High-Frequency Capacitor Performance: Evaluation of Eulex XG Series: XG2 (2-Terminal) and XG3 (3-Terminal) Gap Capacitors

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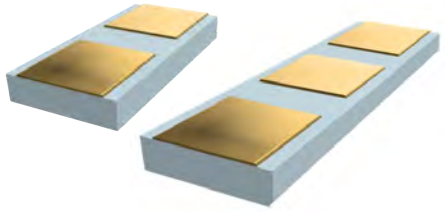


Abstract: High-frequency electronic design demands passive components that maintain signal integrity, minimize noise, and perform reliably across a broad spectrum. The Eulex XG Series introduces a novel gap capacitor architecture that overcomes long-standing limitations of conventional capacitors through a via-free, coplanar electrode design. This innovation achieves ultra-low inductance and high capacitance density in compact packages. Validated through third-party testing up to and beyond 67GHz, the XG2 and XG3 capacitors demonstrate superior performance in impedance matching, filtering, and high-power coupling— enabling more compact, efficient, and reliable RF and high-speed systems.

Introduction

Modern electronic systems, particularly those in 5G cellular networks, advanced driver-assistance systems (ADAS) radar, autonomous vehicle sensor arrays, and high-performance computing platforms, are increasingly pushing the boundaries of speed and capability. As operational frequencies rise, traditional capacitor technologies such as Single-Layer Capacitors(SLCs) and Multilayer Ceramic Capacitors (MLCCs), as well as more advanced options like broadband blocking capacitors and X2Y capacitors, face significant challenges due to parasitic inductance and resistance.

This leads to degraded performance in signal processing, power delivery, and high-speed computing, and exacerbates issues related to the extremely fast transient current demands of modern AI processors. At high frequencies, parasitic inductance can cause these capacitors to act more like inductors, further degrading performance. Capacitors play a crucial role in these high frequency systems, essential for:

- Filtering: Eliminating unwanted noise and spurious signals.
- Decoupling: Decoupling: Providing a stable power supply by suppressing voltage fluctuations due to transient currents.
- Signal Coupling and DC Blocking: Allowing AC signals to pass between circuit stages while blocking DC.
- Impedance Matching: Optimizing signal transfer between circuit stages by minimizing reflections.

Eulex Gap Capacitors are engineered to address these limitations, achieving improved filtering, decoupling, and impedance matching performance compared to traditional solutions in high-frequency applications.

The Limitations of Traditional Capacitor Technologies

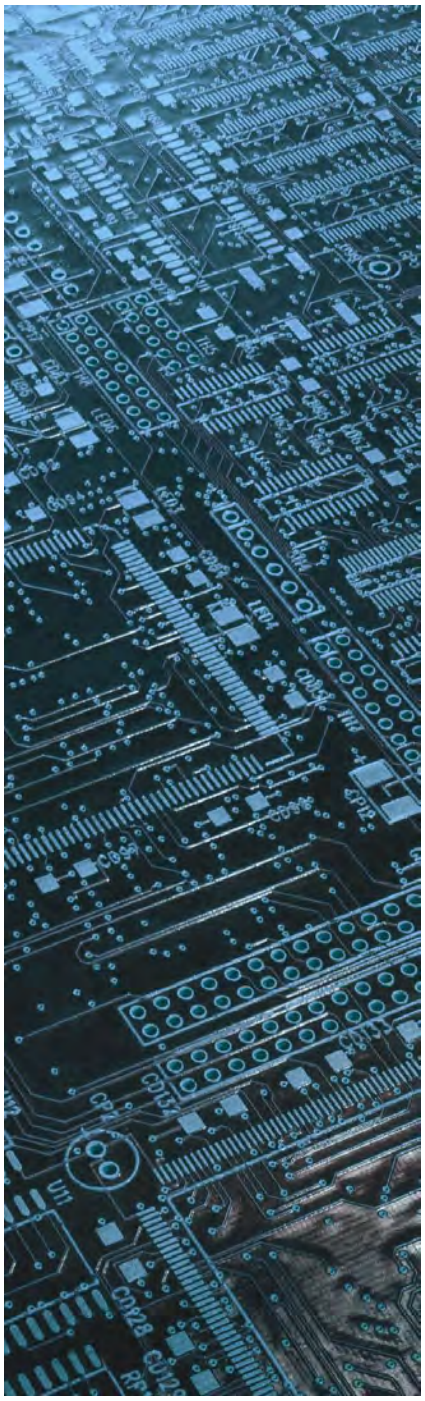
The range of available capacitors includes options that each have limitations when used in high-frequency applications. The specific challenges associated with the most widely used traditional capacitor types are outlined below.

