

## Ruggedized Electrical Double Layer Energy Storage Capacitors Up to 3 V Operating Voltage

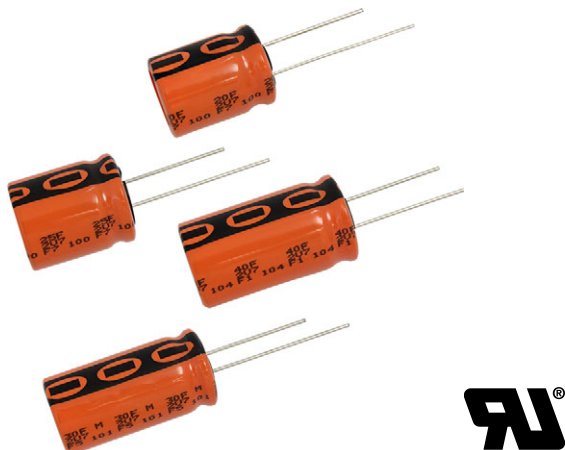


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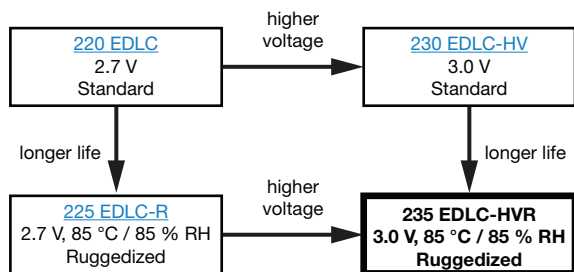


Fig. 1

| QUICK REFERENCE DATA                             |                                                                                                                                                                   |
|--------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| DESCRIPTION                                      | VALUE                                                                                                                                                             |
| Nominal case sizes<br>(Ø D x L in mm)            | 10 x 20; 10 x 25; 10 x 30;<br>12.5 x 20; 12.5 x 25; 12.5 x 30;<br>12.5 x 40; 16 x 20; 18 x 20;<br>16 x 25; 18 x 25; 16 x 31;<br><b>18 x 31</b> ; 18 x 35; 18 x 40 |
| Rated capacitance range, C <sub>R</sub>          | 5 F to 60 F                                                                                                                                                       |
| Rated voltage, U <sub>R</sub><br>(65 °C / 85 °C) | 3.0 V / 2.6 V<br>2.8 V / 2.4 V                                                                                                                                    |
| Category temperature range                       | -40 °C to +85 °C                                                                                                                                                  |
| Endurance test at 85 °C                          | Up to 1000 h                                                                                                                                                      |
| Useful life at 85 °C                             | Up to 2000 h                                                                                                                                                      |
| Useful life at 20 °C                             | > 10 years                                                                                                                                                        |
| Shelf life at 20 °C                              | 2 years                                                                                                                                                           |
| Cycle life                                       | > 500 000 cycles                                                                                                                                                  |

### FEATURES

- Polarized energy storage capacitor with high capacity and energy density
- Rated voltage: 3.0 V
- Available in through-hole (radial) version
- Useful life: up to 2000 h at 85 °C
- Ruggedized for high humidity operation
- Rapid charge and discharge
- Maintenance-free, no service necessary
- AEC-Q200 qualified (rev. E)
- UL 810A recognized
- Material categorization: for definitions of compliance please see [www.vishay.com/doc?99912](http://www.vishay.com/doc?99912)

AUTOMOTIVE  
GRADE



**RoHS**  
COMPLIANT

### APPLICATIONS

- Power backup
- Burst power support
- Storage device for energy harvesting
- Micro UPS power source
- Energy recovery

### MARKING

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

- Rated capacitance (in F)
- Rated voltage (in V)
- Date code, in accordance with IEC 60062
- Code indicating factory of origin
- Logo of manufacturer
- Negative terminal identification
- Series number (235)

### PACKAGING

Supplied loose in box, taped ammo, or in ESD trays.

| <b>SELECTION CHART FOR <math>C_R</math> AND RELEVANT NOMINAL CASE SIZES</b> |                               |
|-----------------------------------------------------------------------------|-------------------------------|
| $C_R$ (F)                                                                   | $U_R$ (V) = 3.0 V             |
| 5                                                                           | 10 x 20                       |
| 7                                                                           | 10 x 25                       |
| 8                                                                           | 12.5 x 20                     |
| 10                                                                          | 10 x 30                       |
| 12                                                                          | 12.5 x 25                     |
| 15                                                                          | 12.5 x 30                     |
| 20                                                                          | 16 x 20                       |
| 22                                                                          | 12.5 x 40                     |
| 25                                                                          | 16 x 25; 18 x 20              |
| 30                                                                          | 18 x 25                       |
| 35                                                                          | 16 x 31                       |
| 40                                                                          | <b>18 x 31</b> <sup>(1)</sup> |
| 50                                                                          | 18 x 35                       |
| 60                                                                          | 18 x 40                       |

