Murata Supercapacitor (EDLC) Technical note
(DMF, DMT/ Version 11, 10th December 2014)

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1. Principle and structure of supercapacitor
1.1. Principle of supercapacitor

Unlike ceramic capacitors or aluminum electrolytic capacitors, supercapacitors which are also called as Electrical Double Layer Capacitors (EDLCs) contain no conventional dielectric. Instead, an electrolyte (solid or liquid) is filled between two electrodes (Fig. 1). In supercapacitor, an electrical state called “electrical double layer”, which is a pair of electrons and positive ions or a pair of holes and negative ions formed between the electrode and the electrolyte, works as a dielectric and gives capacitance.

Capacitance is proportional to the surface area of electrode. Therefore using activated carbon, which has quite large surface area for electrodes, enables supercapacitor to have quite high capacitance. The mechanism of ion absorption and desorption to/from the electrode surface contributes to charge and discharge of supercapacitor. By applying voltage to the facing electrodes, ions are drawn to the surface of the electrode and supercapacitor is charged (Fig. 2). Conversely, they move away when discharging supercapacitor. This is how supercapacitor is charged and discharged.

Fig. 1 Principle of supercapacitor (EDLC)

Fig. 2 Charge/discharge state in supercapacitor (EDLC)
1.2. Structure of Murata’s supercapacitor

In general, supercapacitors consist of positive electrode, negative electrode, electrolyte and separator which prevents facing electrodes from contacting each other. Activated carbon powder is applied to electricity collector (aluminum foil) of the electrodes (Fig. 1).

The structure of Murata’s supercapacitor is shown in Fig. 3, Fig. 4 and Fig. 5. Package is made from aluminum laminate film. Aluminum can protect inner materials (multilayered electrodes, electrolyte and so on) from outside circumstance (moisture and so on). Laminate film is coated by insulating plastic layer on surfaces of inner side and outer side for protection from short circuit.

Inner coating resin has also a function of sealing package. Supercapacitor is sealed around four sides by heat-sealing process. Extracting leads are also sealed by same process.

Supercapacitor has two assemblies of unit multilayered-electrode in one package. Partition insulating film is placed between the two of unit cell. An electrode sheet consists of electricity collector and activated carbon layer. Activated carbon is printed on surface of electricity collector. Such multiple electrode sheets are layered with each sheet separated mechanically and electrically by separator (Fig. 5).

![Fig. 3 Structure of Murata’s supercapacitor (LT cross section)](image1)

![Fig. 4 Structure of Murata’s supercapacitor (WT cross section)](image2)

![Fig. 5 Structure of Murata’s supercapacitor (Multilayered electrode)](image3)
1.3. Equivalent circuit model of Murata’s supercapacitor

Capacitor can be generally described by combination of a capacitor (C), a series resistance (R\(_s\)) and an insulation resistance (R\(_i\)). Murata’s supercapacitor has two unit cells (unit capacitors) which are connected in series in one package. Therefore simple equivalent circuit model is described as Fig. 6. This simple model having two unit cells can be combined to a simpler model such as Fig. 7. In this case, total capacitance value is equal to half of that in unit cell and resistances are equal to two times of that in unit cell.

However such simple model does not generally reflect actual electrical behaviors in supercapacitors. This is because that activated-carbon electrode has various-size pores on the surface. Charges are stored by ions moving to the porous surface as mentioned in section 1.1(Fig. 2). Ions can move easily and quickly in the shallow site of electrode. On the other hand, ions move very slowly in the deep site by physical resistance. This means that the shallow site can be fully-charged quickly but it takes very long time to charge fully at the deep site (Fig. 8). For this reason, detailed equivalent model is described with multiple parallel C and multiple series R as shown in Fig. 8.

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**Fig. 6** Murata’s supercapacitor has two of unit cell in one package

**Fig. 7** Simple equivalent circuit model
2. Features of Murata’s supercapacitors and your benefits

2.1. Key features and your benefits

Murata’s supercapacitors have high capacitance value from some hundreds millifarads to one farad and high rated voltage from 4.2 V to 5.5 V which are suitable for assistance of various batteries and high energy storage (Fig. 9).

Supercapacitors typically have higher energy density than other capacitors and higher power density than various batteries (Fig. 10). Especially power densities of Murata’s supercapacitors are higher than other conventional supercapacitors (Fig. 11) and they can discharge up to 100 W. For this reason, Murata’s ones are suitable for high-peak load leveling, high-peak power function, high-power backup or storage for energy harvest.

The thicknesses are very thin, approx. 3.2 mm to 3.7 mm. Therefore they can be embedded into various compact and slim devices. Another feature of Murata’s supercapacitors is the highest reliability among supercapacitors in the market. This is because our good package sealing prevents supercapacitor from outside moisture which causes degradation (section 2.4).

Fig. 8 Detailed equivalent circuit model

Fig. 9 High capacitance of Murata’s supercapacitors
Fig. 10 Comparison of power density and energy density

Fig. 11 Comparison with conventional supercapacitors

Fig. 12 Key Features of Murata’s supercapacitors and your benefits
2.2. High energy

Murata’s supercapacitors have high energy in a slim package. For example, Murata’s 4.2 V 470 mF supercapacitor has 2,000 mJ even after 5 years passed under 50°C (*1). Such energy is 100 times of high-capacitance tantalum capacitor (6.3 V, 1,500 uF) or 12 times of high-cap aluminum capacitor (16 V, 2,200 uF) (Fig. 13). You can design higher energy or reduce space for energy components in your product by using such high-energy-density Murata’s supercapacitors.