Single-Layer Capacitors (SLCs): While offering high Self-Resonant Frequency (SRF) and low Equivalent Series Resistance (ESR), SLCs suffer from limited capacitance, wire bonding requirements that introduce parasitic inductance, lower power handling (typically up to 20W CW), and mechanical vulnerability due to delicate wire bonds or thin and fragile ceramic dielectrics.

Multilayer Ceramic Capacitors (MLCCs): MLCCs overcome capacitance limitations but at the cost of higher ESR, lower SRF (typically operate effectively below 30 GHz), DC bias sensitivity, and reliability concerns (susceptible to cracking and delamination of internal layers).

Broadband Blocking Capacitors: Specialized for low loss and high Q in microwave applications, they suffer from limited capacitance range and susceptibility to parasitic inductance.

X2Y Capacitors: Designed to provide significantly lower inductance, they come with a complex structure leading to higher cost, and limited capacitance density compared to the Eulex Gap Capacitors.

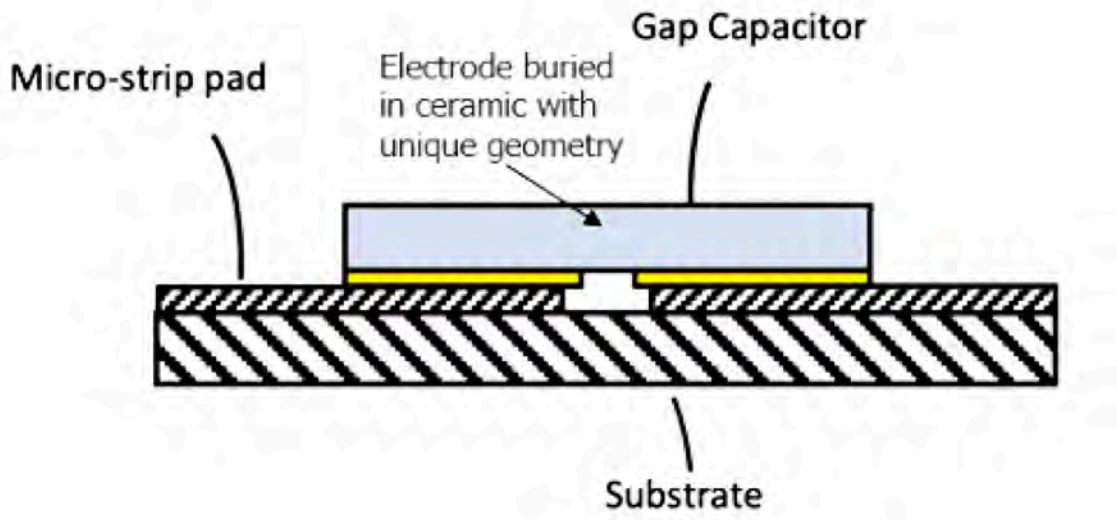


Introducing the Innovation: Eulex Gap Capacitors

Eulex presents a novel capacitor design – a component designed to address the challenges of high-frequency applications. By addressing the limitations of traditional designs, the Eulex Gap Capacitor provides improved performance.

The Eulex Gap Capacitor represents a departure from conventional capacitor designs. Its innovation lies in:

- **Embedded Electrode and Close Proximity:** While the electrodes are coplanar externally, one of the electrodes is partially embedded within the dielectric material, positioned in close proximity to the other electrode. This arrangement reduces the spacing between the electrodes, minimizing the effective dielectric thickness leading to an increase in capacitance, reduced parasitics and overall low ESR and ESL due to the via-free integration mechanism.

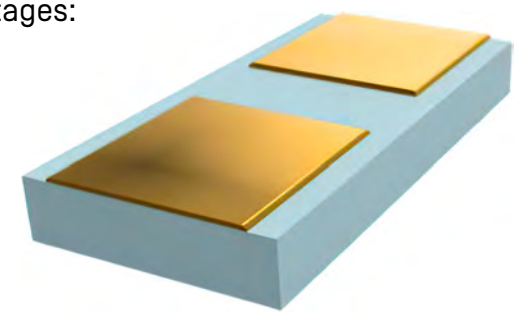


- **Single-Layer Construction:** Unlike MLCCs with their stacked layers, the Eulex Gap Capacitor emulates a true single-layer construction, minimizing resistive losses and enhancing high-frequency performance.

