Wireless Power Transfer for EV
# Power and charging time relation

\[
\text{charging\_time} = \frac{\text{Battery\_energy}}{\text{Power\_charger}}
\]

<table>
<thead>
<tr>
<th>SAE J2954/1 charging standard</th>
<th>WPT1</th>
<th>WPT2</th>
<th>WPT3</th>
<th>WPT4</th>
<th>WPT5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>3.7 kW</td>
<td>7.7 kW</td>
<td>11 kW</td>
<td>22 kW</td>
<td>&gt; 22kW to 150kW</td>
</tr>
<tr>
<td>Charging time (100kWh battery)</td>
<td>27h</td>
<td>13</td>
<td>9</td>
<td>4.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Minimum Target Efficiency</td>
<td>&gt; 85%</td>
<td>&gt; 85%</td>
<td>&gt; 85%</td>
<td>TBD</td>
<td>-</td>
</tr>
<tr>
<td>Frequency</td>
<td>85 kHz within international frequency bandwidth [81.38 – 90] kHz</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target Vehicle</td>
<td>Light-vehicle</td>
<td>Light-vehicle</td>
<td>Light-vehicle</td>
<td>Light-vehicle</td>
<td>Heavy-vehicle (Bus)</td>
</tr>
<tr>
<td>Input Voltage</td>
<td>Single phase 120Vac</td>
<td>Single phase 240Vac</td>
<td>Single phase 240Vac</td>
<td>Three phases 240Vac or 480Vac</td>
<td></td>
</tr>
</tbody>
</table>
AC voltage from the mains is converted into DC to charge the battery supported by a wireless induction power transfer.

AC/DC - EMC filtering, rectifying and smoothing to DC, PFC stage increases efficiency by transforming the input current close to sinusoidal waveform that is in phase with the grid voltage and therefore improving power factor.

DC/AC - creates high frequency AC voltage of 80 to 120kHz.

Compensation networks used to improve system efficiency, reduce additional losses – resonant capacitor.

Sender and receiver coils supported by ferrite plates to enhance and direct the magnetic coupling for wireless transfer.

AC/DC - High frequency AC converted to high power and high voltage DC.

BMS – battery management system – power control, communication, checks the battery level, stable and safe operation.
AC to DC converter
Circuit Description and Operation
Wireless power transfer

Highest efficiency is achieved at resonance

\[ f = \frac{1}{2\pi\sqrt{LC}} \]

- AC Voltage
- Stability with Voltage and Temperature
- High AC current
- AEC-Q200

\[ \text{Efficiency} = \frac{\text{Output Power}}{\text{Input Power}} \times 100\% \]

Usually 80 to 120kHz
KEMET Portfolio

Transmitter (charging stand)

1. AC/DC converter with PFC
2. DC/AC inverter
3. LC compensation network
4. LC compensation network
5. AC/DC converter

Receiver (car)

BMS

grid

1. Customized CMC
2. Safety XY caps X2: F863/F862 Y2: R41 V026 X1: R47 –
3. ALA7D and ALA8D
4. C4AQ series
5. Kc-link
6. Ferrite Tiles

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EMI Safety X/Y Capacitors

F862
X2
310 VAC
0.1 ~ 4.7 μF
Up to +110 °C
15.0 ~ 27.5 mm
1,000hrs @
85°C / 85 R.H.
ΔC ≤ 10%
Δtanδ ≤ 5x10⁻³
Rins: ≥ 50%

F863
X2
310 VAC
0.1 ~ 10.0 μF
Up to +110 °C
15.0 ~ 37.5 mm
500hrs @
85°C / 85 R.H.
ΔC ≤ 10%
Δtanδ ≤ 5x10⁻³
Rins: ≥ 50%

R41
Y2
300 VAC
1,000 – 1,5000 Vdc
0.001 ~ 1 μF
Up to +110 °C
10 ~ 37.5 mm
1,000hrs @
85°C / 85 R.H.
ΔC ≤ 10%
Δtanδ ≤ 5x10⁻³; Rins: ≥ 50%

R47
X1
440 VAC
0.0047 ~ 2.2 μF
Up to +110°C
10.0 ~ 37.5 mm
Under Development
500hrs @
85°C / 85 R.H.
F874
Common mode chokes

customized ferrite or nanocrystal choke solutions up to 60A / 1000VDC
Temperature ranges up to 155°C ambient AEC-Q200 / PPAP / IMDS plant experienced engineering team