*1 Supercapacitors degrade little by little. Therefore the performance keeps gradually decreasing during long-term use (details in section 6.3). Prediction of performance after degradation is discussed in section 8.1.

Fig. 13 Stored-energy comparison with high-capacitance tantalum capacitor and aluminum capacitor

2.3. High power

Murata’s supercapacitors have high power in a slim package. Lithium coin batteries (Li·MnO₂), lithium thionyl chloride batteries (Li·SOCl₂) etc are being used widely in long-life devices. However those batteries have only quite low power (Fig. 14). In this reason, devices with those batteries are limited to low power function. And although alkaline battery has higher energy than those batteries, it will have shorter life time under high-power load. Murata’s supercapacitors can assist those batteries for high-power function or long-time working with their quite higher power (Fig. 14).

Fig. 14 Power comparison of Murata’s supercapacitor with various batteries
2.4. High reliability

In general, supercapacitors have aging issue which is caused by moisture from outside. And they also have dry up failure issue. Murata’s supercapacitors were improved in aging and dry up.

Moisture enters into package via sealant part. Murata’s supercapacitors are designed its sealant part to be small in order to inhibit moisture (Fig. 15). Therefore there is little damage by moisture compared with cylindrical supercapacitors which can be damaged heavily (Fig. 16). This smallest-designed sealant can also cut down on evaporation of electrolyte which causes dry up failure (Details in section 6.2).

![Diagram showing moisture entry and effect on cylindrical and Murata supercapacitors](image)

**Fig. 15 Good package sealing of Murata’s supercapacitor for high reliability (against outside use and dry up of electrolyte)**

![Graphs showing capacitance and ESR over time for cylindrical and Murata supercapacitors](image)

**Fig. 16 Excellent reliability of Murata’s supercapacitor than cylindrical one (40°C, 4.5V test)**

- ▶️Cylinder supercap has large degradation.
- ▶️Murata’s supercap has **small degradation**.
3. Supercapacitor solutions in your devices

3.1. High peak load leveling

When you have a problem about lack of battery power, Murata’s supercapacitor can support it. Boosted power can be gained by connecting supercapacitor to your battery in parallel (Fig. 17). This will enable you to improve product quality. For example, it can improve RF transmission distance to be long, bass sound quality and so on.

If your battery voltage is over supercapacitor’s rated voltage (4.2 V~5.5 V), you can use a few supercapacitor in series connection (This is discussed in section 9.2). Please ask Murata if you have a question.

![Fig. 17 Supercapacitor for high peak load leveling](image)

3.2. High peak power function

When you have a problem about quite high peak power in your product, Murata’s supercapacitor can support it. Murata’s supercapacitors can discharge up to some tens ampere for such peak load. Supercapacitor is charged from power source in advance. And then when high power load happens, supercapacitor discharge to load (Fig. 18). This will enable you to add new high power function to your product. For example, high brightness LED flash can be added to smart phone, high peak motor function can be added with low power battery.

If your battery voltage is over supercapacitor’s rated voltage (4.2 V~5.5 V), you can use a few supercapacitor in series connection (This is discussed in section 9.2). Please ask Murata if you have a question.

![Fig. 18 Supercapacitor for high peak power function](image)
3.3. High-power backup

When you have problems about lack of backup energy in your system, Murata's supercapacitor can support it. Supercapacitor is placed between power source and load in parallel. Supercapacitor is charged by power source all the time. When power interruption happens, supercapacitor can discharge to load (Fig. 19). This will enable you to gain high-power and long-time backup in your product. For example, SSD can have high-power and long-life backup into slim devices, portable devices can keep working during battery replacement.

If voltage of power source is over supercapacitor’s rated voltage (4.2 V~5.5 V), you can use a few supercapacitor in series connection (This is discussed in section 9.2). Please ask Murata if you have a question.

![High-power Back up](image)

**Fig. 19 Supercapacitor for high-power back up**

3.4. Storage for energy harvest

Energy harvest systems have unstable power generation from solar power, wind energy, thermal energy and so on. Murata’s supercapacitors can be charged and discharged easily. Therefore they are suitable for energy storage for unstable power generation. Supercapacitor is placed between harvester and load. If supercapacitor is charged enough, it can provide stable power to load (Fig. 20).

![Storage for Energy Harvest](image)

**Fig. 20 Supercapacitor for storage of energy harvesting**
4. Lineup of Murata’s supercapacitor

4.1. Standard supercapacitors: DMF series

DMF series is a standard type for versatile applications. DMF has a feature of ultra high power performance up to 100 W discharge (up to 40 W even at -40°C) that other conventional supercapacitors do not have. Two products are in the lineup, one is 470 mF and the other is 1,000 mF (Table 1). The thickness is 3.2 mm to 3.7 mm that can realize mounting on surface of a circuit board (not reflowable). Therefore these can fit slim products. DMF has also excellent reliability (small aging and excellent durability to dry up failure) in comparison with other supercapacitors in the market.