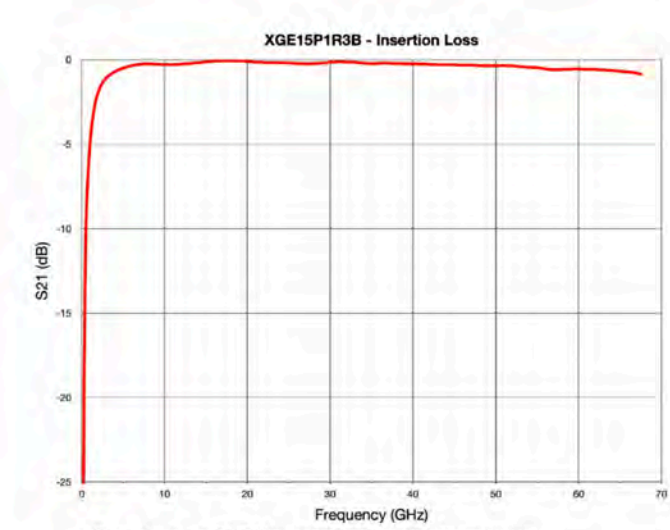
- **Elimination of Wire Bonds and Vias:** The coplanar electrode design eliminates wire bonds and obviates the need for vias – the primary sources of parasitic inductance and mechanical vulnerability.

XG2 Series (2-Terminal) Eulex Gap Capacitor

The XG2 Eulex Gap Capacitor offers these performance advantages:



- **Reduced Inductance:** By eliminating wire bonds and minimizing the distance between electrodes, the Eulex Gap Capacitor reduces parasitic inductance, resulting in a higher SRF and improved impedance characteristics.
- **Increased Capacitance Density:** The design enables an order of magnitude higher capacitance density compared to traditional SLCs.
- **Enhanced Reliability:** The absence of wire bonds eliminates a point of failure. The Eulex Gap Capacitor is less susceptible to mechanical stress, vibration, and temperature cycling.
- **Extended Frequency Range:** The 2-Terminal Eulex Gap Capacitor demonstrates effective performance up to 67 GHz and beyond with improved flatness across the frequency range compared to conventional capacitors.



Test data to 67GHz supplied by X-Microwave.

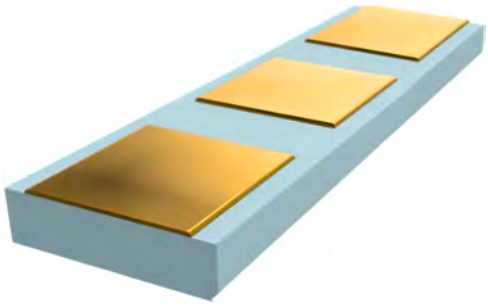
Applications:

- Impedance Matching
- Microstrip AC Coupling (DC Block)
- Bias Line Noise Filtering

Available footprints range from 0201 to 0805 with capacitances from 0.34pF up to 24,000pF. Up to 20x capacitance for any given size compared to competition.

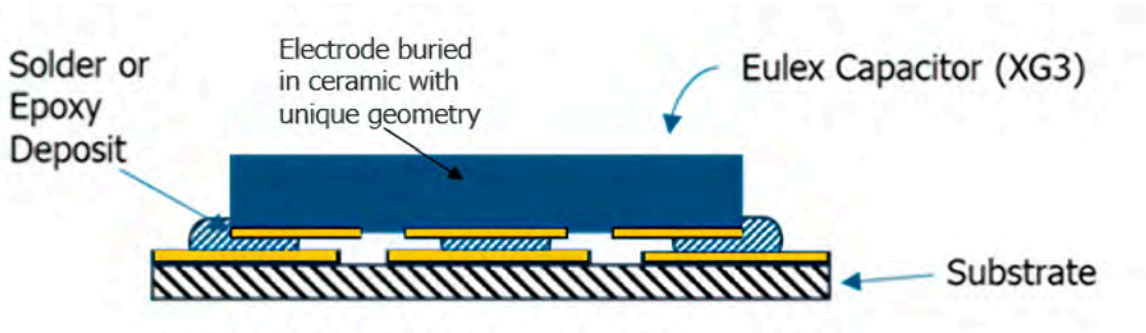
Binary capacitor variants are also available for extremely high power (100~3kW CW) DC blocking applications.

