

# **Capacitors for Reduced Microphonics and Sound Emission**

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## **Abstract**

Multilayer ceramic capacitors (MLCC), made with class 2 or class 3 dielectrics, typically exhibit a piezoelectric effect when placed under electric field. The piezoelectric effect results in a physical distortion with amplitude related to the intensity of the electric field. If the electric field is an AC field with frequency in the audible range (ca. 20 Hz to 20 KHz), the distortions due to the piezoelectric effect may result in sound emission. If the MLCC is soldered directly to a circuit board, the sound emission increases analogous to a speaker. Additionally, it is not atypical for several MLCC on a circuit board to combine to further amplify the sound emission to the point that it is noticeable, if not annoying (i.e., ‘singing capacitors’). The inverse of this effect is that the MLCC may also act as a microphone when subjected to shock or vibration, thereby adding noise to electronic signals in a circuit, for example in the case of a high vibration application. In these situations, it is prudent either to use a class 1 dielectric MLCC, or to reduce the extent of mechanical coupling of the MLCC and the circuit board or, to use an MLCC comprised of a lower distortion class 2 dielectric, or to use a capacitor device that utilizes a dielectric system that is not piezoelectric such as a tantalum capacitor or an organic tantalum capacitor. This paper discusses options for reduced sound emission and microphonics, including high capacitance per unit volume COG MLCC, lead frame class 2 X7R MLCC, lower distortion class 2 X7R MLCC and Ta capacitors. The various options are compared and contrasted in order to determine the most suitable solution for the intended application. Acoustic data for lead frame class 2 X7R MLCC, lower distortion class 2 X7R MLCC, and standard class 2 X7R MLCCs are also presented.

## **Introduction**

Today, Multilayer Ceramic Capacitor (MLCC) technology produces ceramic capacitors with very high volumetric efficiency, at a relatively low cost. Today’s decoupling and bypassing solutions demand MLCCs with higher capacitance per unit volume (CV) values. The continued development of higher K dielectrics, along with the development of thinner dielectric and electrode layers, provides the technology necessary to meet the demands of circuit designers for HICV MLCC. This development effort will continue the trend in increasing CV for the foreseeable future.

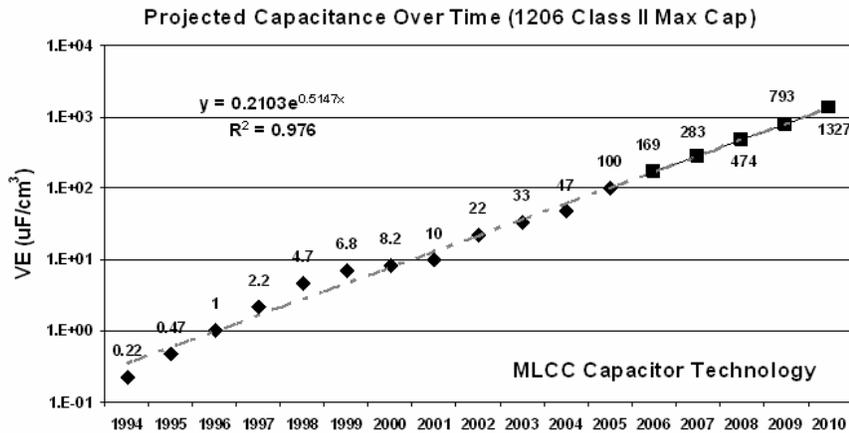


Figure 1. Increase in capacitance volumetric efficiency over time, MLCC.<sup>1</sup>

One result of the drive to increase volumetric efficiencies in MLCC is that high K materials are favored in high CV MLCCs. These high K materials are typically ferroelectric in character, enabling a relatively high number of dipoles per unit volume. These materials typically exhibit piezoelectric behavior, as well as ferroelectric behavior as described below.