• Today no standard parts are available
• Due to various mechanical standards KEMET can semi-customize products in specific existing shapes with different wires (diameter, turns, number of parallel wires) ->> for smaller volumes
• Flat top surface capable to be attached to a heat sink
• Full customization is available for volumes from ~ 500k pcs EAU upwards and 5 to 10 years lifetime of projects
High temperature common mode chokes for automotive power applications

- Materials: 5HT, 7HT is the new material that offers 40% better noise attenuation in the same dimensions
- Ambient temperatures above 150°C
Common mode chokes

CM current superposition characteristics (Coil: FR47 D1.8-3P 10T Single)

\[ L = \frac{\mu_0 \mu_r A_c n^2}{l_{\text{eff}}} \]
## Dual Mode Chokes
### SCN Series

**Magnetic flux is under control based on electromagnetic simulation.**

<table>
<thead>
<tr>
<th><strong>Wire diameter</strong></th>
<th>$\Phi1.2\text{mm}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Turns</strong></td>
<td>$17\ T$</td>
</tr>
<tr>
<td><strong>Rated current</strong></td>
<td>$25\text{A}$</td>
</tr>
<tr>
<td><strong>Common Mode Impedance</strong></td>
<td>$100\text{kHz}$</td>
</tr>
<tr>
<td></td>
<td>$200\text{kHz}$</td>
</tr>
<tr>
<td><strong>Common Mode Inductance</strong></td>
<td>$100\text{kHz}$</td>
</tr>
<tr>
<td><strong>Differential Mode Inductance</strong></td>
<td>$100\text{kHz}$</td>
</tr>
<tr>
<td><strong>$R_{DC}$ per line Typ.</strong></td>
<td></td>
</tr>
</tbody>
</table>
AC/DC leakage current sensor with excellent offset characteristics with temperature & current

Contribute to 6mA DC detection based on IEC62752
C4AF - AC Filtering Capacitor - Snubber

- **Applications**
  - Clamping
  - AC and Harmonic Filtering
  - Power Factor Correction
  - Inverter Systems
  - Motor Drives
  - Renewable Energy Systems
  - Battery Chargers

- **Benefits**
  - Self-healing
  - Low losses
  - High ripple current
  - High contact reliability
  - Optimized AC voltage performance
  - Suitable for high frequency applications
  - High Reliability on Harsh Environmental Conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Capacitance</td>
<td>62 uF</td>
</tr>
<tr>
<td>Maximum Voltage (at 85°C)</td>
<td>400 VAC</td>
</tr>
<tr>
<td></td>
<td>280 VAC</td>
</tr>
<tr>
<td>Maximum Temperature</td>
<td>+105 °C</td>
</tr>
<tr>
<td>THB @ 85°C / 85 R.H.</td>
<td>500 Hours</td>
</tr>
<tr>
<td>Qualification</td>
<td>AEC-Q200</td>
</tr>
</tbody>
</table>

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C4AQ - DC-Link Capacitor

• **Applications**
  Motor drives  
  Inverters; rectifiers  
  Charging stations  
  Energy Storage  
  On-Board Battery Chargers  
  Wireless power transfer EV

• **Benefits**
  polypropylene metallized film  
  rectangular plastic box-type  
  AEC-Q200; harsh environment  
  High Capacitance Density  
  100,000 hours at Hot Spot ≤70°C  
  Low losses  
  High ripple current  
  Requiring more than 10 years of expected life in steady conditions  
  **Lifetime dependant from the operating voltage and temperature**

<table>
<thead>
<tr>
<th>Maximum Capacitance</th>
<th>270 μF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Voltage</td>
<td>1,500 VDC</td>
</tr>
<tr>
<td>Maximum Temperature</td>
<td>+105 °C</td>
</tr>
<tr>
<td>Qualification</td>
<td>AEC-Q200</td>
</tr>
</tbody>
</table>

improve the efficiency of the systems, balancing the power difference between the input source and output load, and minimizing voltage variation.
C4AQ series DC-Link Applications
Hot spot calculation

The hot spot is the internal point of the capacitor where the temperature reaches maximum value.

Rth and ESR are listed in the catalogue as a function of cap and Rated Voltage.