XG3 Series (3-Terminal) Eulex Gap Capacitor



The XG3 Eulex Gap Capacitor refines the 2-Terminal design to further reduce parasitic and mounting inductance:

XG3 Design: The 3-terminal design features dedicated ground terminals that directly connect to the PCB ground plane, minimizing the current loop area and further reducing parasitic inductance. Further Reduction in Inductance: The 3-Terminal configuration achieves ultra-low mounting inductance.



Improved Signal Integrity: The low inductance of the 3-Terminal design improves signal integrity, reducing reflections and minimizing noise.

Enhanced Stability Under DC Bias: The 3-Terminal Eulex Gap Capacitor maintains its capacitance value consistently under DC bias compared to some MLCCs.

Key Advantages (XG Series):

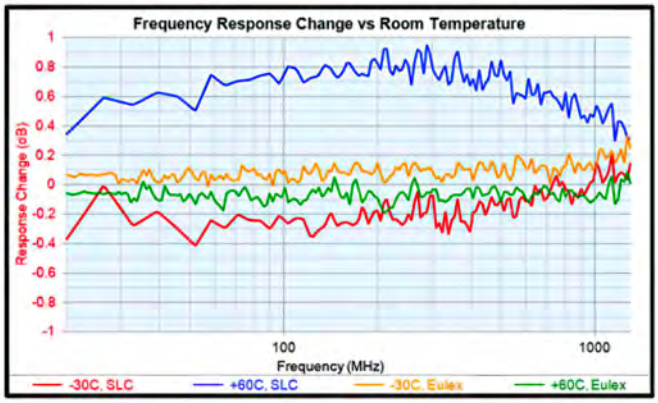
- Extremely low ESL (typically <15pH)
- Low ESR enables high power handling
- Large capacitance achievable in reasonable size
- Broadband performance from kHz to 10s of GHz
- Can replace 10s of MLCC with a single component
- For DC Bias line filtering/EMI filtering

Testing and Validation

Eulex Gap Capacitors have undergone rigorous testing and validation.

Bird Technologies Testing

Bird conducted testing on the XG3 Eulex Gap Capacitor within a Grounded Coplanar Waveguide (GCPW) design. The GCPW, a common transmission line structure in high-frequency circuits, provided a controlled environment to evaluate the capacitor's performance as a shunt component. The testing focused on characterizing the insertion loss and stability of the capacitor over a wide frequency range and under varying temperature conditions.



"The XG Series is our answer to a 5-year search for a better capacitor that has Class 1 stability, high capacitance and great frequency response, allowing us to better meet our specifications over time and temperature."

Martin Dummermuth
Chief Technologist
Bird Technologies

Key outcomes from Bird's Testing:

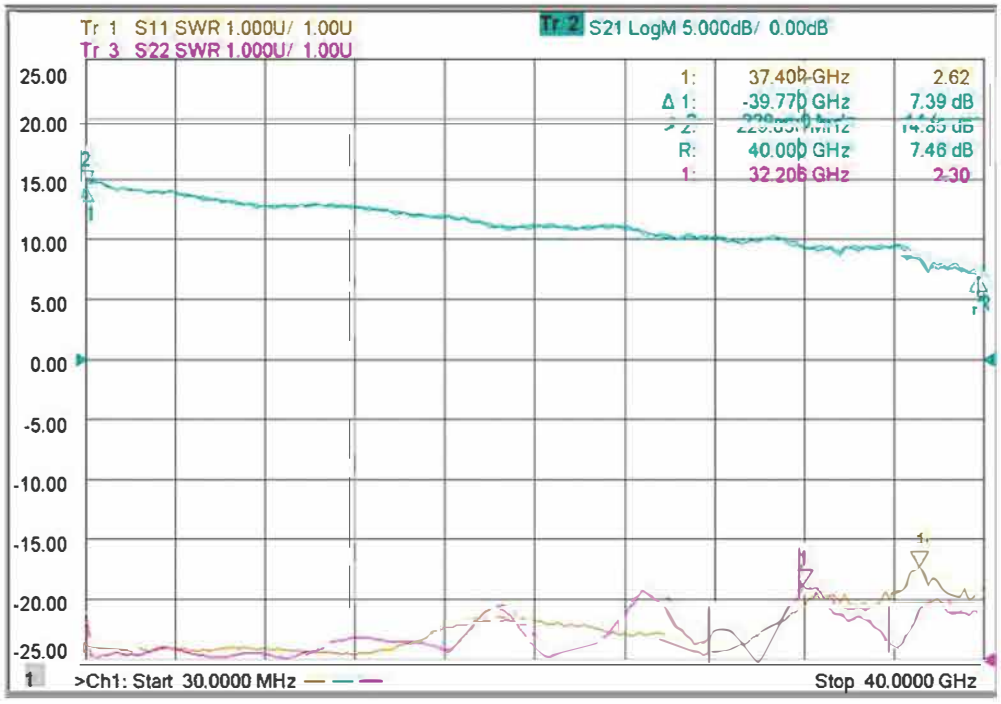
- Eulex XG3 exhibited exceptional performance, especially at lower frequencies, where traditional capacitors often struggle due to increased impedance.
- The Eulex XG3 also showed remarkably stable performance over a wide temperature range, outperforming a standard single layer capacitor in the same GCPW configuration.