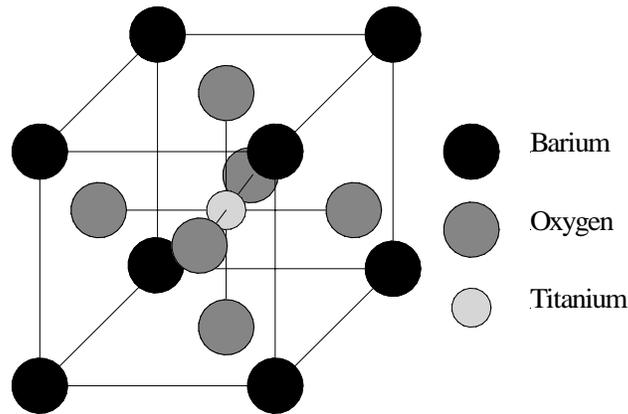
Piezoelectricity is not exhibited appreciably in non-crystalline materials (i.e., glasses). Piezoelectricity is exhibited in 20 of the 32 crystallographic classes of crystalline materials. All of these 20 classes are non-centrosymmetric (see Table 1). All high K ferroelectric materials are also polar. Barium titanate (BaTiO<sub>3</sub>), the basis for most high K dielectrics, exhibits 4 different crystallographic classes (rhombohedral, orthorhombic, tetragonal and cubic) over the temperature range of -55°C to ~130°C, three of these four crystallographies are non-centrosymmetric and polar and thus piezoelectric in nature (the cubic form is not appreciably piezoelectric). Without its availability for use, MLCC manufacturers would be limited to Class 1 K values of less than ~750 or to Pb containing dielectrics or to other, lower performance class 2 dielectric materials systems.

Table 1. Crystal Groups and Piezoelectric Behavior<sup>2</sup>

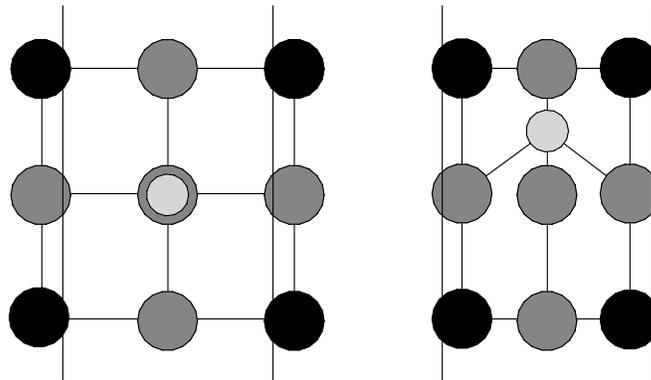
Optical Axes	Crystal Class	Centrosymmetric Point Groups		Noncentrosymmetric Point Groups				
				Polar		Nonpolar		
Biaxial	Triclinic	<1>		1		None		
	Monoclinic	2 or m		2	m	None		
	Orthorhombic	mmm		mm2		222		
Uniaxial	Tetragonal	4 or m	4 or mmm	4	4mm	<4>	<4>2m	22
	Trigonal	<3>	<3>m	3	3m	32		
	Hexagonal	6 or m	6 or mmm	6	6mm	<6>	<6>m2	622
Optically Isotropic	Cubic	m3	m3m	None		432	<3>m	23
Total Number		11 Groups		10 Groups		11 Groups		

Ferroelectric BaTiO<sub>3</sub> has been the basis for ceramic dielectric technology for decades, and will continue to be the basis for years to come. BaTiO<sub>3</sub>'s ferroelectric properties allow for very high K values, enabling the development of the dielectric materials required in today's HICV capacitors.

