
I_{IH} input high current ($V_{in} = 5$ V)	—	250 μ A

Digital I/O Characteristics

Figure 5. P0.<0..7>: I_{oh} versus V_{oh}

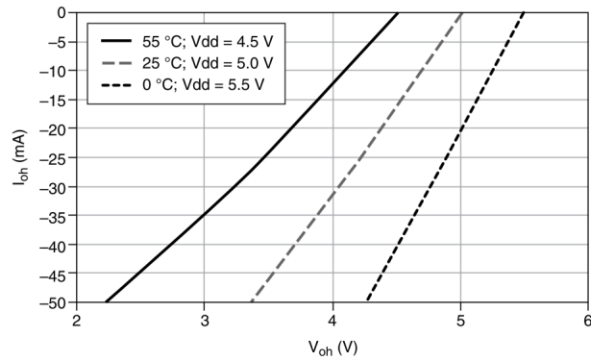


Figure 6. PFI <0..15>/P1/P2: I_{oh} versus V_{oh}

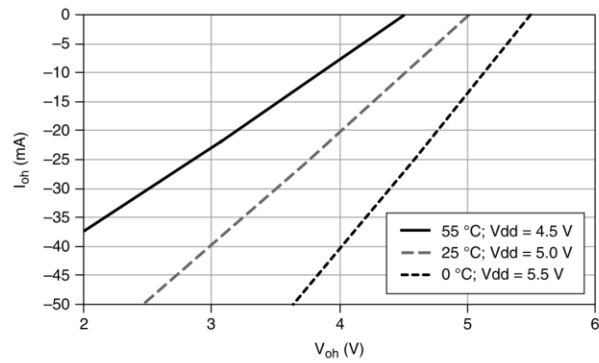


Figure 7. P0.<0..7>: I_{ol} versus V_{ol}

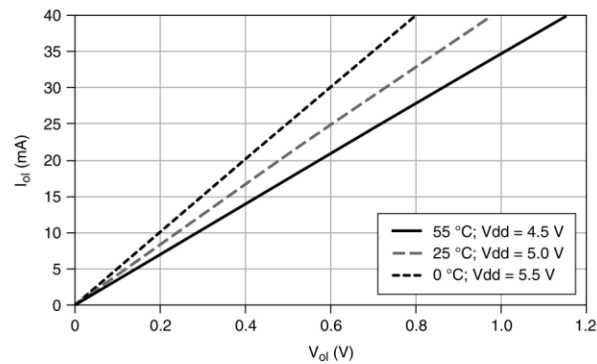
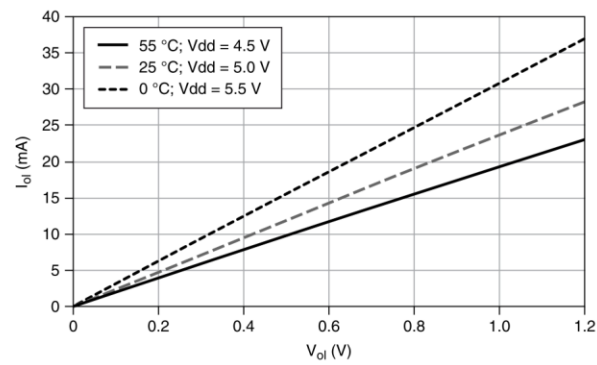


Figure 8. PFI <0..15>/P1/P2: I_{ol} versus V_{ol}



General-Purpose Counters/Timers

Number of counter/timers	2
Resolution	32 bits
Counter measurements	Edge counting, pulse, semi-period, period, two-edge separation
Position measurements	X1, X2, X4 quadrature encoding with Channel Z reloading; two-pulse encoding
Output applications	Pulse, pulse train with dynamic updates, frequency division, equivalent time sampling

Internal base clocks	80 MHz, 20 MHz, 0.1 MHz
External base clock frequency	0 MHz to 20 MHz
Base clock accuracy	50 ppm
Inputs	Gate, Source, HW_Arm, Aux, A, B, Z, Up_Down
Routing options for inputs	Any PFI, RTSI, PXI_TRIG, PXI_STAR, analog trigger, many internal signals
FIFO	2 samples
Data transfers	
PCI/PCI Express/PXI/PXI Express	Dedicated scatter-gather DMA controller for each counter/timer; interrupts, programmed I/O
USB	USB Signal Stream, programmed I/O

Frequency Generator

Number of channels	1
Base clocks	10 MHz, 100 kHz
Divisors	1 to 16
Base clock accuracy	50 ppm

Output can be available on any output PFI or RTSI terminal.