Table 1 Line up of standard supercapacitor: DMF series

<table>
<thead>
<tr>
<th>P/N</th>
<th>Rated Voltage</th>
<th>Capacitance</th>
<th>Max ESR (1 kHz)</th>
<th>Dimensions</th>
<th>Operating temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMF3Z5R5H474M3DTA0</td>
<td>5.5V</td>
<td>470 mF ±20%</td>
<td>55 mΩ</td>
<td>14 x 21 x 3.2 mm</td>
<td>-40°C to 70°C</td>
</tr>
<tr>
<td>DMF4B5R5G105M3DTA0</td>
<td>5.5V</td>
<td>1,000 mF ±20%</td>
<td>50 mΩ</td>
<td>14 x 30 x 3.7 mm</td>
<td>-40°C to 70°C</td>
</tr>
</tbody>
</table>

4.2. SSD-specific supercapacitor: DMT series

DMT series is SSD-specific type that is specially designed for Solid State Drives (SSDs) application. DMT can be used at higher temperature condition up to 85°C compared with DMF series. It has high power performance up to 10W discharge per one piece. One product is in the lineup at this moment. The capacitance is 470 mF and the thickness is 3.5 mm (Table 2) that can realize mounting on surface of a circuit board (not reflowable). DMT has also excellent reliability (small aging and excellent durability to dry up failure) in comparison with other supercapacitors in the market.

Table 2 Line up of SSD-specific supercapacitor: DMT series

<table>
<thead>
<tr>
<th>P/N</th>
<th>Rated Voltage</th>
<th>Capacitance</th>
<th>Max ESR (1 kHz)</th>
<th>Dimensions</th>
<th>Operating temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMT334R2S474M3DTA0</td>
<td>4.2V</td>
<td>470 mF ±20%</td>
<td>150 mΩ</td>
<td>14 x 21 x 3.5 mm</td>
<td>-40°C to 85°C</td>
</tr>
</tbody>
</table>
5. Performance of Murata’s supercapacitors

5.1. Constant current discharge

When supercapacitor discharges in constant current condition, voltage on supercapacitor drops almost linearly as time passes (Fig. 21).

There is an initial voltage drop at the moment of discharge by internal resistance (ESR) in supercapacitor ($\Delta V \approx I \cdot ESR$). Initial voltage drop becomes larger in higher current condition. Or it becomes larger also in higher ESR supercapacitor.

After the initial drop, voltage of supercapacitor drops as time passes. The drop speed depends on current level and nominal capacitance value ($\Delta V/\Delta t \approx I/C$). The higher current is or the lower capacitance is, the more quickly voltage drops. However this relation of $\Delta V/\Delta t \approx I/C$ is equal to the ideal state (see left picture in Fig. 8). In case of quite high current discharge or quite low current discharge, the drop speed becomes out of the relation because supercapacitors have complex circuit of multiple parallel C (see right picture in Fig. 8).

Fig. 22 and Fig. 23 are actual behaviors in Murata’s supercapacitors in constant current discharge. More than 10 A current can be actually discharged from supercapacitor.

![Fig. 21 Constant current discharge in supercapacitor](image1)

![Fig. 22 Constant current discharge of DMF3Z5R5H474M3DTA0 (discharge from 5.5 V @25°C)](image2)
5.2. Constant power discharge

When supercapacitor discharges in constant power condition, voltage on supercapacitor drops as time passes (Fig. 24).

There is an initial voltage drop at the moment of discharge by internal resistance (ESR) in supercapacitor ($\Delta V \approx P \cdot ESR/V_c$). Initial voltage drop becomes larger in higher power condition. Or it becomes large also in higher ESR supercapacitor.

After the initial drop, voltage of supercapacitor drops as time passes. The drop speed depends on discharge power, nominal capacitance value and voltage level at the moment ($dv/dt = P/CV_n$). The higher power is or the lower capacitance is, the more quickly voltage drops. In addition, the drop speed becomes higher in lower voltage level as time passes (Fig. 24). However this relation of $dv/dt = P/CV_n$ is equal to the ideal state (see left picture in Fig. 8). In case of quite high power discharge or quite low power discharge, the drop speed becomes out of the relation because supercapacitors have complex circuit of multiple parallel C (see right picture in Fig. 8).

Fig. 25 and Fig. 26 are actual behaviors of Murata’s supercapacitors in constant power discharge. More than 10 W power can be discharged from supercapacitor.
5.3. Temperature dependence in capacitance, ESR and thickness

Murata’s supercapacitors have temperature dependence in capacitance, ESR and thickness (Fig. 27, Fig. 28).

DMF3Z5R5H474M3DTA0 has almost no change in capacitance at temperature range from -40°C to 70°C. ESR becomes higher at lower temperature and ESR at -40°C is 2.5 times of one at 25°C. This dependence is caused by temperature dependence in viscous resistance of electrolyte. Thickness becomes larger at higher temperature than room temperature and it get slightly thicker approx. 0.25 mm at 70°C.

In case of DMT334R2S474M3DTA0, capacitance becomes lower at lower temperature. It is 70% at -40°C compared with 25°C capacitance. This is because that DMT has higher inner resistances especially at lower temperature and ions at deeper site are not discharged easily (Fig. 8). It means that electrical charges cannot be discharged fully at low temperature. ESR changes with temperature. It becomes higher at lower temperature and ESR at -40°C is 9 times of one at 25°C. This dependence is caused by temperature dependence in viscous resistance of electrolyte. Thickness does not change much even at both of lower temperature and high temperature.
5.4. Charge current and leakage current

Supercapacitors have characteristic behaviors in current during charging. Fig. 29 and Fig. 30 show charge current behaviors in an ideal capacitor and in a supercapacitor each other.

In the case of an ideal capacitor, charge current will decrease rapidly as time passes and it will get fully-charged in a short time. After fully charged, leakage current will remain (Fig. 29).