**Note**
<sup>(1)</sup> Preferred case size

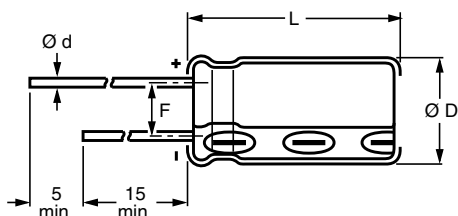
**DIMENSIONS in millimeters AND AVAILABLE FORMS**


Fig. 2 - Form CA / TRAY: long leads

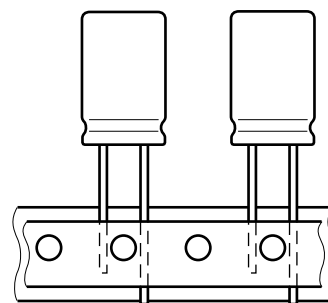


Fig. 3 - Form TFA: taped in box (ammopack)

**Table 1**

| <b>DIMENSIONS in millimeters, MASS, AND PACKAGING QUANTITIES</b> |           |     |                     |                   |           |             |                      |          |           |
|------------------------------------------------------------------|-----------|-----|---------------------|-------------------|-----------|-------------|----------------------|----------|-----------|
| NOMINAL CASE SIZE<br>Ø D x L                                     | CASE CODE | Ø d | Ø D <sub>max.</sub> | L <sub>max.</sub> | F         | MASS<br>(g) | PACKAGING QUANTITIES |          |           |
|                                                                  |           |     |                     |                   |           |             | FORM CA              | FORM TFA | FORM TRAY |
| 10 x 20                                                          | 16        | 0.6 | 10.5                | 22                | 5.0 ± 0.5 | ≈ 2.2       | 500                  | 800      | -         |
| 10 x 25                                                          | 16L       | 0.6 | 10.5                | 27                | 5.0 ± 0.5 | ≈ 3.0       | 500                  | 800      | -         |
| 10 x 30                                                          | 16LL      | 0.8 | 10.5                | 32                | 5.0 ± 0.5 | ≈ 3.5       | 500                  | 800      | -         |
| 12.5 x 20                                                        | 17        | 0.6 | 13.0                | 22                | 5.0 ± 0.5 | ≈ 4.0       | 500                  | 500      | -         |
| 12.5 x 25                                                        | 18        | 0.6 | 13.0                | 27                | 5.0 ± 0.5 | ≈ 5.0       | 250                  | 500      | -         |
| 12.5 x 30                                                        | 18L       | 0.8 | 13.0                | 33.5              | 5.0 ± 0.5 | ≈ 5.5       | 250                  | 500      | -         |
| 12.5 x 40                                                        | 18LL      | 0.8 | 13.0                | 42.5              | 5.0 ± 0.5 | ≈ 7.0       | 250                  | 500      | -         |
| 16 x 20                                                          | 19a       | 0.8 | 16.5                | 22                | 7.5 ± 0.5 | ≈ 6.0       | 250                  | 250      | 200       |
| 16 x 25                                                          | 19        | 0.8 | 16.5                | 27                | 7.5 ± 0.5 | ≈ 8.0       | 250                  | 250      | 200       |
| 18 x 20                                                          | 1820      | 0.8 | 18.5                | 22                | 7.5 ± 0.5 | ≈ 7.0       | 100                  | 250      | 200       |
| 18 x 25                                                          | 1825      | 0.8 | 18.5                | 27                | 7.5 ± 0.5 | ≈ 10.0      | 100                  | 250      | 200       |
| 16 x 31                                                          | 20        | 0.8 | 16.5                | 33.5              | 7.5 ± 0.5 | ≈ 9.0       | 100                  | 250      | 200       |
| 18 x 31                                                          | 1831      | 0.8 | 18.5                | 33.5              | 7.5 ± 0.5 | ≈ 12.5      | 100                  | 250      | 200       |
| 18 x 35                                                          | 22        | 0.8 | 18.5                | 37.5              | 7.5 ± 0.5 | ≈ 14.5      | 100                  | 250      | 200       |
| 18 x 40                                                          | 1840      | 0.8 | 18.5                | 42.5              | 7.5 ± 0.5 | ≈ 16.5      | 100                  | -        | 150       |



| ELECTRICAL DATA |                                                  |
|-----------------|--------------------------------------------------|
| SYMBOL          | DESCRIPTION                                      |
| $C_R$           | Rated capacitance, tolerance -20 % / +50 %       |
| $I_P$           | Max. peak current                                |
| $I_L$           | Max. leakage current after 0.5 h / 72 h at $U_R$ |