Phase-Locked Loop (PLL)



Note PCI/PCI Express/PXI/PXI Express devices only.

Number of PLLs	1
Reference signal	PXI_STAR, PXI_CLK10, RTSI <0..7>
Output of PLL	80 MHz Timebase; other signals derived from 80 MHz Timebase including 20 MHz and 100 kHz Timebases

External Digital Triggers

Source	Any PFI, RTSI, PXI_TRIG, PXI_STAR
Polarity	Software-selectable for most signals
Analog input function	Start Trigger, Reference Trigger, Pause Trigger, Sample Clock, Convert Clock, Sample Clock Timebase
Analog output function	Start Trigger, Pause Trigger, Sample Clock, Sample Clock Timebase
Counter/timer function	Gate, Source, HW_Arm, Aux, A, B, Z, Up_Down
Digital waveform generation (DO) function	Sample Clock
Digital waveform acquisition (DI) function	Sample Clock

Device-to-Device Trigger Bus

PCI/PCI Express	RTSI <0..7> ⁴
PXI/PXI Express	PXI_TRIG <0..7>, PXI_STAR
USB source	None
Output selections	10 MHz Clock, frequency generator output, many internal signals
Debounce filter settings	125 ns, 6.425 µs, 2.56 ms, disable; high and low transitions; selectable per input

Bus Interface

PCI/PXI	3.3 V or 5 V signal environment
PCI Express	
Form factor	x1 PCI Express, specification v1.0a compliant
Slot compatibility	x1, x4, x8, and x16 PCI Express slots ⁵

⁴ In other sections of this document, RTSI refers to RTSI <0..7> for the PCI/PCI Express devices or PXI_TRIG <0..7> for PXI/PXI Express devices.

⁵ Some motherboards reserve the x16 for graphics use. For PCI Express guidelines, refer to ni.com/pciexpress.

PXI Express

Form factor	x1 PXI Express peripheral module, specification rev 1.0 compliant
Slot compatibility	x1 and x4 PXI Express or PXI Express hybrid slots
USB	USB 2.0 Hi-Speed or full-speed ^{6, 7}
DMA channels (PCI/PCI Express/PXI/PXI Express)	6, can be used for analog input, analog output, digital input, digital output, counter/timer 0, counter/timer 1
USB Signal Stream	4, can be used for analog input, analog output, digital input, digital output, counter/timer 0, counter/timer 1

The PXI device supports one of the following features:

- May be installed in PXI Express hybrid slots
- Or, may be used to control SCXI in PXI/SCXI combo chassis

Table 4. PXI/SCXI Combo and PXI Express Chassis Compatibility

M Series Part Number	SCXI Control in PXI/SCXI Combo Chassis	PXI Express Hybrid Slot Compatible
191325D-03/191325E-03L	No	Yes
191325D-13/191325E-13L	Yes	No
191325C-0x/191325B-0x	Yes	No

The PXI Express device can be installed in PXI Express slots or PXI Express hybrid slots.

Power Requirements

Current draw from bus during no-load condition⁸

PCI/PXI	
+5 V	0.03 A
+3.3 V	0.725 A
+12 V	0.35 A

⁶ If you are using an USB M Series device in full-speed mode, device performance will be lower and you will not be able to achieve maximum sample/update rates.

⁷ Operating on a full-speed bus may result in lower performance.

⁸ Does not include P0/PFI/P1/P2 and +5 V terminals.

PCI Express	
+3.3 V	0.925 A
+12 V	0.35 A
PXI Express	
+3.3 V	0.45 A
+12 V	0.5 A
Current draw from bus during AI and AO overvoltage condition ⁸	
PCI/PXI	
+5 V	0.03 A
+3.3 V	1.2 A
+12 V	0.38 A
PCI Express	
+3.3 V	1.4 A
+12 V	0.38 A
PXI Express	
+3.3 V	0.48 A
+12 V	0.71 A



Caution USB devices must be powered with an NI offered AC adapter or a National Electric Code (NEC) Class 2 DC source that meets the power requirements for the device and has appropriate safety certification marks for country of use.

USB power supply requirements	11 to 30 VDC, 20 W, locking or non-locking power jack with 0.080 in. diameter center pin, 5/16-32 thread for locking collars
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Current Limits



Caution Exceeding the current limits may cause unpredictable behavior by the device and/or PC/chassis.