The key to the high K properties of BaTiO<sub>3</sub> is its perovskite unit cell structure that exhibits several crystallographic forms that are non-centrosymmetric in nature. In the cubic form (above 130°C), the structure is centrosymmetric and piezoelectric behavior is largely absent. The cubic form of the barium titanate perovskite crystal structure has Barium ions at the corners, Oxygen ions at the face centers, and a Titanium ion in the center of the unit cell (Fig. 2). This means that the structure is symmetric and no net polarization exists. Below 130°C the titanium ion shifts its position in the unit cell away from the center creating a distortion of the unit cell (now tetragonal, orthorhombic or rhombohedral, depending upon the local chemistry and the temperature of interest) and thus making the barium titanate crystallography non-centrosymmetric at temperatures below ~130°C. Once the titanium ion shifts away from the center, a net polarization exists within the structure creating a dipole. Since the spontaneous polarities can be reversed, BaTiO<sub>3</sub> is strongly ferroelectric as well, exhibiting K values that are typically 1 to 3 orders of magnitude greater than exhibited by non-ferroelectric materials.<sup>3</sup>

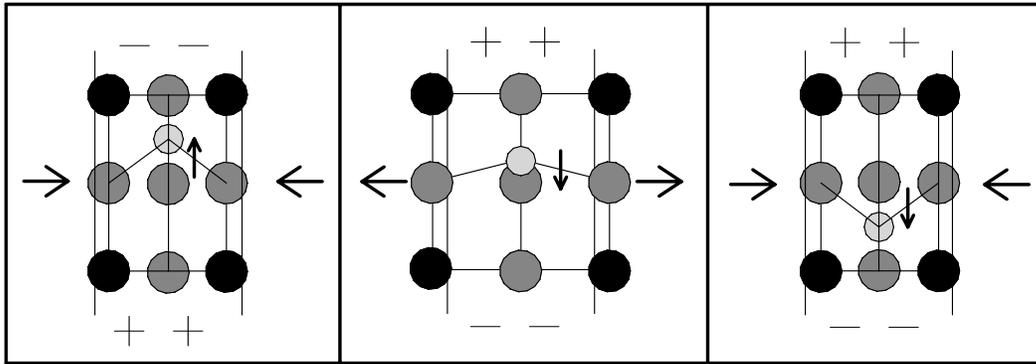


**Figure 2. BaTiO<sub>3</sub> perovskite crystal structure.**

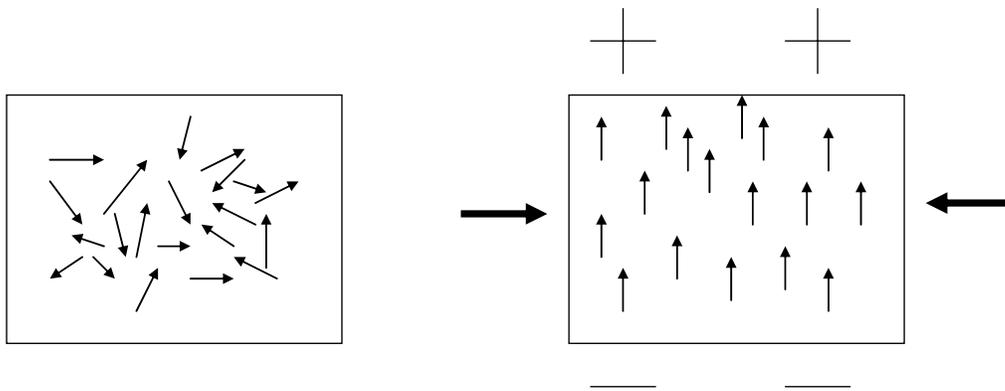


**Figure 3. Structure of BaTiO<sub>3</sub> above and below 130°C. Left – Above 130°C, cubic. Right – Below 130°C, tetragonal (dipole).**

When the structure is in the presence of an electric field, the titanium ion will shift depending on the orientation of the field. When the shifting of the ion occurs, the BaTiO<sub>3</sub> structure will distort perpendicular to the direction of the ion movement. For example, the structure will contract as the ion moves away from the center and expand as it moves towards the center.