However supercapacitor actually has a lot of various-size pores in activated-carbon electrodes and a complex equivalent circuit model as mentioned in section 1.3 (Fig. 8, Fig. 30). Combination of multiple parallel C and series R contributes to characteristic charge-current. Shallow site of electrode generally has low C and low R. Therefore high current will flow for quite short time. In contrast, deep site has high C and high R. Therefore trickle current will keep flowing for quite long time. From those reasons, supercapacitor takes quite long time to be charged fully and low charge-current trickles for long time.

For lots of application, there is no need to consider such trickle charge-current, however when supercapacitor is used for applications that have low charge power such as energy harvester, it should be considered.

Fig. 31 and Fig. 32 show charge-current behavior of actual Murata’s supercapacitors. Trickle current can be observed for hundreds hours. Real leakage current can be considered as less than 1 uA.
Fig. 29 Charge current in an ideal capacitor

\[ i = i_0 \exp\left(-\frac{t}{C \cdot R_s}\right) = \frac{V}{R_s} \exp\left(-\frac{t}{C \cdot R_i}\right) \]

\[ \ln i = -\frac{1}{C \cdot R_s} t + \ln \frac{V}{R_s} \]

C: capacitance
R_s: series resistance
R_i: Insulation resistance (>>R_s)

Fig. 30 Charge current in a supercapacitor

\[ i = i_0 + i_1 + i_2 + \cdots + i_n \]

\[ \ln i = -\frac{1}{C_s \sum R_u} t + \ln \left(\frac{V}{(R_u + R_{u_1} + R_{u_2} + \cdots + R_{u_n})}\right) \]

C: capacitance
R_u: series resistance
R_i: Insulation resistance

Fig. 31 Charge current of DMF3Z5R5H474M3DTA0 (5.5 V 25°C, n=10)
6. Reliability of Murata’s supercapacitors (Failure and degradation)

6.1. Failure and degradation

Dry up failure and aging degradation occur in Murata’s supercapacitors. Dry up failure is caused by gradual evaporation of inside electrolyte to outside during long term use. This failure is open mode. Aging degradation is caused by electrochemical reaction between inner moisture and electrolyte.

6.2. Dry up failure

Dry up is caused by evaporation of inner electrolyte to outside. Such evaporation occurs little by little for long time. Electrolyte has limited minimum amount for supercapacitor to work well. If there is enough amount of electrolyte inside over minimum value, it does not affect supercapacitor performance. At the moment the amount of electrolyte becomes under limited minimum value by evaporation, shortage of ions occurs and available electrode area becomes smaller. As a result, capacitance becomes lower rapidly, ESR becomes larger rapidly and supercapacitor cannot work in the end (Fig. 33). Dry up failure is open mode.

Murata’s supercapacitors are designed to have extra amount of electrolyte in order to expand dry up life time. And also the package is designed to prevent dry up (Fig. 34). Evaporation speed depends on temperature condition, in other words, dry up life time also depends on it. Please refer indication of Fig. 35 for considering how long time supercapacitor can work. However the limited operating time should be also considered (see section 7.2).
Fig. 33 Capacitance and ESR change by dry up

Fig. 34 Good package design of Murata’s supercapacitor for reducing dry up

Fig. 35 Dryup life time
6.3. Aging degradation

Aging is caused by electrochemical reaction between inner moisture and electrolyte. Such electrochemical reaction makes product on surface of electrode. Such product causes performance degradation (capacitance decrease and ESR increase, Fig. 36). Moisture enter inside from outside little by little, therefore the degradation occurs little by little (Fig. 36), not sudden death. Electrochemical reaction amount depends on temperature and voltage, and moisture entering depends on temperature. Therefore aging speed depends on temperature and voltage.

Murata’s supercapacitors are designed to reduce aging speed by selecting good materials and designing good package (Fig. 15).

![Fig. 36 Capacitance and ESR change by aging](image)

6.4. How to consider reliability

There are aging degradation and dry up failure in using supercapacitor as explained above. However those two are actually not mixed and there is only aging mode until dry up starts (Fig. 37). Therefore only aging mode should be considered if dry up lifetime is expected to be long enough.

![Fig. 37 Capacitance and ESR change in actual case](image)
6.5. Examples of reliability test (DMF test for 9,000 hours at 4.2 V 40°C and DMT test for 12,000 hours at 4.2 V 70°C)

Fig. 38 and Fig. 39 show the results of test at 4.2 V 40°C for 9,000 hours to DMF3Z5R5H474M3DTA0 and 4.2 V 70°C for 12,000 hours to DMT334R2S474M3DTA0. The aging degradation can be observed in them. Although such degradation is large at first, it converges gradually.

Fig. 38 Capacitance and ESR change in test at 4.2 V 40°C for 9,000 hours to DMF3Z5R5H474M3DTA0

Fig. 39 Capacitance and ESR change in test at 4.2 V 70°C for 12,000 hours to DMT334R2S474M3DTA0
7. Cautions for use

Cautions in using supercapacitor are mentioned in this section. However please be sure to check the cautions in the specification sheet of each product before using.

7.1. Limitation to applications

Please contact us before using our products for the applications listed below which require especially high reliability for the prevention of defects which might directly cause damage to the third party’s life, body or property.

(1) Aircraft equipment, (2) Aerospace equipment, (3) Undersea equipment, (4) Power plant control equipment, (5) Medical equipment, (6) Transportation equipment (vehicles, trains, ships, etc.), (7) Traffic signal equipment, (8) Disaster prevention / crime prevention equipment, (9) Data-processing equipment, (10) Application of similar complexity and/or reliability requirements to the applications listed in the above.