PCI, +5 V terminal	1 A maximum ⁹
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⁹ Older revisions have a self-resetting fuse that opens when current exceeds this specification. Newer revisions have a traditional fuse that opens when current exceeds this specification. This fuse is not customer-replaceable; if the fuse permanently opens, return the device to NI for repair.

PCI Express

Without disk drive power connector installed	
+5 V terminals combined	0.35 A maximum ⁹
P0/PFI/P1/P2 and +5 V terminals combined	0.39 A maximum
With disk drive power connector installed	
+5 V terminal	1 A maximum ⁹
P0/PFI/P1/P2 combined	0.39 A maximum

PXI/PXI Express

+5 V terminal	1 A maximum ⁹
P0/PFI/P1/P2 and +5 V terminals combined	2 A maximum

USB

+5 V terminal	1 A maximum ⁹
P0/PFI/P1/P2 and +5 V terminals combined	2 A maximum
Power supply fuse	2 A, 250 V

Physical Characteristics

Dimensions

PCI printed circuit board	10.6 cm × 15.5 cm (4.2 in. × 6.1 in.)
PCI Express printed circuit board	9.9 cm × 16.8 cm (3.9 in. × 6.6 in.) (half-length)
PXI/PXI Express printed circuit board	Standard 3U PXI
USB Screw Terminal enclosure (includes connectors)	26.67 cm × 17.09 cm × 4.45 cm (10.5 in. × 6.73 in. × 1.75 in.)
USB BNC enclosure (includes connectors)	28.6 cm × 17 cm × 6.9 cm (11.25 in. × 6.7 in. × 2.7 in.)
USB Mass Termination enclosure (includes connectors)	18.8 cm × 17.09 cm × 4.45 cm (7.4 in. × 6.73 in. × 1.75 in.)
USB OEM	Refer to the <i>NI USB-622x/625x/628x OEM User Guide</i>

Weight

PCI	149 g (5.2 oz)
PCI Express	161 g (5.7 oz)
PXI	222 g (7.8 oz)
PXI Express	208 g (7.3 oz)
USB Screw Terminal	1.2 kg (2 lb 10 oz)
USB Mass Termination	816 g (1 lb 12.8 oz)
USB OEM	140 g (4.9 oz)

I/O connector

PCI/PCI Express/PXI/PXI Express	1 68-pin VHDCI
USB Screw Terminal	64 screw terminals
USB BNC	21 BNCs and 30 screw terminals
Mass Termination	1 68-pin SCSI

PCI Express disk drive power	Standard ATX peripheral connector (not serial ATA)
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USB Screw Terminal/BNC screw terminal wiring	16 to 28 AWG
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Calibration

Recommended warm-up time

PCI/PXI/PCI Express/PXI Express	15 minutes
USB	30 minutes

Calibration interval	2 years
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Maximum Working Voltage

Maximum working voltage refers to the signal voltage plus the common-mode voltage.

Channel-to-earth	11 V, Measurement Category I
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Measurement Category I is for measurements performed on circuits not directly connected to the electrical distribution system referred to as MAINS voltage. MAINS is a hazardous live electrical supply system that powers equipment. This category is for measurements of voltages from specially protected secondary circuits. Such voltage measurements include signal levels, special equipment, limited-energy parts of equipment, circuits powered by regulated low-voltage sources, and electronics.



Caution Do not use for measurements within Categories II, III, or IV.



Note Measurement Categories CAT I and CAT O (Other) are equivalent. These test and measurement circuits are not intended for direct connection to the MAINS building installations of Measurement Categories CAT II, CAT III, or CAT IV.

Environmental

Operating temperature	
PCI/PXI/PXI Express	0 °C to 55 °C
PCI Express	0 °C to 50 °C
USB	0 °C to 45 °C
Storage temperature	-20 °C to 70 °C
Humidity	10% RH to 90% RH, noncondensing
Maximum altitude	2,000 m
Pollution Degree (indoor use only)	2

Indoor use only.

Shock and Vibration (PXI and PXI Express Only)

Operational shock	30 g peak, half-sine, 11 ms pulse (Tested in accordance with IEC 60068-2-27. Test profile developed in accordance with MIL-PRF-28800F.)
Random vibration	
Operating	5 Hz to 500 Hz, 0.3 g _{rms}
Nonoperating	5 Hz to 500 Hz, 2.4 g _{rms} (Tested in accordance with IEC 60068-2-64. Nonoperating test profile exceeds the requirements of MIL-PRF-28800F, Class 3.)