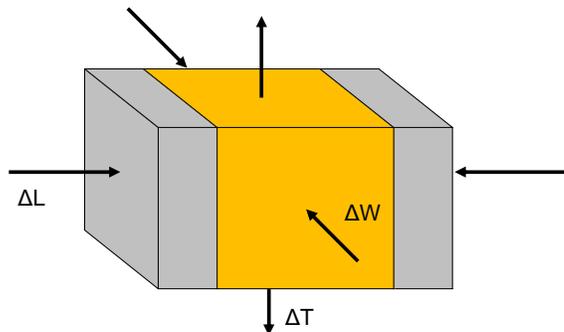


**Figure 4. BaTiO<sub>3</sub> structure under different polarities.**

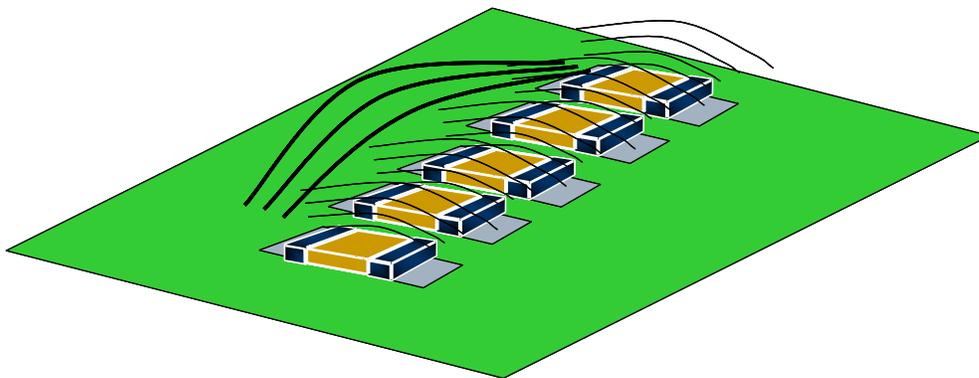


**Figure 5. Dipole arrangement as a function of applied electric field. Left – No electric field applied. Right – Electric field applied.**

Since high CV MLCCs are typically constructed using the ferroelectric materials, the capacitors exhibit a mechanical distortion with applied electric field (piezoelectric effect as described above). If the electric field is an AC field with frequency in the audible range (ca. 20 Hz to 20 KHz), the distortions due to the piezoelectric effect may result in acoustic emission or “noise.” Alone, the capacitor typically does not produce enough sound to be detected by a human ear. However, when mounted on a printed circuit board, the mechanical energy created by the capacitor is transferred to the board through the relatively stiff solder joint. The board acts as a mechanical amplifier (i.e., speaker) making it quite possible to detect the noise with the human ear as a “buzz” or “singing”.<sup>4</sup>



**Figure 6. Capacitor distortion when under an applied electric field.**



**Figure 7. Capacitor distortion transferred to the PCB acting as an amplifier.**

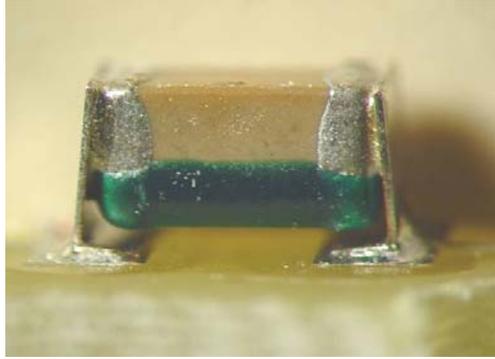
The noise generated during this scenario is typically undesirable and is a challenge for designers to overcome when designing laptop computers, audio circuits, LCD TV's, plasma displays, etc. The pursuit of low noise solutions is currently a "hot topic" and significant development of low noise capacitor products are underway in the industry. Noise may be reduced or eliminated via several approaches such as use of non ferroelectric dielectric MLCC (class 1 COG or the like), use of low distortion dielectric class 2 dielectrics (anti-ferroelectrics, reduced field sensitivity ferroelectrics, increased dielectric thickness or the like), use of film dielectric multilayer capacitors, etc. Depending upon the application, class 1 dielectric MLCC and film capacitors may not offer sufficient CV. Low distortion class 2 capacitors typically do not offer CV values high enough for many applications either. Tantalum capacitors offer high CV and are a good solution if the application involves relatively low frequencies (<~10 MHz), but are not typically used for frequencies above ~10 MHz due to capacitance roll off.