Please do not use this product for any applications related to military equipment.

7.2. Limited operating time

Each product has specific limited operating time to get failure which depends on use condition. Fig. 40 and Fig. 41 show the limited operating time of DMF3Z5R5H474M3DTA0 and DMT334R2S474M3DTA0 each other.

In the case of DMF3Z5R5H474M3DTA0 (Fig. 40), if it is used at continuous 5.5 V charge, limited operating time is 500 hours at 70°C, 3,200 hours at 50°C and 6,400 hours at 40°C. In using at less than 4.2 V, it is 3,000 hours at 70°C, 20,000 hours at 50°C and 40,000 hours at 40°C. If voltage or temperature is intermittent, the time will be longer.

In the case of DMT334R2S474M3DTA0 (Fig. 41), voltage level does not affect the time. The limited operating time is 9,000 hours at 85°C, 40,000 hours at 70°C and more than 300,000 hours at 40°C. If temperature is intermittent, the time will be longer.
Fig. 40 Use condition and limited operating time of DMF3Z5R5H474M3DTA0

Fig. 41 Use condition and limited operating time of DMT334R2S474M3DTA0

7.3. Voltage
7.3.1. Voltage balance

Murata’s supercapacitor consists of two individual cells connected electrically in series (Fig. 42). When in use, please be sure to control the voltage of each cell and keep capacitor voltage within operating voltage range (0V ~ the rated voltage). Balance control is needed in order to prevent the excessive voltage (over 1/2 voltage of applied voltage) being applied to either cell. Excessive voltage of either cell may shorten the lifetime of capacitor, distort the capacitor shape or cause electrolyte leakage. For more details about voltage balance, please see section 10.
7.3.2. Polarity

Please verify the orientation of supercapacitor and use in correct polarity in accordance with the marking on the product. In principle, supercapacitor has no polarity. However, if the inverse voltage is applied to supercapacitor, significant degradation of capacitance or leakage of electrolyte may be possibly caused.

7.4. Temperature and self heating

Please use supercapacitors within the specific operating temperature range with considering not only circumstance temperature but also self heating of supercapacitors. For reference, please see section 12.2.

7.5. Soldering and assembling

Reflow and flow soldering cannot be accepted because body temperature of supercapacitor will get higher than allowable maximum temperature. Please use other mounting methods such as hand iron soldering, auto iron soldering, connector and so on.

Please do not apply excessive force to the capacitor during insertion as well as after soldering. The excessive force may result in damage to electrode terminals and/or degradation of electrical performance.

Recommendation of iron soldering is discussed in section 11.

Please do not wash the device after soldering.

8. Simulation of performance in your use condition through life

8.1. Simulation of performance and degradation

Please note that the performance of supercapacitor will decrease gradually. It depends on your use condition (applied voltage to supercapacitor and surround temperature). For your design, Murata has simulation tools that can calculate Cap/ESR degradation and discharge performance at the end of your set life in given condition (Fig. 43).

This calculation is based on the acceleration factors of voltage and temperature. Such acceleration...
Factors were gained from several actual acceleration tests. Please contact us for details of performance in your condition.

![Simulation tools, available in any conditions.](image)

**[use-condition parameters]**

- Charge voltage to supercapacitor
- Surround temperature
- Expected life time
- Discharge current or power
- Minimum working voltage you can accept
- P/N of supercapacitor
- Connection number of supercapacitors (series or/and parallel)

**[Simulation output]**

- Capacitance/ESR degradation in your condition (voltage per cell and temperature)
- Supercapacitor discharge behavior (voltage vs time) in initial and end of your set life

Fig. 43 Simulation tool for performance in any condition of Murata’s supercapacitors

### 8.2 Examples of capacitance and ESR degradation in various conditions

Several examples of estimated capacitance and ESR degradation in various conditions are shown in this section. They are the times at which capacitance reaches 75% of the initial value and ESR reaches 2 times of the initial values (Fig. 44).

![Graphs showing capacitance and ESR degradation](image)

**Fig. 44** Times at which capacitance reaches 75% and ESR reaches 2 times of the initial values
8.2.1. Examples of DMF series

Estimated time at which capacitance reaches 75% of the initial value and ESR reaches 2 times of the initial value in DMF series are shown in Table 3 and Table 4. The conditions are 3.0 V to 5.5 V at 20 °C to 40 °C.

Table 3 Times at which capacitance reaches 75% of the initial value in DMF series

<table>
<thead>
<tr>
<th>DMF series</th>
<th>20 °C</th>
<th>30 °C</th>
<th>40 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0 V</td>
<td>180,000 hours (20 years)</td>
<td>90,000 hours (10 years)</td>
<td>45,000 hours (5 years)</td>
</tr>
<tr>
<td>3.6 V</td>
<td>130,000 hours (15 years)</td>
<td>90,000 hours (10 years)</td>
<td>45,000 hours (5 years)</td>
</tr>
<tr>
<td>4.2 V</td>
<td>35,000 hours (4 years)</td>
<td>22,000 hours (2.5 years)</td>
<td>13,000 hours (1.5 years)</td>
</tr>
<tr>
<td>5.0 V</td>
<td>17,000 hours (2 years)</td>
<td>9,000 hours (1 year)</td>
<td>5,000 hours (0.6 years)</td>
</tr>
<tr>
<td>5.5 V</td>
<td>10,000 hours (1.2 years)</td>
<td>6,000 hours (0.7 years)</td>
<td>3,500 hours (0.4 years)</td>
</tr>
</tbody>
</table>