**Note**

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

**ORDERING EXAMPLE**

Capacitor series 235 EDLC-HVR

40 F / 3.0 V

Nominal case size: Ø 18 mm x 31 mm; Form TRAY

Ordering code: MAL223591001E3

**Table 2**

| ELECTRICAL DATA AND ORDERING INFORMATION |                       |                       |                                    |                    |                                         |                                             |                                                 |                                         |       |                                                              |                                        |       |                                                 |       |                               |             |              |
|------------------------------------------|-----------------------|-----------------------|------------------------------------|--------------------|-----------------------------------------|---------------------------------------------|-------------------------------------------------|-----------------------------------------|-------|--------------------------------------------------------------|----------------------------------------|-------|-------------------------------------------------|-------|-------------------------------|-------------|--------------|
| $U_R$<br>(V)                             | $U_{MT}^{(1)}$<br>(V) | $U_{CT}^{(2)}$<br>(V) | $U_S$<br>(V)<br>( $< 1\text{ s}$ ) | $C_R^{(3)}$<br>(F) | NOMINAL<br>CASE SIZE<br>Ø D x L<br>(mm) | MAX.<br>$ESR_{DC}^{(3)}$<br>INITIAL<br>(mΩ) | MAX.<br>$ESR_{AC}$<br>INITIAL,<br>1 kHz<br>(mΩ) | $I_P$<br>MAX.<br>PEAK<br>CURRENT<br>(A) |       | $I_L$<br>MAX.<br>LEAKAGE<br>CURRENT<br>AFTER<br>72 h<br>(µA) | STORED<br>ENERGY<br>E AT $U_R$<br>(Wh) |       | SPECIFIC<br>ENERGY<br>$E_d$ AT $U_R$<br>(Wh/kg) |       | ORDERING CODE<br>MAL2235..... |             |              |
| 65 °C                                    | 75 °C                 | 85 °C                 |                                    |                    |                                         |                                             |                                                 | 65 °C                                   | 85 °C |                                                              | 65 °C                                  | 85 °C | 65 °C                                           | 85 °C | FORM<br>CA                    | FORM<br>TFA | FORM<br>TRAY |
| 3.0                                      | 2.8                   | 2.6                   | 3.15                               | 5                  | 10 x 20                                 | 74                                          | 37                                              | 12                                      | 10    | 25                                                           | 0.006                                  | 0.005 | 2.8                                             | 2.1   | 51011E3                       | 31011E3     | -            |
| 3.0                                      | 2.8                   | 2.6                   | 3.15                               | 7                  | 10 x 25                                 | 60                                          | 30                                              | 12                                      | 10    | 35                                                           | 0.009                                  | 0.007 | 2.9                                             | 2.2   | 51012E3                       | 31012E3     | -            |
| 3.0                                      | 2.8                   | 2.6                   | 3.15                               | 8                  | 12.5 x 20                               | 58                                          | 29                                              | 15                                      | 12    | 40                                                           | 0.010                                  | 0.008 | 2.5                                             | 1.9   | 51014E3                       | 31014E3     | -            |
| 3.0                                      | 2.8                   | 2.6                   | 3.15                               | 10                 | 10 x 30                                 | 46                                          | 24                                              | 15                                      | 12    | 45                                                           | 0.013                                  | 0.009 | 3.6                                             | 2.7   | 51013E3                       | 31013E3     | -            |
| 3.0                                      | 2.8                   | 2.6                   | 3.15                               | 12                 | 12.5 x 25                               | 41                                          | 23                                              | 17                                      | 14    | 55                                                           | 0.015                                  | 0.011 | 3.0                                             | 2.3   | 51015E3                       | 31015E3     | -            |
| 3.0                                      | 2.8                   | 2.6                   | 3.15                               | 15                 | 12.5 x 30                               | 34                                          | 20                                              | 20                                      | 17    | 70                                                           | 0.019                                  | 0.014 | 3.4                                             | 2.6   | 51016E3                       | 31016E3     | -            |
| 3.0                                      | 2.8                   | 2.6                   | 3.15                               | 20                 | 16 x 20                                 | 38                                          | 22                                              | 25                                      | 20    | 75                                                           | 0.025                                  | 0.019 | 4.2                                             | 3.1   | 51003E3                       | 31003E3     | 91003E3      |
| 3.0                                      | 2.8                   | 2.6                   | 3.15                               | 22                 | 12.5 x 40                               | 26                                          | 15                                              | 25                                      | 20    | 75                                                           | 0.028                                  | 0.021 | 3.9                                             | 3.0   | 51017E3                       | 31017E3     | -            |
| 3.0                                      | 2.8                   | 2.6                   | 3.15                               | 25                 | 16 x 25                                 | 34                                          | 20                                              | 25                                      | 20    | 75                                                           | 0.031                                  | 0.023 | 3.9                                             | 2.9   | 51006E3                       | 31006E3     | 91006E3      |
| 3.0                                      | 2.8                   | 2.6                   | 3.15                               | 25                 | 18 x 20                                 | 36                                          | 19                                              | 25                                      | 20    | 75                                                           | 0.031                                  | 0.023 | 4.5                                             | 3.4   | 51004E3                       | 31004E3     | 91004E3      |
| 3.0                                      | 2.8                   | 2.6                   | 3.15                               | 30                 | 18 x 25                                 | 26                                          | 17                                              | 30                                      | 25    | 140                                                          | 0.038                                  | 0.028 | 3.8                                             | 2.8   | 51007E3                       | 31007E3     | 91007E3      |
| 3.0                                      | 2.8                   | 2.6                   | 3.15                               | 35                 | 16 x 31                                 | 24                                          | 18                                              | 30                                      | 25    | 200                                                          | 0.044                                  | 0.033 | 4.9                                             | 3.7   | 51002E3                       | 31002E3     | 91002E3      |
| 3.0                                      | 2.8                   | 2.6                   | 3.15                               | 40                 | 18 x 31                                 | 24                                          | 16                                              | 35                                      | 30    | 200                                                          | 0.050                                  | 0.038 | 4.0                                             | 3.0   | 51001E3                       | 31001E3     | 91001E3      |
| 3.0                                      | 2.8                   | 2.6                   | 3.15                               | 50                 | 18 x 35                                 | 22                                          | 14                                              | 35                                      | 30    | 250                                                          | 0.063                                  | 0.047 | 4.3                                             | 3.2   | 51008E3                       | 31008E3     | 91008E3      |
| 3.0                                      | 2.8                   | 2.6                   | 3.15                               | 60                 | 18 x 40                                 | 22                                          | 13                                              | 35                                      | 30    | 300                                                          | 0.075                                  | 0.056 | 4.5                                             | 3.4   | 51009E3                       | -           | 91009E3      |