A new solution involves the use of a low profile lead frame attached to a HICV MLCC. This solution utilizes a relatively compliant lead frame structure in order to mechanically decouple the high CV ferroelectric MLCC and the circuit board, which results in very significant reduction in the sound emission of the device.

KEMET has developed a low profile lead frame MLCC using a Clip on Lead Frame (CoLF).<sup>5,6</sup> A CoLF capacitor is an MLCC that is raised off the PCB by less than 10 mils using a clip on lead frame attachment. The lead frames are constructed from a relatively compliant metallurgy that provides a good "shock absorber" for the capacitor. The lead frame shock absorber strongly inhibits the mechanical vibration of the capacitor from transferring to the PCB. Tin over nickel plating of the lead frames makes it ideal for IR solder applications. The base of the capacitor is coated with a thin layer (less than 2 mils) of solder resist which prevents solder from attaching to the capacitor during PCB mounting.<sup>5</sup> This provides an effective, low noise, high CV solution to the "singing capacitor" problem.



**Figure 8. Clip on Lead Frame Capacitor (CoLF).**

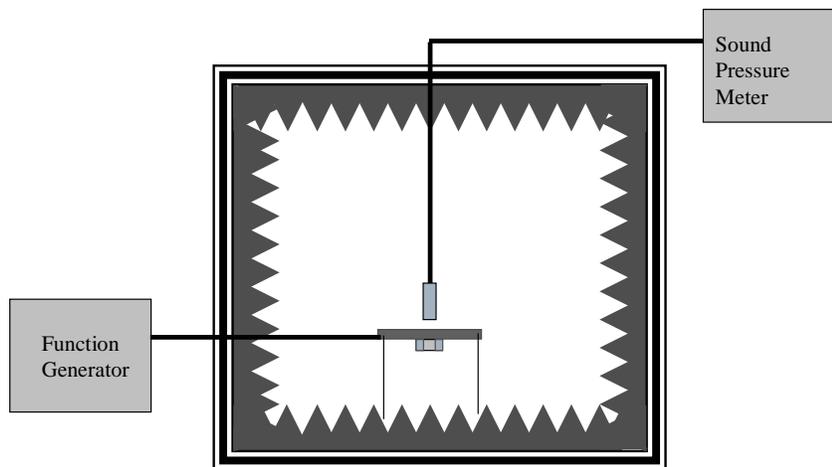


**Figure 9. Picture shows a COLF MLCC attached to an FR4 board.**

### Acoustic Measurement Technique

Accurate measurement of acoustic emission of capacitors is challenging since it's almost impossible to replicate the use environment. It is valuable, however, in that it can provide accurate comparisons of different acoustic noise solutions over a variety of input parameters. This paper details useful methods for comparing different solutions, as well as the comparison of various solutions to the “singing” capacitor problem.

In order to evaluate the acoustic noise performance for the different solutions, representative samples of each of the device types evaluated were mounted on a suitable FR4 substrate measuring 2” x 2” x 0.03” using IR reflow. A 1206 X7R 1uF MLCC with no lead frames was chosen as the control chip while a leaded version of the 1206 1uF was used as the CoLF chip. To measure the noise, a highly sensitive microphone was placed 3mm above the substrate mounted with the device under test (DUT) and fed into a sound pressure meter. In order to isolate any outside noise, an anechoic chamber was fabricated to house the test samples and microphone and was placed in an isolated room (see following figures for schematic details).



