

# Using MLCCs in Wireless Power Transfer Resonant Circuits

From watches and phones to electric vehicles, wireless power transfer (WPT) systems for charging batteries are becoming ubiquitous. Wireless power transfer offers many advantages, including the elimination of power cords and the increase of safety and durability.

Automotive applications always require special care, and WPT in electric vehicles are no exception. Reliability and safety are both critical for users and regulated by third parties. So properly understanding, selecting, and using components is of the utmost importance.

## HOW A WIRELESS POWER TRANSFER RESONANT CIRCUIT WORKS

In electronic circuits, a resonant circuit is formed whenever an inductor (L) and capacitor (C) are connected. The values of the L and C form a resonant frequency, which is the frequency at which the circuit will resonate, continuing to oscillate on its own after an initial introduction of energy.

Frequency of an ideal resonant circuit:

$$f_0 = \frac{\omega_0}{2\pi} = \frac{1}{2\pi\sqrt{LC}} *$$

In an ideal circuit, this resonating circuit would continue to oscillate indefinitely, but in real life there are impedances involved in every real circuit that won't allow perpetual resonance. But resonant circuits still have a lot of value when it comes to wireless power transfer circuits.

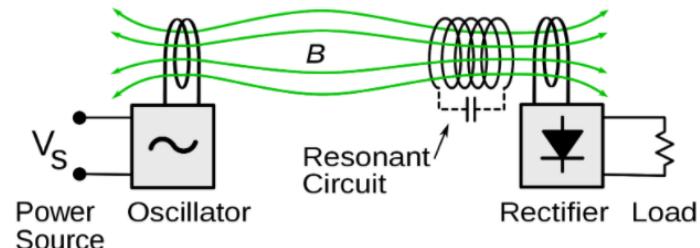


Figure 1: A Basic Resonant Inductively Coupled WPT

In its most basic form, a wireless power transfer resonant circuit works by powering an oscillator that is inductively coupled to a resonant circuit in the target device. That resonant circuit causes the inductive coupling to strengthen, creating a higher efficiency power transfer. That transferred power is then rectified and used by the load in the target device.

More advanced versions of WPT resonant circuits use a resonant circuit on both the source and load sides or have other improvements and advanced designs, but the fundamental concept of the resonant circuit for WPT remains the same.

## WHERE MLCCS FIT IN

WPT applications require capacitors with very stable capacitance versus temperature, voltage and time. In addition, these applications can generate high AC currents which can cause excessive heating in lossy components. Class I C0G and U2J Multilayer ceramic capacitors (MLCCs) are ideal for WPT circuits as compared to Class II MLCCs and other capacitor technologies. Class I MLCCs have very stable capacitance versus temperature, voltage, and time and have very high ripple current capability versus other technologies. The below figure shows the benefits of Class I C0G and U2J dielectrics compared to Class II X7R.

Capacitor Characteristics	Class 1 C0G/U2J	Class 2 X7R
Capacitance Density	○	●
Capacitance Stability vs Temperature (TCC)	●	○
Capacitance Stability vs Voltage (VCC)	●	○
Low Equivalent Series Resistance (ESR)	●	○
Low Equivalent Series Inductance (ESL)	●	●
High AC Voltages	●	○
High AC Current	●	○
High Temperature Operation (>125C)	●	●
High Frequency Operation (>100kHz)	●	○
Mechanical Robustness (Modulus of Rupture)	●	○
High dV/dT Capability	●	○

● - Excellent     ○ - Fair

Figure 2: Key Characteristics Comparison Between Class II X7R and Class I C0G/U2J

In many WPT applications, the capacitance, AC voltage, and AC current requirements are beyond what a single capacitor can provide. Therefore, it is common to have a series/parallel combination of MLCCs to achieve the application requirements. For example, adding MLCCs in parallel will increase the overall capacitance and AC current handling capability. Adding MLCCs in series will decrease the overall capacitance and increase the AC voltage capability. And using a series/parallel combination can provide an overall capacitor solution capable of handling very high-power levels. KEMET offers tools to help designers optimize the number of MLCCs in parallel and series to meet application requirements.