PMI Testing

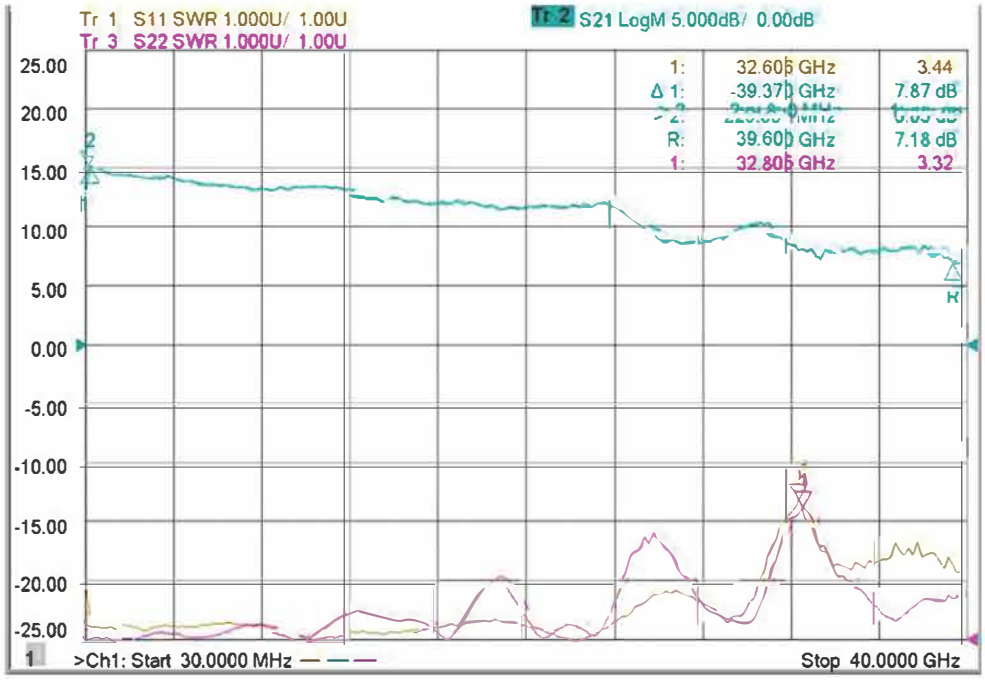
PMI tested the XG3 Eulex Gap Capacitor in a Low Noise Amplifier (LNA). By replacing one (1) single layer capacitor (SLC) with one (1) XG3 Eulex Gap Capacitor in PMI's PE2-12-30M40G-5R5-18-12-292FF LNA, the test yielded the following significant performance improvements.

- Reduced Voltage Standing Wave Ratio (VSWR) from 3.3:1 to 2.3:1, indicating a better impedance match and reduced signal reflection.
- Improved gain ripple from +/-2dB to +/-0.5dB, demonstrating a more consistent gain performance across the frequency band.