**Figure 10. Setup for measuring noise performance of test samples.**

A 100Hz and 1kHz square wave with a 50% duty cycle was used to provide the alternating electric field across the capacitor. At 100Hz, the voltage was swept from 1V<sub>peak</sub> – 9 V<sub>peak</sub>. At 1 kHz, the voltage was swept from 0.25 V<sub>peak</sub> – 5 V<sub>peak</sub>. At each of the frequencies and voltages, the sound pressure meter was used to capture the overall sound pressure of the spectrum. The sound pressure meter was set to measure under ‘A’ weighting to simulate the human ear. This is done by emphasizing the frequencies in the 3 – 6 kHz range which is most sensitive the human ear while attenuating the very high and very low frequencies which is not sensitive to the human ear.<sup>7</sup> The following plots show the acoustic performance for the control, low distortion, and Clip-on-

Lead Frame sample. Since Tantalum and COG parts have no noticeable acoustic effects, these data were not shown in the plots.

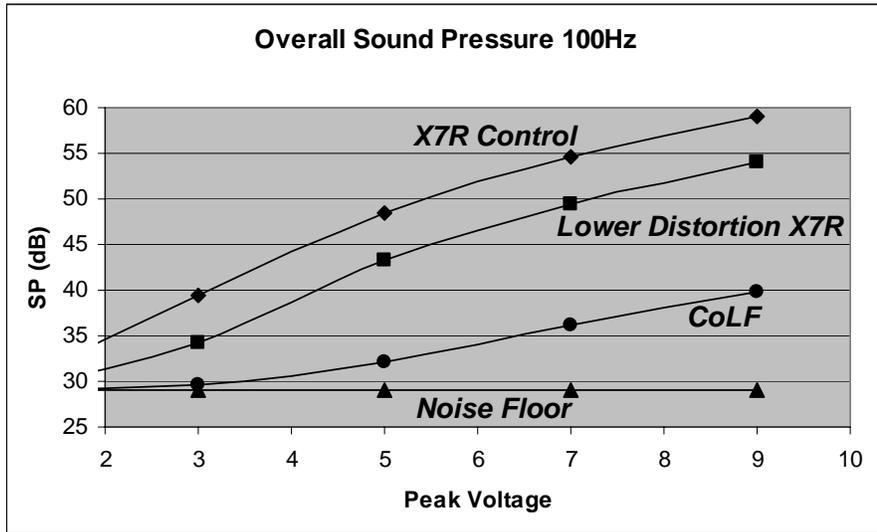


Figure 11. Sound pressure results versus 100 Hz input A/C voltage for 1206 control, low distortion, and Clip-on-lead-frame.

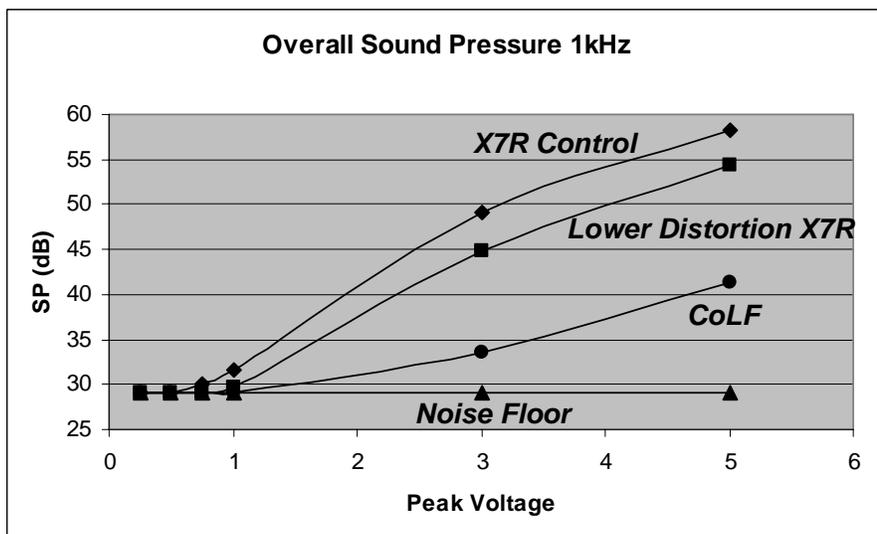


Figure 12. Sound pressure results versus 1 kHz input A/C voltage for 1206 control, low distortion, and Clip-on-lead-frame.