Table 4 Times at which ESR reaches 2 times of the initial value in DMF series

<table>
<thead>
<tr>
<th>DMF series</th>
<th>20 °C</th>
<th>30 °C</th>
<th>40 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0 V</td>
<td>180,000 hours (20 years)</td>
<td>90,000 hours (10 years)</td>
<td>45,000 hours (5 years)</td>
</tr>
<tr>
<td>3.6 V</td>
<td>180,000 hours (20 years)</td>
<td>90,000 hours (10 years)</td>
<td>45,000 hours (5 years)</td>
</tr>
<tr>
<td>4.2 V</td>
<td>180,000 hours (20 years)</td>
<td>90,000 hours (10 years)</td>
<td>45,000 hours (5 years)</td>
</tr>
<tr>
<td>5.0 V</td>
<td>70,000 hours (8 years)</td>
<td>38,000 hours (4.5 years)</td>
<td>22,000 hours (2.5 years)</td>
</tr>
<tr>
<td>5.5 V</td>
<td>40,000 hours (4.5 years)</td>
<td>23,000 hours (2.5 years)</td>
<td>13,000 hours (1.5 years)</td>
</tr>
</tbody>
</table>

8.2.2. Examples of DMT series

Estimated time at which capacitance reaches 75% of the initial value and ESR reaches 2 times of the initial value in DMT series are shown in Table 5 and Table 6. The conditions are 3.0 V to 4.2 V at 40 ºC to 80 ºC.

Table 5 Times at which capacitance reaches 75% of the initial value in DMT series

<table>
<thead>
<tr>
<th>DMT series</th>
<th>40 °C</th>
<th>50 °C</th>
<th>70 °C</th>
<th>80 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0 V</td>
<td>27,000 hours</td>
<td>18,000 hours</td>
<td>8,000 hours</td>
<td>5,500 hours</td>
</tr>
<tr>
<td>3.6 V</td>
<td>17,000 hours</td>
<td>11,000 hours</td>
<td>5,000 hours</td>
<td>3,500 hours</td>
</tr>
<tr>
<td>4.2 V</td>
<td>12,000 hours</td>
<td>8,000 hours</td>
<td>3,500 hours</td>
<td>2,500 hours</td>
</tr>
</tbody>
</table>
9. **For increasing capacitance, energy, power or voltage**

9.1. **Solution of parallel connection of supercapacitors**

When higher energy and/or higher power are required in your system, you can get it by connecting some supercapacitors in parallel (Fig. 45). If N pieces of supercapacitors are connected in parallel, total capacitance becomes high to N times and total ESR becomes low to 1/N. You can get both of higher energy (calculated from $E=\frac{1}{2}C*V^2$) and higher power. In parallel connection case, it is possible to connect different parts of supercapacitors.

Please design balance circuit in any connection (described in section 10).

![Fig. 45 Parallel connection of supercapacitors](image)

9.2. **Solution of series connection of supercapacitors**

When higher voltage is required to supercapacitor in your system, you can get it by connecting some supercapacitors in series. For example, in case that battery voltage is over the rated voltage 4.2 V of supercapacitor, the voltage to supercapacitor should be reduced by buck convertor or some supercapacitors should be connected in series (Fig. 46). And also when you require higher energy, you can get it by boosting voltage to supercapacitor with some supercapacitors connected in series.

Please note that in case of N pieces connection in series, total capacitance becomes low to 1/N and total ESR becomes high to N times. However you would get higher energy (calculated from $E=\frac{1}{2}C*V^2$).

Additionally series connection has also an effect to reduce degradation of supercapacitor through long term. Such degradation depends on voltage. Therefore it is possible to reduce it by derating the impressed voltage per one supercapacitor.

In the case of series connection, please do not pair any different part (different capacitance, different series, new/old, and so on). Please pair supercapacitors of completely same part number.
If n pieces of supercapacitors are connected in series, the acceptable voltage of supercapacitor will be n times of the rated voltage.

Please design balance circuit in any connection (described in section 10).

![Series connection of supercapacitors](image)

**Fig. 46 Series connection of supercapacitors**

### 10. Balance circuit for long time use

Murata’s supercapacitors are consisted of two of capacitor unit cell in series for increasing voltage (Fig. 47). For example, DMF3Z5R5H474M3DTA0 (470mF) has two of 940mF cell in series. Therefore there is a possibility that each voltage that is impressed to each capacitor may be unbalanced due to variation of each capacitance or insulated resistance. When such unbalance occurs during using supercapacitor, impressed voltage to one cell will be high. If the voltage exceeds the limited value, it causes large electrical degradation. And difference of impressed voltage may also cause difference of life time between each cell, as a result, it may reduce life time of supercapacitor product.

For balance of such voltages, supercapacitors need to have balance control of each impressed voltages. There are two methods, one is passive balance control and the other is active balance control.

![Passive balance control](image)

**Fig. 47 Murata’s supercapacitors have two capacitors in series into one package**
10.1. Passive balance control

Passive balance control consists of resistances (Fig. 48). This is a simple and low cost solution. The resistance value should be decided with considering load pattern or current value. The lower resistance is, the faster balance convergence is. However power loss consumed through resistances becomes higher in using lower resistances (Table 7). Such power consumption loss will keep continuously even after voltage convergence.

For your choice, please choose resistance value within the range of your acceptable power consumption. Also please do not exceed the limited maximum value as shown in (Table 8).