**Notes**

- (1)  $U_{MT}$  = rated voltage at 75 °C  
 (2)  $U_{CT}$  = rated voltage at upper category temperature  
 (3) Rated capacitance  $C_R$  and maximum  $ESR_{DC}$  are typical values for case sizes

**Table 3**

| ENDURANCE TEST DURATION AND USEFUL LIFE |           |                           |                             |
|-----------------------------------------|-----------|---------------------------|-----------------------------|
| NOMINAL CASE SIZE<br>Ø D x L            | CASE CODE | ENDURANCE AT 85 °C<br>(h) | USEFUL LIFE AT 85 °C<br>(h) |
| 10 x 20                                 | 16        | 750                       | 1000                        |
| 10 x 25                                 | 16L       | 750                       | 1000                        |
| 10 x 30                                 | 16LL      | 750                       | 1000                        |
| 12.5 x 20                               | 17        | 1000                      | 1500                        |
| 12.5 x 25                               | 18        | 1000                      | 1500                        |
| 12.5 x 30                               | 18L       | 1000                      | 1500                        |
| 12.5 x 40                               | 18LL      | 1000                      | 1500                        |
| 16 x 20                                 | 19a       | 1000                      | 2000                        |
| 16 x 25                                 | 19        | 1000                      | 2000                        |
| 18 x 20                                 | 1820      | 1000                      | 2000                        |
| 18 x 25                                 | 1825      | 1000                      | 2000                        |
| 16 x 31                                 | 20        | 1000                      | 2000                        |
| 18 x 31                                 | 1831      | 1000                      | 2000                        |
| 18 x 35                                 | 22        | 1000                      | 2000                        |
| 18 x 40                                 | 1840      | 1000                      | 2000                        |