The plots show that the low distortion samples reduce the sound emission by as much as 5dB at 100Hz and 4dB at 1kHz, while the CoLF samples reduced the sound emission by as much as 20dB at 100Hz and 17dB at 1kHz. Despite the high A/C voltage on the CoLF samples, the sound emission pressure never exceeded 42dB for both frequencies. The reduced sound emission by the CoLF sample shows that the lead frame effectively isolates the MLCC from the circuit board. When the MLCC was excited by the A/C source, the induced vibrations were carried through the lead frames, but were dampened.

The system of MLCC → Lead Frame → PCB is also symmetric. That is, an excited vibration in the board will also be mechanically isolated from the MLCC causing a reduction in induced noise in the MLCC. Typically,

vibrations that are brought onto the PCB through external sources, such as a motor, piezo speaker, transformer or unexpected shock or the like, can stimulate the capacitor as well, causing noise in the circuit. These vibrations and shocks can be converted to electrical signals due to the capacitors piezoelectric behavior sending unwanted voltage spikes to other elements such as a microprocessor or the like. CoLF capacitors provide mechanical isolation needed effectively reducing these signals from making it to PCB traces.

**Table 2. Comparison between capacitor types for different applications**

	Clip-on-Lead Frame	Lower Distortion X7R MLCC	Tantalum	COG
Noise Reduction	A-	C+	A	A
Volumetric Efficiency	A	B+	A	C
Effective Series Inductance	B	A	B-	B+
Effective Series Resistance	A	A	B-	A
Flex Robustness	A	C	A	B-
Cost	B	B	C	C
Overall Performance for General Applications	A-	B	B	C+
Overall Performance for HiCV Low Noise Low Cost Applications	<b>A</b>	<b>B-</b>	<b>B</b>	<b>C+</b>

Table 2 provides a quick view on characteristics for general and HiCV low noise applications. For these purposes, the Clip-on-Lead-Frame capacitor provides a HiCV, low noise, low cost, and Flex robust solution. Flex testing has shown that the CoLF samples typically do not experience any flex cracks out to and beyond 10mm board flexure.

### Summary and Conclusion

Current designs require considerations for more than just lower ESL and ESR capacitors. Vibration and noise are also significant considerations in the development of new devices. The Clip-on-Lead-Frame (CoLF) capacitor provides a low noise, HiCV solution enabling electronic designers an effective option for capacitors for sound sensitive applications.

<sup>1</sup> M. Randall “Capacitor Considerations for Power Management” 2006 CARTS Conference Proceedings, April 2006, Orlando, FL

<sup>2</sup> B. Jaffe, W. Cooke, H. Jaffe, Piezoelectric Ceramics, Academic Press, 1971.

<sup>3</sup> S. L. Swartz “Topics in Electrical Ceramics” IEEE Transactions on Electrical Insulation Vol. 25 No. 5, October 1990

<sup>4</sup> John D. Prymak “Piezoelectric Effects Ceramic Chip Capacitors (Singing Capacitors)” 2006-08 Arrow Asian Times Article

<sup>5</sup> Prymak US - 06903920B1 Clip-on Leadframe for Large Ceramic SMD

<sup>6</sup> Other Patents Pending

<sup>7</sup> Weighting filter, Wikipedia website, viewed 13 February 2007, <[http://en.wikipedia.org/wiki/Weighting\\_filter](http://en.wikipedia.org/wiki/Weighting_filter)>