Table 1 – Ratings & Part Number Reference

<table>
<thead>
<tr>
<th>Cap Value (μF)</th>
<th>VDC</th>
<th>Dimensions (mm)</th>
<th>dV/dt</th>
<th>Ipkr</th>
<th>ESL 70°C at 10 kHz</th>
<th>Irms* 70°C at 10 kHz</th>
<th>Rth (HS/Amb) (°C/W)</th>
<th>Packaging Quantity</th>
<th>PART NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.6</td>
<td>500</td>
<td>11</td>
<td>20</td>
<td>31.5</td>
<td>27.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>500</td>
<td>13</td>
<td>25</td>
<td>31.5</td>
<td>27.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.5</td>
<td>500</td>
<td>14</td>
<td>28</td>
<td>31.5</td>
<td>27.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>500</td>
<td>19</td>
<td>29</td>
<td>31.5</td>
<td>27.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>500</td>
<td>22</td>
<td>37</td>
<td>31.5</td>
<td>27.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>500</td>
<td>20</td>
<td>40</td>
<td>37.5</td>
<td>10.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>500</td>
<td>28</td>
<td>37</td>
<td>37.5</td>
<td>10.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>500</td>
<td>30</td>
<td>45</td>
<td>37.5</td>
<td>20.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Life calculation example:
Hotspot = 85°C
Working voltage 810Vdc,
Rated Voltage 1100Vdc (select the graph)
Lifetime expectancy requested → 100,000 hours

Step 1) Select 85°C Hotspot curve
Step 2) Select the Voltage
Step 3) Output lifetime expectancy
The value of Lifetime Expectancy is higher than 100k hours
Ceramic Resonant, DC-LINK, and Snubber Capacitor
KC-LINK™ Class I Ceramic Capacitors

- No change of Capacitance due to applied voltage
- Ultra low ESR gives rise to high ripple current capability with minimal self heating; (Ripple Currents >>15 Amps achievable)
- Specifically designed to work with stable operation even up to 150°C
Ceramic Resonant, DC-LINK, and Snubber Capacitor
KC-LINK™ Class I Ceramic Capacitors – product range

<table>
<thead>
<tr>
<th>Capacitance</th>
<th>Cap Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.7 nF</td>
<td>472</td>
</tr>
<tr>
<td>5.6 nF</td>
<td>562</td>
</tr>
<tr>
<td>6.8 nF</td>
<td>622</td>
</tr>
<tr>
<td>8.2 nF</td>
<td>682</td>
</tr>
<tr>
<td>10 nF</td>
<td>103</td>
</tr>
<tr>
<td>12 nF</td>
<td>123</td>
</tr>
<tr>
<td>15 nF</td>
<td>153</td>
</tr>
<tr>
<td>18 nF</td>
<td>183</td>
</tr>
<tr>
<td>22 nF</td>
<td>223</td>
</tr>
<tr>
<td>33 nF</td>
<td>333</td>
</tr>
<tr>
<td>39 nF</td>
<td>393</td>
</tr>
<tr>
<td>47 nF</td>
<td>473</td>
</tr>
<tr>
<td>56 nF</td>
<td>563</td>
</tr>
<tr>
<td>68 nF</td>
<td>683</td>
</tr>
<tr>
<td>82 nF</td>
<td>823</td>
</tr>
<tr>
<td>100 nF</td>
<td>104</td>
</tr>
<tr>
<td>150 nF</td>
<td>154</td>
</tr>
<tr>
<td>180 nF</td>
<td>184</td>
</tr>
<tr>
<td>220 nF</td>
<td>224</td>
</tr>
<tr>
<td>470 nF</td>
<td>474</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case Size</th>
<th>1812</th>
<th>2220</th>
<th>3640</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Voltage (VDC)</td>
<td>650</td>
<td>1,000</td>
<td>500</td>
</tr>
<tr>
<td>Capacitance Tolerance</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Ceramic Resonant Capacitor
KC-LINK with KONNEKT for High Power Density

- KONNEKT uses a Transient Liquid Phase Sintering (TLPS) technology to combine multiple components together using a conductive mechanical bond.
- KONNEKT allows for much higher power densities by creating a single component which can be mounted in low loss orientation.
- Low ESR, low inductance, and low thermal resistance allows for very high ripple current capability.
AEC-Q200 Electrolytic Snap-In Capacitors—ALA7D/8D

- Main application is the on-board charger, WPT, inverters
- AEC-Q200 approved
- Can withstand vibrations up to 20G
- 85°C and 105°C products in voltage ranges from 400V-600V
- Lifetime up to 15kh under applied rated voltage and ripple current
- High ripple current
- Low ESR and ESL
- High voltage
- Optimized designs available on request