Safety

This product is designed to meet the requirements of the following electrical equipment safety standards for measurement, control, and laboratory use:

- IEC 61010-1, EN 61010-1
- UL 61010-1, CSA 61010-1



Note For UL and other safety certifications, refer to the product label or the [Online Product Certification](#) section.

Electromagnetic Compatibility

This product meets the requirements of the following EMC standards for electrical equipment for measurement, control, and laboratory use:

- EN 61326-1 (IEC 61326-1): Class A emissions; Basic immunity
- EN 55011 (CISPR 11): Group 1, Class A emissions
- AS/NZS CISPR 11: Group 1, Class A emissions
- FCC 47 CFR Part 15B: Class A emissions
- ICES-001: Class A emissions



Note In the United States (per FCC 47 CFR), Class A equipment is intended for use in commercial, light-industrial, and heavy-industrial locations. In Europe, Canada, Australia, and New Zealand (per CISPR 11) Class A equipment is intended for use only in heavy-industrial locations.



Note Group 1 equipment (per CISPR 11) is any industrial, scientific, or medical equipment that does not intentionally generate radio frequency energy for the treatment of material or inspection/analysis purposes.



Note For EMC declarations and certifications, refer to the [Online Product Certification](#) section.

CE Compliance

This product meets the essential requirements of applicable European Directives, as follows:

- 2014/35/EU; Low-Voltage Directive (safety)
- 2014/30/EU; Electromagnetic Compatibility Directive (EMC)
- 2011/65/EU; Restriction of Hazardous Substances (RoHS)

Online Product Certification

Refer to the product Declaration of Conformity (DoC) for additional regulatory compliance information. To obtain product certifications and the DoC for this product, visit ni.com/certification, search by model number or product line, and click the appropriate link in the Certification column.

Environmental Management

NI is committed to designing and manufacturing products in an environmentally responsible manner. NI recognizes that eliminating certain hazardous substances from our products is beneficial to the environment and to NI customers.

For additional environmental information, refer to the *Minimize Our Environmental Impact* web page at ni.com/environment. This page contains the environmental regulations and directives with which NI complies, as well as other environmental information not included in this document.

Waste Electrical and Electronic Equipment (WEEE)



EU Customers At the end of the product life cycle, all NI products must be disposed of according to local laws and regulations. For more information about how to recycle NI products in your region, visit ni.com/environment/weee.

电子信息产品污染控制管理办法（中国 RoHS）



中国客户 National Instruments 符合中国电子信息产品中限制使用某些有害物质指令 (RoHS)。关于 National Instruments 中国 RoHS 合规性信息，请登录 ni.com/environment/rohs_china。(For information about China RoHS compliance, go to ni.com/environment/rohs_china.)