**Table 4**

| <b>RUGGEDIZED FOR HIGH HUMIDITY - BIASED HUMIDITY TESTING</b> |                              |                                                                                                                                                                                                                                                                                    |
|---------------------------------------------------------------|------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| PARAMETER                                                     | PROCEDURE (AT RATED VOLTAGE) | REQUIREMENTS                                                                                                                                                                                                                                                                       |
| Humidity (relative)                                           | 85 %                         | After loading the capacitor for the specified time at maximum category temperature $T_{max.} = 85^{\circ}\text{C}$ and 85 % relative humidity, and derated permissible maximum operation voltage $U = 2.6\text{ V}$ , following parameters are valid within a timeframe of 1000 h: |
| Temperature                                                   | 85 °C                        | No visible damage<br>No leakage of electrolyte<br>$\Delta C/C$ : within $\pm 30\%$ of minimum initial specified value<br>ESR: less than 3 x initial specified value<br>Leakage: less than initial specified value                                                                  |

| <b>TEST PROCEDURES AND REQUIREMENTS <sup>(1)</sup></b> |                                                                                                                                                                                                                                                                                                                                            |                                                      |
|--------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------|
| NAME OF TEST                                           | PROCEDURE<br>(quick reference)                                                                                                                                                                                                                                                                                                             |                                                      |
| Capacitance $C_R$ and $ESR_{DC}$                       | Measured by DC discharging method as described in "Measuring of Characteristics". <sup>(2)</sup>                                                                                                                                                                                                                                           |                                                      |
| Maximum peak current                                   | Non-repetitive current for maximum 1 s at specified operating temperature. Maximum operating voltage (refer to derating table) must not be exceeded. Usually to be tested with constant current discharge from $U_R$ to $0.5 \times U_R$ . Maximum current should not be used in normal operation and is only provided as reference value. |                                                      |
| Leakage current $I_L$                                  | Measured at $U_R$ . Capacitor is charged to the rated voltage at $20^{\circ}\text{C}$ . Leakage current is the current at specified time that is required to keep the capacitor charged at the rated voltage.                                                                                                                              |                                                      |
| Endurance                                              | After loading the capacitor of specified time at maximum category temperature $T_{max.} = 85^{\circ}\text{C}$ and derated permissible maximum operating voltage $U = 2.6\text{ V}$ , following parameters are valid within a timeframe as specified in Table 3:                                                                            |                                                      |
|                                                        | Capacitance                                                                                                                                                                                                                                                                                                                                | Within $\pm 30\%$ of minimum initial specified value |
|                                                        | ESR                                                                                                                                                                                                                                                                                                                                        | Less than 3 x initial specified value                |
|                                                        | Leakage                                                                                                                                                                                                                                                                                                                                    | Within specified value                               |
| Useful life                                            | After loading the capacitor of specified time at maximum category temperature $T_{max.} = 85^{\circ}\text{C}$ and derated permissible maximum operating voltage $U = 2.6\text{ V}$ , following parameters are valid within a timeframe as specified in Table 3:                                                                            |                                                      |
|                                                        | Capacitance                                                                                                                                                                                                                                                                                                                                | Within $\pm 50\%$ of minimum initial specified value |
|                                                        | ESR                                                                                                                                                                                                                                                                                                                                        | Less than 4 x initial specified value                |
|                                                        | Leakage                                                                                                                                                                                                                                                                                                                                    | Within specified value                               |
| Storage at upper category temperature                  | After loading the capacitor of specified time at maximum category temperature $T_{max.} = 85^{\circ}\text{C}$ and without charge and under 40 % RH, following parameters are valid within a timeframe of 1000 h:                                                                                                                           |                                                      |
|                                                        | Capacitance                                                                                                                                                                                                                                                                                                                                | Within $\pm 30\%$ of minimum initial specified value |
|                                                        | ESR                                                                                                                                                                                                                                                                                                                                        | Less than 3 x initial specified value                |
|                                                        | Leakage                                                                                                                                                                                                                                                                                                                                    | Within specified value                               |
| Shelf life                                             | Stored uncharged at $20^{\circ}\text{C}$ .<br>Parameter within initial specification                                                                                                                                                                                                                                                       |                                                      |
| Cycle life                                             | Cycles at $20^{\circ}\text{C}$ between rated voltage and half of rated voltage $U_R$ with constant current and 1 s rest between charge and discharge: > 500 000 cycles                                                                                                                                                                     |                                                      |
|                                                        | Capacitance                                                                                                                                                                                                                                                                                                                                | Within $\pm 30\%$ of minimum initial specified value |
|                                                        | ESR                                                                                                                                                                                                                                                                                                                                        | Less than 3 x initial specified value                |
| Stored energy $E_s$ , specific energy $E_d$ and $E_v$  | $E [\text{Wh}] = \frac{1}{2} \times C \times (U_R)^2 \times 1/3600$<br>$E_d [\text{Wh/kg}] = \frac{1}{2} \times C \times (U_R)^2 \times 1/3600 \times 1/\text{mass}$<br>$E_v [\text{Wh/L}] = \frac{1}{2} \times C \times (U_R)^2 \times 1/3600 \times 1/\text{volume}$                                                                     |                                                      |
| Soldering                                              | Hand or wave soldering allowed. For details refer to soldering requirements for radial aluminum electrolytic capacitors in supplementary document.                                                                                                                                                                                         |                                                      |
| Cleaning                                               | For printed circuit board cleaning apply non-aggressive cleaning agents only.<br>For details refer to cleaning requirements for aluminum electrolytic capacitors in supplementary document.                                                                                                                                                |                                                      |
| Environmental conditions                               | Do not expose capacitors to <ul style="list-style-type: none"> <li>temperatures outside specified range</li> <li>high humidity atmospheres</li> <li>corrosive atmospheres, e.g. halogenides, sulphurous or nitrous gases, acid or alkaline solutions, etc.</li> <li>environments containing oil and grease</li> </ul>                      |                                                      |