Anti-Vibration Groove fix the winding in the can

Post-Grooved Can
Line-Up Snap-In Capacitors

- **ELH**
  - General Purpose
  - 2khrs / 85°C
  - High Ripple / LOW ESR and ESL

- **PEH506**
  - Long Life (up to 3kh)
  - High Ripple

- **PEH526**
  - Long Life (up to 3kh)
  - High Ripple, High Vib

- **ALC10**
  - Very Long Life (up to 18kh)
  - High Ripple

- **ALC40**
  - Long Life (up to 9kh)
  - High Ripple

- **ALC70**
  - High CV / Small Size
  - Long Life / High Ripple

- **ALC80**
  - High CV / Small Size
  - Long Life / High Ripple

- **ALF70**
  - Press fit
  - No soldering

- **ALF80**
  - Press fit
  - No soldering

- **ALA7D**
  - Automotive
  - AEC-Q200

- **ALA8D**
  - Automotive
  - AEC-Q200

- **ELG**
  - General Purpose
  - 2khrs / 105°C
  - High Ripple
  - Long Life / LOW ESR and ESL

- **PEH532/534/536**
  - High Ripple
  - Long Life

- **ELD**
  - General Purpose
  - 3khrs / 105°C
  - Long Life / LOW ESR and ESL

- **ALC10**
  - Long Life
  - High Ripple / LOW ESR and ESL

- **ALC40**
  - Long Life (up to 9kh)
  - High Ripple

- **ALC80**
  - High CV / Small Size
  - Long Life / High Ripple

- **ALF70**
  - Press fit
  - No soldering

- **ALF80**
  - Press fit
  - No soldering

- **ALA7D**
  - Automotive
  - AEC-Q200

- **ALA8D**
  - Automotive
  - AEC-Q200
AEC-Q200 Electrolytic Snap-In Capacitors

- Unique Selling Point
  - Post-Grooved Can
  - Anti-Vibration Groove fix the winding in the can

The Winding is fixed by the additional Anti-Vibration-Groove

- Diameter maximization of the wound element – maximum fit to can
- Optimized materials for excellent crush of the wound element – axial and radial fixation
- Post-grooved aluminum can – radial fixation
- Anti-vibration groove – radial fixation
Lifetime Calculator on the web
https://elc.kemet.com/
<table>
<thead>
<tr>
<th>Results</th>
<th>1.19</th>
<th>1.19</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal res. (core-can) °C/W</td>
<td>2.63</td>
<td>2.63</td>
</tr>
<tr>
<td>Thermal res. (can-ambient) °C/W</td>
<td>0.74</td>
<td>1.63</td>
</tr>
<tr>
<td>Total wattage W</td>
<td>72.84</td>
<td>86.21</td>
</tr>
<tr>
<td>Core temperature °C</td>
<td>71.96</td>
<td>84.27</td>
</tr>
<tr>
<td>Can base temperature °C</td>
<td>84</td>
<td>31</td>
</tr>
<tr>
<td>Life (per condition) khrs</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**LIFE (aggregate) khrs**

**45**

**End of Life Criteria**

- Capacitance change
- ESR change
- Leakage current change

**Comparison to competition is needed!**

Samples with Thermocouples are available on request to confirm the calculation.
Pulse and resonant capacitors
Metallized and Film-Foil Polypropylene

- **R73**
  - **Film- Foil**
  - $-55 \, ^\circ\mathrm{C} \sim +105 \, ^\circ\mathrm{C}$
  - $100 \sim 2,000 \, \text{VDC}$
  - $100 \, \text{pF} \sim 2.2 \, \mu\text{F}$
  - Resonance, Snubber, and Switching circuits

- **R74**
  - **Single Metallized**
  - Up to $125^\circ\mathrm{C}$ Available
  - $250-900 \, \text{VDC}$
  - $470 \, \text{pF} - 3.3 \, \mu\text{F}$
  - High current & voltage applications
  - Electronic Lighting
  - Pulse with high AC content

- **R75**
  - **Single Metallized**
  - $-55^\circ\mathrm{C} \sim +105^\circ\mathrm{C}$
  - $160 - 2,000 \, \text{VDC}$
  - $220 \, \text{pF} - 33 \, \mu\text{F}$
  - Multi purposes
  - Resonant Circuits
  - PFC, Coupling
  - Timing, Oscillators

- **R76**
  - **Double Metallized**
  - $-55^\circ\mathrm{C} \sim +105^\circ\mathrm{C}$
  - $250 - 2,000 \, \text{VDC}$
  - $100 \, \text{pF} - 15 \, \mu\text{F}$
  - Switching spikes suppression
  - High voltage
  - & high current
  - Commutation circuits
Magnetics
Wireless charging ferrite

➢ increase system efficiency by shielding and reflecting of the magnetic field within the inductive transfer area
➢ Increased efficiency in high power WPT systems from 3.7 to 11kW.
➢ High operating frequency range up to 1MHz
➢ Low temperature rise with high magnetic flux density -40°C to 125°C operating temperature.