## EXAMPLE APPLICATION CIRCUIT DESIGN

Let's look at an example design. For this design, we will be designing the capacitor selection for a WPT resonant circuit for an electric vehicle charging system.

For this system, we will need to select the appropriate KEMET capacitor for a WPT system defined as follows:

- AC Voltage: 350Vrms
- DC Voltage: 0V
- AC Current: 12.3Arms
- Frequency: 85kHz
- Application Temperature: 55°C
- Resonant Capacitance Required 66nF

### Step 1: Determine the Minimum DC Voltage Rating

Although this application is strictly using AC voltage, MLCCs do not have an AC voltage rating. Therefore, we must determine the minimum MLCC DC voltage rating required for the application. To determine the minimum DC voltage rating needed for the capacitor, there are two rules that both must be satisfied:

Rule #1 is that the DC rating of the capacitor must be larger than the peak AC voltage plus the DC voltage (if any) in the application. Basically, the peak voltage can never exceed the rated voltage of the MLCC.

$$V_p + V_{dc} < V_{rated\ DC}$$

Rule #1

The peak AC voltage ( $V_p$ ) can be calculated using the equation below.

$$V_p = V_{rms} * \sqrt{2}$$

$$V_p = 350 * \sqrt{2} = 495V$$

Back to Rule #1:

$$495 + 0 = 495$$

So, to satisfy Rule #1, the DC rated voltage must be greater than 495V.

Rule #2 is that the peak AC voltage ( $V_p$ ) must be less than half the rated DC voltage. You can also convert this to RMS and say that the AC RMS voltage must be less than the MLCC rated voltage divided by two times square root two.

$$V_p < \frac{V_{rated\ DC}}{2} \quad \rightarrow \quad V_{rms} < \frac{V_{rated\ DC}}{2\sqrt{2}}$$

Rule #2

We can use the peak voltage of the AC waveform to calculate the minimum DC rating of the capacitor network:

$$V_p * 2 = V_{rated\ DC}$$

$$495 * 2 = 990V$$

So, to satisfy Rule #2, the DC rated voltage of the capacitor network must be greater than 990V.

By looking at both Rule #1 and Rule #2, we see that the capacitor network rated voltage must be greater than 990V (which is the greater of the two rules).

### Step 2: Find a Capacitor that Meets the Requirements

Now that we know the required capacitance (66nF) and DC voltage rating (> 990V) for our WPT resonant circuit application, we need to find a suitable capacitor. KEMET's KC-LINK capacitors are ideal for resonant applications, so let's look at their offerings. The following table is from the KC-LINK datasheet, found [here](#).