Fig. 48 Passive balance circuit

Table 7 Balance resistance value and balance current/power consumption

<table>
<thead>
<tr>
<th>Resistance value</th>
<th>Maximum balance current</th>
<th>Convergence speed</th>
<th>Power consumption through resistances</th>
<th>Circuit loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1kΩ</td>
<td>4.2 mA</td>
<td>Faster</td>
<td>8.82 mW</td>
<td>Higher</td>
</tr>
<tr>
<td>10kΩ</td>
<td>420 uA</td>
<td>↑</td>
<td>882 uW</td>
<td>↑</td>
</tr>
<tr>
<td>100kΩ</td>
<td>42 uA</td>
<td>↓</td>
<td>88.2 uW</td>
<td>↓</td>
</tr>
<tr>
<td>1MΩ</td>
<td>4.2 uA</td>
<td>↓</td>
<td>8.82 uW</td>
<td></td>
</tr>
<tr>
<td>10MΩ</td>
<td>420 nA</td>
<td>Lower</td>
<td>882 nW</td>
<td>Lower</td>
</tr>
</tbody>
</table>

(note) Values in chart is in case of 4.2 V impressed to supercapacitor products.

(Reference) Insulated resistance of supercapacitor is over 1Mohm.
### 10.2. Active balance control

Active balance control is a circuit using operational amplifier (Fig. 49). This can provide faster convergence of voltage balance by current amplification function even if high resistances are used.

The rated voltage of operational amplifier should be higher than Vcc. Damping resistor may be needed in order to avoid abnormal oscillation. Operational amplifier should be chosen with considering power consumption and drive current (Table 9).

Active balance circuit works only in the condition of voltage unbalance. After voltage balance converged, there is only power consumption of unloaded condition. Therefore Active balance is excellent in energy efficiency. Operational amplifier with high slew rate has high speed motion and an advantage for short-time balance convergence. However such high-speed amplifier has high power consumption (Table 9). It should be chosen with considering your purpose.

There are dedicated ICs for voltage balance of supercapacitor. Table 10 shows the examples. Some ICs include charge/discharge voltage control function. Using these ICs is the best solution for voltage balance. In case of charge pump system IC, necessary external parts are only ceramic capacitors. However charge current is lower. In case of buck system IC or buck-boost system IC, charge current is high. However FET, power inductor and so on are needed.

<table>
<thead>
<tr>
<th>Impressed Voltage between + and -</th>
<th>Max. Balance Resistance value</th>
<th>P/N</th>
<th>Max. Balance Resistance value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>DMF3Z5R5H474M3DTA0</td>
<td>DMT334R2S474M3DTA0</td>
</tr>
<tr>
<td>~2.7V</td>
<td>No need balance</td>
<td>4.7 MΩ</td>
<td>4.7 MΩ</td>
</tr>
<tr>
<td>~3.0V</td>
<td>4.7 MΩ</td>
<td>4.7 MΩ</td>
<td></td>
</tr>
<tr>
<td>~3.2V</td>
<td>2.2 MΩ</td>
<td>2.2 MΩ</td>
<td></td>
</tr>
<tr>
<td>~3.6V</td>
<td>1.0 MΩ</td>
<td>1.0 MΩ</td>
<td></td>
</tr>
<tr>
<td>~4.0V</td>
<td>470 kΩ</td>
<td>220 kΩ</td>
<td></td>
</tr>
<tr>
<td>~4.2V</td>
<td>220 kΩ</td>
<td>4.7 kΩ</td>
<td></td>
</tr>
<tr>
<td>~4.5V</td>
<td>47 kΩ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>~5.0V</td>
<td>4.7 kΩ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Over 5.0V</td>
<td>1.0 kΩ</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 9 Operational amplifier properties

<table>
<thead>
<tr>
<th>Indication for choice</th>
<th>General Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow rate</td>
<td>Low ↔ High</td>
</tr>
<tr>
<td>Drive current</td>
<td>Low ↔ High</td>
</tr>
<tr>
<td>Power consumption</td>
<td>Low ↔ High</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>Narrow ↔ Wide</td>
</tr>
<tr>
<td>Application</td>
<td>Wide use ↔ Particular use</td>
</tr>
<tr>
<td>Cost</td>
<td>Low ↔ High</td>
</tr>
</tbody>
</table>

Table 10 Examples of dedicated ICs

<table>
<thead>
<tr>
<th>IC P/N</th>
<th>LTC3128</th>
<th>LTC3225</th>
<th>LTC3625</th>
<th>TPS61325</th>
</tr>
</thead>
<tbody>
<tr>
<td>Company</td>
<td>Linear Technology</td>
<td>Linear Technology</td>
<td>Linear Technology</td>
<td>TI</td>
</tr>
<tr>
<td>Circuit system</td>
<td>Buck-Boost</td>
<td>Charge pump</td>
<td>Buck-Boost</td>
<td>Boost</td>
</tr>
<tr>
<td>Max charge current</td>
<td>3 A</td>
<td>150 mA</td>
<td>1 A</td>
<td>220 mA</td>
</tr>
<tr>
<td>Input voltage</td>
<td>1.73 V ~ 5.5 V</td>
<td>2.8 V ~ 5.5 V</td>
<td>2.7 V ~ 5.5 V</td>
<td>2.5 V ~ 5.5 V</td>
</tr>
<tr>
<td>Output voltage</td>
<td>1.8 V ~ 5.5 V (variable)</td>
<td>4.8 V</td>
<td>4.8 V</td>
<td>3.825 V ~ 5.7 V</td>
</tr>
<tr>
<td>Package</td>
<td>20 pin QFN</td>
<td>10 pin DFN</td>
<td>12 pin DFN</td>
<td>20 pin CSP</td>
</tr>
<tr>
<td></td>
<td>24 pin TSSOP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