Two materials: BH1T and BH8

Low loss
➢ BH1T: the temperature characteristics of loss is flat
➢ BH8: The lowest loss at high operating temperature (120°C)

• Initial permeability
➢ BH1T: 3000 (at 100kHz)
➢ BH8: 2300 (at 100kHz)

• Standard or customized solutions – manufactured by our own ferrite material, can adapt the material type and shape to the customer application
Magnetics
Wireless charging ferrite - BH1T Data sheet

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Dimensions (mm)</th>
<th>Weight (g)</th>
<th>Power (kW)</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>FPL100/100/4-BH1T</td>
<td>100</td>
<td>100</td>
<td>4</td>
<td>195</td>
</tr>
<tr>
<td>FPL100/100/6-BH1T</td>
<td>100</td>
<td>100</td>
<td>6</td>
<td>295</td>
</tr>
<tr>
<td>FPL100/100/8-BH1T</td>
<td>100</td>
<td>100</td>
<td>8</td>
<td>395</td>
</tr>
<tr>
<td>FPL100/100/10-BH1T</td>
<td>100</td>
<td>100</td>
<td>10</td>
<td>490</td>
</tr>
<tr>
<td>FPL100/100/12-BH1T</td>
<td>100</td>
<td>100</td>
<td>12</td>
<td>590</td>
</tr>
</tbody>
</table>

Almost the same attenuation

Lower losses than competitor

Fig 1. Permeability $\mu'$, $\mu''$ vs Frequency

Fig 2. Permeability $\mu_i$ vs Temperature

Fig 4. Core loss $P_{cv}$ vs Flax density $B$

Fig 5. Core loss $P_{cv}$ vs Temperature
Flexsuppressor® Sheets
Noise suppression sheets for EMI and interference

- High frequency attenuation / cross talk challenges >1GHz
- 2 noise suppression series AEC-Q200 compliant - FF1 & EFF4
- BMS systems, GaN & SiC HF attenuation
- Sandwich materials i.e. PET isolation top on request
- Partner for specific cuts available per customer drawing

Features

<table>
<thead>
<tr>
<th></th>
<th>High permeability AECQ200</th>
<th>Extra high permeability AECQ200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>FF1</td>
<td>EFF4</td>
</tr>
<tr>
<td>Effective Frequency</td>
<td>Up to 10 GHz</td>
<td>Up to 10 GHz</td>
</tr>
<tr>
<td>Operating Temperature (ºC)</td>
<td>-40 to +105</td>
<td>-40 to +105</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>0.05/0.1/0.2/0.3</td>
<td>0.1/0.2/0.3/0.5</td>
</tr>
<tr>
<td>Standard Dimensions (mm)</td>
<td>240 x 240 (roll on request)</td>
<td>240 x 240</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>3.1 typical</td>
<td>3.7 typical</td>
</tr>
<tr>
<td>Surface Resistance (Ω)</td>
<td>1.0 x 10⁶ minimum</td>
<td>1.0 x 10⁶ minimum</td>
</tr>
<tr>
<td>Therm. Conductivity(W/m-K)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approved Standard</td>
<td>UL94 V-0</td>
<td>UL File No. E176124</td>
</tr>
<tr>
<td>Environment</td>
<td>RoHS Compliant</td>
<td>Compliant</td>
</tr>
<tr>
<td></td>
<td>Halogen Free</td>
<td>Free</td>
</tr>
<tr>
<td></td>
<td>PVC Free</td>
<td>Free</td>
</tr>
<tr>
<td></td>
<td>Lead Free</td>
<td>Free</td>
</tr>
<tr>
<td></td>
<td>Red Phosphorus</td>
<td>Free</td>
</tr>
</tbody>
</table>

Remarks

- μ100 high permeability, AECQ200 qualified Flame retardant (UL 94 V-0 certified)
- μ140 high permeability, AECQ200 qualified for FM, LTE 1GHz

Fig. from IEC62333-2
THANK YOU

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