**Notes**

- General remark: temperatures to be measured at capacitor case
- <sup>(1)</sup> Conditions: electrical measurements at  $20^{\circ}\text{C}$ , unless otherwise specified
- <sup>(2)</sup> Rated capacitance  $C_R$  and  $ESR_{DC}$

## MEASURING OF CHARACTERISTICS

### CAPACITANCE (C)

Capacitance shall be measured by constant current discharge method.

- Constant current charge with 10 mA/F to  $U_R$
- Constant voltage charge at  $U_R$
- Constant current discharge with 10 mA/F to 0.1 V

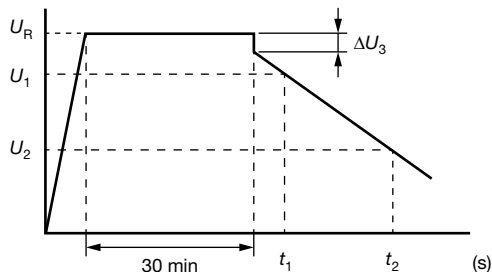


Fig. 4 - Voltage Diagram for Capacitance Measurement

Capacitance value  $C_R$  is given by discharge current  $I_D$ , time  $t$  and rated voltage  $U_R$ , according to the following equation:

$$C_R [F] = \frac{I_D [A] \times (t_2 [s] - t_1 [s])}{U_1 [V] - U_2 [V]}$$

|              |                                                                   |
|--------------|-------------------------------------------------------------------|
| $C_R$        | Rated capacitance, in F                                           |
| $U_R$        | Rated voltage, in V                                               |
| $U_1$        | Starting voltage, $0.8 \times U_R$ in V                           |
| $U_2$        | Ending voltage, $0.4 \times U_R$ in V                             |
| $\Delta U_3$ | Voltage drop at internal resistance, in V                         |
| $t_1$        | Time from start of discharge until voltage $U_1$ is reached, in s |
| $t_2$        | Time from start of discharge until voltage $U_2$ is reached, in s |
| $I_D$        | Absolute value of discharge current, in A                         |

### EQUIVALENT SERIES RESISTANCE ( $ESR_{DC}$ )

- Constant current charge to  $U_R$
- Constant voltage charge at  $U_R$
- Constant current discharge to 0.1 V

$$ESR_{DC} [\Omega] = \frac{\Delta U_3 [V]}{I_D [A]}$$

|              |                                           |
|--------------|-------------------------------------------|
| $ESR_{DC}$   | Equivalent series resistance, in $\Omega$ |
| $\Delta U_R$ | Voltage drop at internal resistance, in V |
| $I_D$        | Absolute value of discharge current, in A |

Statements about product lifetime are based on calculations and internal testing. They should only be interpreted as estimations. Also due to external factors, the lifetime in the field application may deviate from the calculated lifetime. In general, nothing stated herein shall be construed as a guarantee of durability.



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