Capacitance	Capacitance Code	Case Size/Series	CKC18C				CKC21C				CKC33C					
			1812				2220				3640					
			C	W	D	E	C	W	D	E	C	W	D	E		
Product Availability and Chip Thickness Codes See Packaging Specs for Chip Thickness Dimensions																
500VDC																
4.700 pF	472	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MA	MA	MA	MA		
5.500 pF	512	F G J K M	GD	GD	GD	GD	JL	JL	JL	JL	MA	MA	MA	MA		
5.600 pF	562	F G J K M	GD	GD	GD	GD	JL	JL	JL	JL	MA	MA	MA	MA		
6.300 pF	622	F G J K M	GD	GD	GD	GD	JN	JN	JN	JN	MA	MA	MA	MA		
6.400 pF	642	F G J K M	GD	GD	GD	GD	JN	JN	JN	JN	MA	MA	MA	MA		
7.500 pF	752	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
8.200 pF	822	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
9.100 pF	912	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
10.000 pF	1012	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
12.000 pF	1212	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
13.000 pF	1312	F G J K M	GD	GD	GD	GD	JE	JE	JE	JE	MC	MC	MC	MC		
13.500 pF	1352	F G J K M	GD	GD	GD	GD	JE	JE	JE	JE	MC	MC	MC	MC		
18.000 pF	1812	F G J K M	GD	GD	GD	GD	JE	JE	JE	JE	MC	MC	MC	MC		
22.000 pF	2212	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
27.000 pF	2712	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
32.000 pF	3212	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
39.000 pF	3912	F G J K M	GD	GD	GD	GD	JE	JE	JE	JE	MC	MC	MC	MC		
47.000 pF	4712	F G J K M	GD	GD	GD	GD	JE	JE	JE	JE	MC	MC	MC	MC		
54.000 pF	5412	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
64.000 pF	6412	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
82.000 pF	8212	F G J K M	GD	GD	GD	GD	JN	JN	JN	JN	MB	MB	MB	MB		
1.1 pF	112	F G J K M	GD	GD	GD	GD	JE	JE	JE	JE	MB	MB	MB	MB		
1.15 pF	1152	F G J K M	GD	GD	GD	GD	JE	JE	JE	JE	MB	MB	MB	MB		
1.18 pF	1182	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
1.21 pF	1212	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
1.25 pF	1252	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
1.28 pF	1282	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
1.31 pF	1312	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
1.34 pF	1342	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
1.38 pF	1382	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
1.41 pF	1412	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
1.45 pF	1452	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
1.48 pF	1482	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
1.51 pF	1512	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
1.54 pF	1542	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
1.58 pF	1582	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
1.61 pF	1612	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
1.64 pF	1642	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
1.67 pF	1672	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
1.71 pF	1712	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
1.74 pF	1742	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
1.78 pF	1782	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
1.81 pF	1812	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
1.84 pF	1842	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
1.87 pF	1872	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
1.91 pF	1912	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
1.94 pF	1942	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
1.97 pF	1972	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
2.01 pF	2012	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
2.04 pF	2042	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
2.07 pF	2072	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
2.11 pF	2112	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
2.14 pF	2142	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
2.18 pF	2182	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
2.21 pF	2212	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
2.24 pF	2242	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
2.27 pF	2272	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
2.31 pF	2312	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
2.34 pF	2342	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
2.38 pF	2382	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
2.41 pF	2412	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
2.44 pF	2442	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
2.48 pF	2482	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
2.51 pF	2512	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
2.54 pF	2542	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
2.58 pF	2582	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
2.61 pF	2612	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
2.64 pF	2642	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
2.68 pF	2682	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
2.71 pF	2712	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
2.74 pF	2742	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
2.78 pF	2782	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
2.81 pF	2812	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
2.84 pF	2842	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
2.88 pF	2882	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
2.91 pF	2912	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
2.94 pF	2942	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
2.98 pF	2982	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
3.01 pF	3012	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MB	MB	MB	MB		
3.04 pF	3042	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK	MC	MC	MC	MC		
3.08 pF	3082	F G J K M	GD	GD	GD	GD	JK	JK	JK	JK</						

### Step 3: Determine Ripple Current Capability

Now that two possible capacitors have been identified, we must determine the ripple current capability of each to see if either will work in our application. Using KEMET's free online circuit simulator, KSIM (<https://ksim3.kemet.com/>), we can simulate the ripple current in each device:

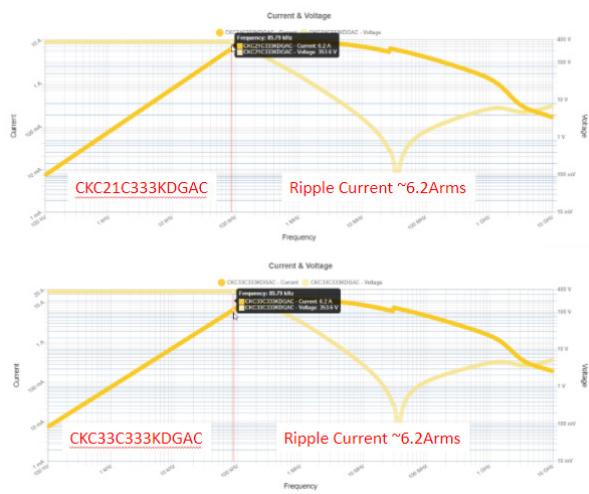


Figure 4: Simulations to Determine Ripple Current of Possible Capacitors

For each of the capacitors under evaluation, the ripple current is ~6.2Arms. By placing two of these capacitors in parallel, the total capacitance will be 66nF with an AC current of 12.4Arms which meets our application needs.