10.3. Comparison between passive balance and active balance

Table 11 shows comparison between passive balance and active balance. Passive balance method has advantages of small mount area and low cost. On the other hand, active balance method has advantages of high-speed balance convergence. Please choose balance method with considering function and cost.
Table 11 Comparison of passive and active balance

<table>
<thead>
<tr>
<th>Type</th>
<th>Passive balance (Resistances)</th>
<th>Active balance (OPAMP)</th>
<th>Active balance (Dedicated IC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mount area</td>
<td>Small</td>
<td>Middle to Large</td>
<td>Large</td>
</tr>
<tr>
<td>Circuit cost</td>
<td>Low</td>
<td>Middle</td>
<td>High</td>
</tr>
<tr>
<td>Power consumption</td>
<td>Low (1MΩ) ~ High (1kΩ)</td>
<td>Middle</td>
<td>Middle</td>
</tr>
<tr>
<td>Convergence speed</td>
<td>Slow</td>
<td>Fast</td>
<td>Fast</td>
</tr>
<tr>
<td>Operating voltage</td>
<td>No limit</td>
<td>Limited</td>
<td>Limited</td>
</tr>
<tr>
<td>Multiple series connection of supercaps</td>
<td>Possible</td>
<td>Possible</td>
<td>Limited</td>
</tr>
<tr>
<td>Operation during power-off</td>
<td>Possible</td>
<td>Impossible</td>
<td>Impossible</td>
</tr>
<tr>
<td>Control of charge voltage</td>
<td>Impossible</td>
<td>Impossible</td>
<td>Possible</td>
</tr>
</tbody>
</table>

11. Solder mounting method

Murata’s supercapacitor DMF/DMT series should be mounted by hand soldering. Please make pretreatment of your PCB in advance. The procedure is described below (Fig. 50).

1. Please put the solder paste on the land.
2. Please melt solder paste by reflow process (* 2) and form solder layer on the land.
3. Please temporarily fix the supercapacitor on the PCB by a double-stick tape or something.

![Fig. 50 Process of pretreatment]

After the pretreatment, please solder supercapacitor by hand. The procedure is described below (Fig. 51). Choose step 1-2-4 or step 1-3-4. There is a video tutorial for soldering. Please ask us for it.

1. Please heat both of supercapacitor terminal and PCB land by soldering iron and melt a solder on the land.
2. Please put the pre-cut length of solder wire (for Φ1mm, 2-3mm length) on a terminal (*4) and heat until it melts (*3).
3. Please put solder wire on a terminal and heat until it melts (*3).

*2 The condition of reflow profile depends on solder materials. Please confirm it with the vendor of solder paste. For reference, please see the following example of the reflow profile (Fig. 52).
*3 There is limited time for heating. It is 3.0 (+1/-0) seconds per one terminal (Fig. 53). Allowable soldering frequencies are 3 times per one supercapacitor. Please do not touch laminate package directly by solder iron.
*4 Please be careful not to break the terminals by pulling them by tweezers because those aluminum part is breakable.
**12. Safety of Murata's supercapacitors**

**12.1. Case of short circuit by any possibility**

Even if charged supercapacitor is externally short-circuited by any possibility, there are no leakage of electrolyte, no smoke, no ignition or no rupture. The reason is because of low energy inside unlike batteries. DMF or DMT has just only 5 to 10 joules of energy. Such energy is just equal to only 1°C to 2°C temperature increase of 1 g water. Therefore there is little heat generation in case of short.

For your information, when DMF3Z5R5H474M3DTA0 charged to 5.5 V is short-circuited, 120 A current will be flowed for a very short time (Fig. 54). Maximum current depends on internal resistance.

**12.2. Heat generation during use**

When you use supercapacitors, please note heat generation during charge/discharge. Such heat generation may be very small and it causes no problem in many situations because of very low energy in supercapacitors. However in case of high power and high frequency use, heat generation could be high as explained below.

Heating depends on consumption energy during charge or discharge of supercapacitor. Supercapacitor
has very lower energy than battery. For example, while 4V 3,000 mAh battery has approximately 40 kJ energy, DMF3Z5R5H474M3DTA0 (5.5V 470mF) or DMT334R2S474M3DTA0 (4.2V 470mF) has only approximately 4 J to 7 J energy (E=1/2*CV²). Therefore heat generation during charge or discharge will be very small. At a rough estimate, those Murata’s supercapacitors have approximately 1 J/K heat capacity, therefore even if all the energy is instantly discharged (short circuit case), temperature will possibly increase less than 10°C. And such temperature increase is momentary and it will decrease quickly by heat radiation.

However if charge/discharge cycle is repeated frequently, heat may be possibly accumulated into supercapacitor and increased temperature may keep continuously. It depends on current, frequency and duty ratio. It is related with balance between heat generation and heat radiation (Fig. 55).

Fig. 56 is an example of actual heat generation of supercapacitor. If 5A 30ms peak current is repeated per second to DMF4B5R5G105M3DTA0 (5.5V 1,000mF), temperature increases gradually. And it converges at 3°C increase after 300 seconds. This converging status means that heating generation is equal to heat radiation.