Device Pinouts

Figure 9. NI PCI/PCIe/PXI/PXIe-6251 Pinout

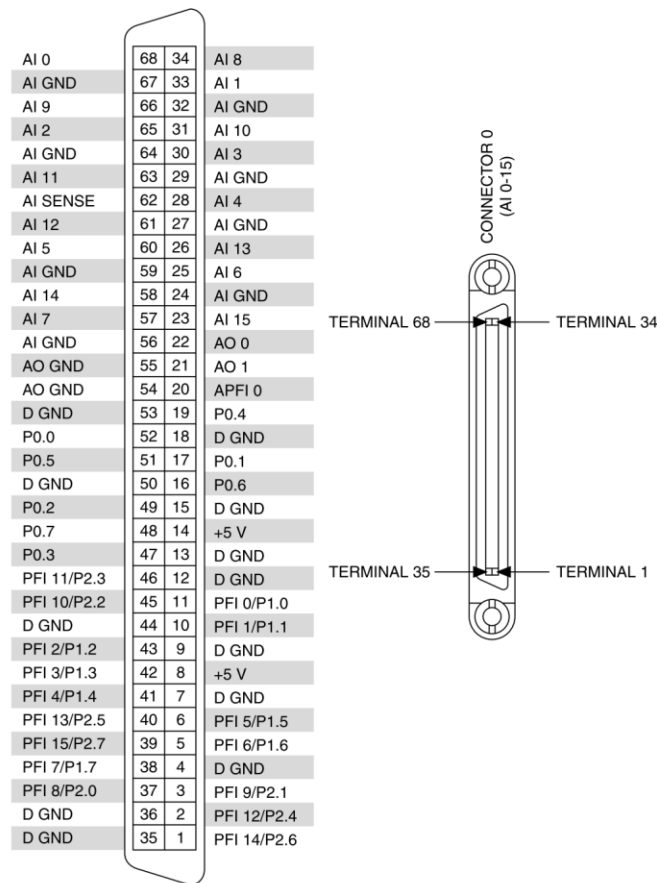


Figure 10. NI USB-6251 Screw Terminal Pinout

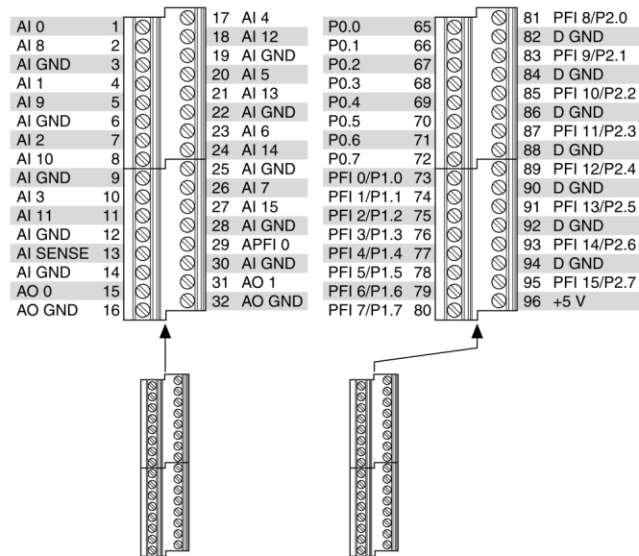


Figure 11. NI USB-6251 BNC Front Panel and Pinout

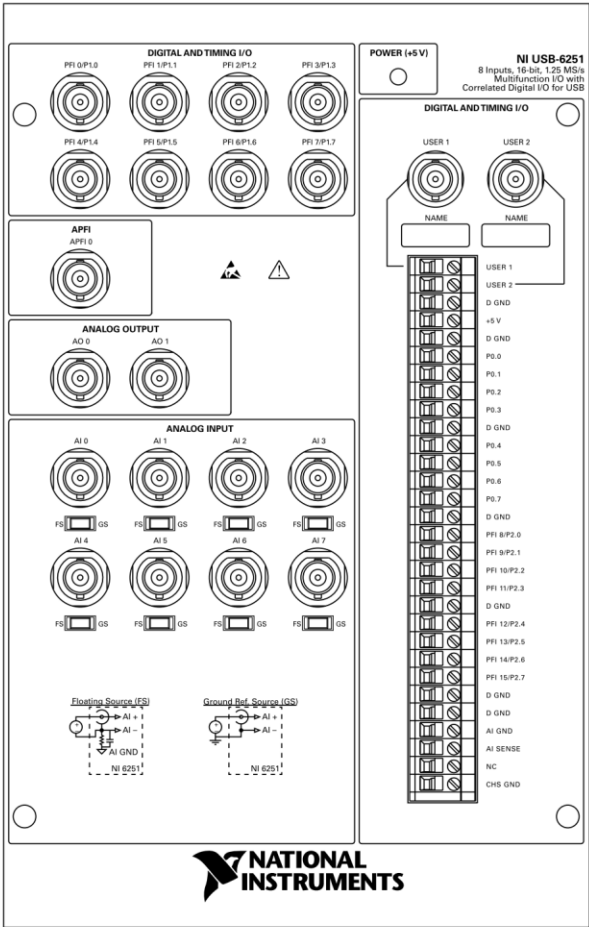
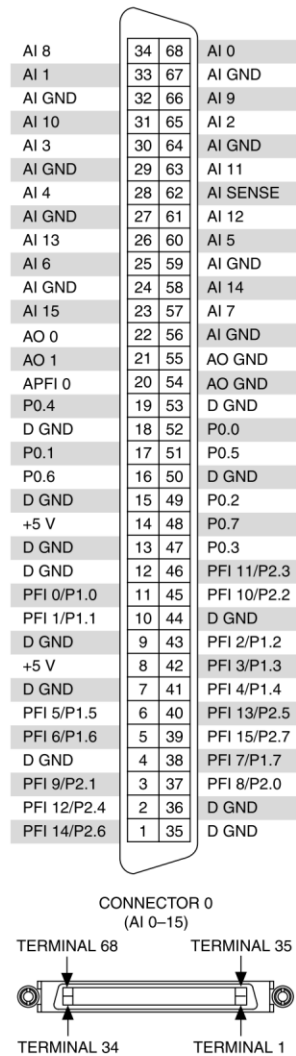


Figure 12. NI USB-6251 Mass Termination Pinout



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