## VOLTAGE AND CURRENT LIMITED REGIONS

Two other considerations when analyzing a capacitor's voltage and current ratings in AC applications are their operation in the voltage-limited region and current-limited region.

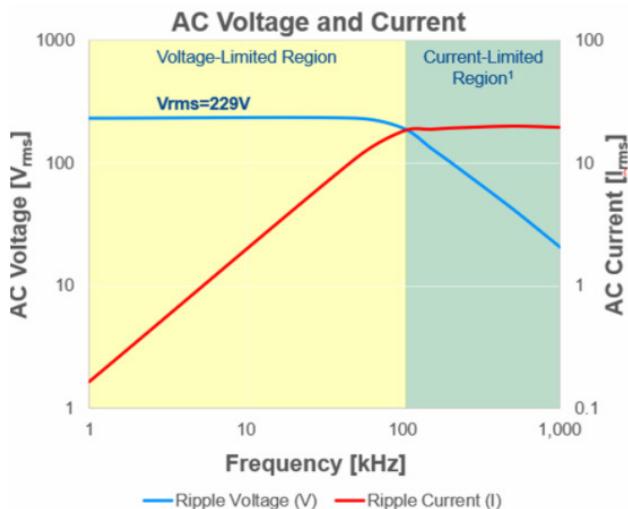


Figure 5: AC Voltage and Current Ratings vs Frequency

As demonstrated in the sample graph, at lower frequencies the voltage rating is the limiting factor, while at higher frequencies the current rating is the limiting factor. At a certain frequency, there is a crossover point.

In the voltage-limited region, the primary risk to MLCCs is breakdown or damage due to high AC voltages. Proper capacitor selection and derating for the operating environments and conditions are important to ensure reliable operation in this region.

In the current-limited region, the primary risk to MLCCs is breakdown or damage due to self-heating due to i2R losses. Every real-life capacitor has an equivalent series resistance (ESR), and as frequencies and/or capacitance increases for the same AC voltage, the AC current increases through the capacitor. For this reason, it is again critical to select capacitors with low ESR and derated properly for the application.

## KEMET KONNEKT

KEMET offers a patented technology called KONNEKT that allows two, three, or four ceramic capacitors to be stacked vertically without using any metal strips on the sides. This technology utilizes a transient liquid phase sintering process (TLPS) and can be mounted using tradition reflow processes.

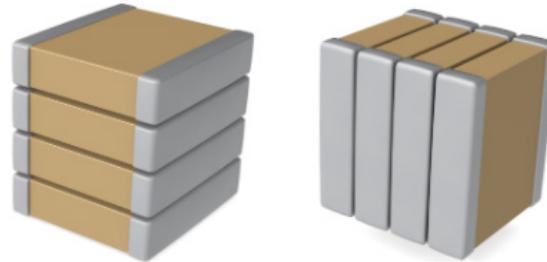


Figure 6: KONNEKT Technology for Stacked SMD Capacitors

Stacking ceramic capacitors on top of each other is a way to solve the problem of tight spaces. Because of the increasing miniaturization of electronic devices and the requirements for smaller electronic components with more capabilities, higher ratings, and robust reliability, a smaller footprint on a circuit board is critical. Traditionally, components are stacked on top of each other to conserve space and to hold them in place, using metal beds – or lead frames. However, lead frames are costly and introduce power loss. KEMET KONNEKT technology creates a low loss, low inductance package capable of handling high temperatures and high power while taking up a very small footprint on the board.

## CONCLUSION

For wireless power transfer (WPT) resonant circuits, KEMET's KC-LINK capacitors, stacked together with their patented KONNEKT technology, offer an ideal solution. WPT resonant circuits used to power and charge electric vehicles are likely to become more common, and more advanced and improved solutions are on their way. KEMET technologies will be there every step of the way.

For more information, visit [KEMET.com](https://www.kemet.com).