Using Eulex Gap Capacitor

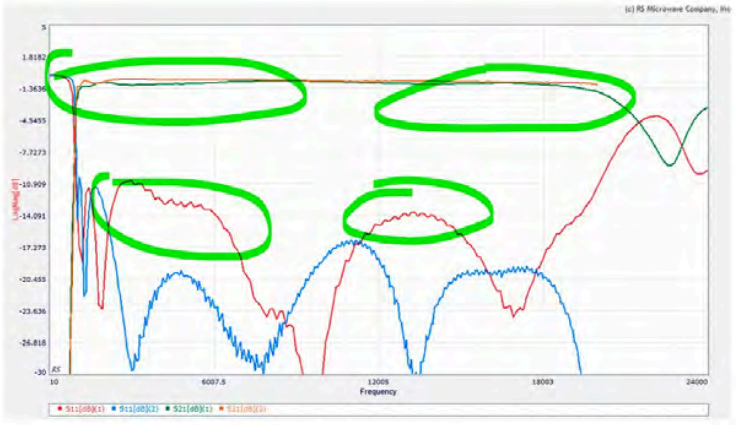


Using Conventional SLC

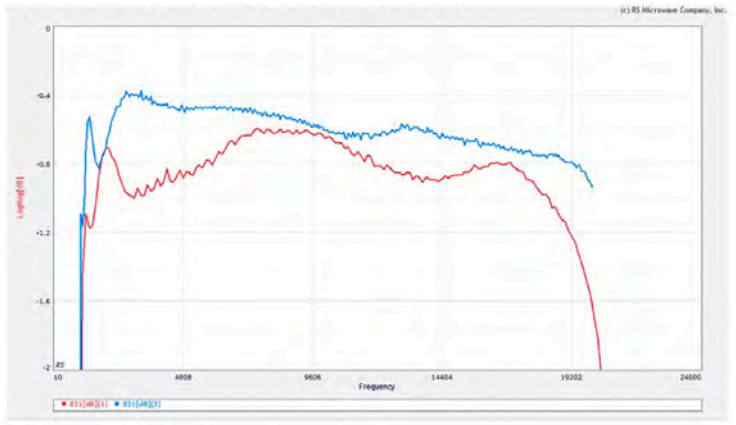


PMI further tested the XG3 Eulex Gap Capacitor in a High Pass Filter. By replacing one (1) single layer capacitor (SLC) with one (1) XG3 Eulex Gap Capacitor in PMI's HP-118-CD- SFF, the XG3 Eulex Gap Capacitor replacement demonstrated the following superior characteristics:

- Improved return loss from 11dB (typical) to 20dB (typical).
- Improved insertion loss (approximately 0.4 dB improvement up to 18GHz and 1dB at 20GHz.
- Lower coupling loss at the cutoff frequency (fc); that is, the cutoff angle closest to 90 degrees.
- Maintained performance up to 20 GHz, enabling a broader frequency range without self-resonance.
- Increased power handling capability from 1W to 50W. Note: While this improvement included an inductor upgrade, the XG3 Eulex Gap Capacitor was a key enabler for achieving this higher power handling.



Orange and Blue - XG3 Eulex Gap Capacitor
Green and Red - Single Layer Capacitor



Blue - XG3 Eulex Gap Capacitor
Red - Single Layer Capacitor

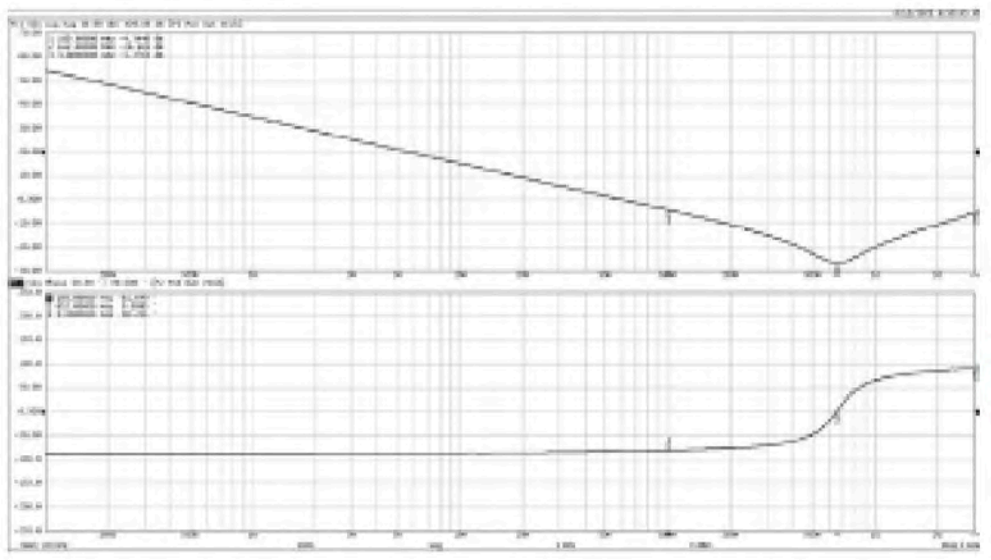
PMI's overall testing highlighted several key advantages of the Eulex Gap Capacitors:

- **Higher Q (Quality Factor):** Demonstrating lower losses and greater rejection before the cut-off frequency and improved efficiency.
- **Lower Parasitic Effects:** Reducing unwanted inductance and resistance, leading to better high-frequency performance.
- **Consistent Performance:** Maintaining similar performance characteristics across different capacitance values within the same footprint.
- **High-Frequency Capability:** Sustaining performance at frequencies up to 67GHz and beyond.
- **Simplified Design:** Reducing the need for complex tuning or wire bonds, simplifying the manufacturing process, easy to assemble, reducing labor costs
- **Enhanced Power and Voltage Handling:** Providing improved performance compared to traditional SLC capacitors.

"Our independent evaluation of the Eulex Gap Capacitors (Single Layer, High-Q) has revealed outstanding performance across a range of critical parameters. The combination of lower cost, higher Q, better RF metrics (VSWR, SRF, flatness, Loss, etc.) increased power/voltage handling and the elimination of wirebonds represents a significant advancement in capacitor technology. These capacitors offer a compelling solution for high performance RF designs."
Sebastian Palacio
VP/GM
PMI

Picotest Testing

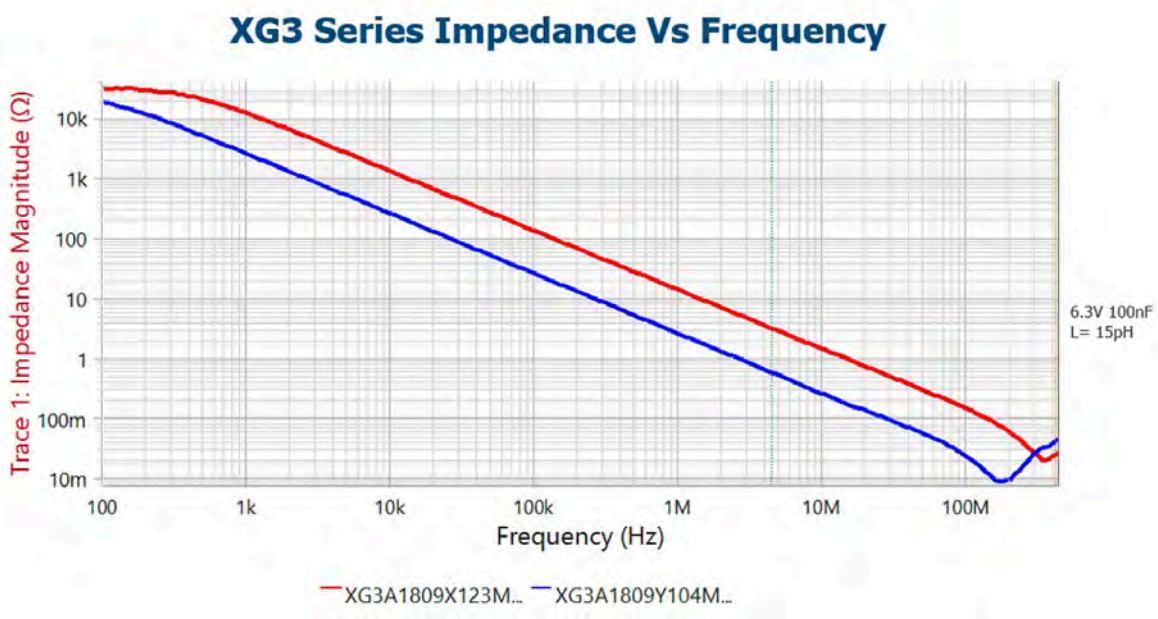
Picotest conducted a low frequency high power application test utilizing its specialized Bode 500 measurement tool to independently verify the inductance of the XG3 Eulex Gap Capacitor. The testing protocol focused on quantifying the capacitor's Equivalent Series Inductance (ESL) with the aim of accurately measuring inductance values at the pico-Henry level.



Key outcomes from Picotest's Testing:

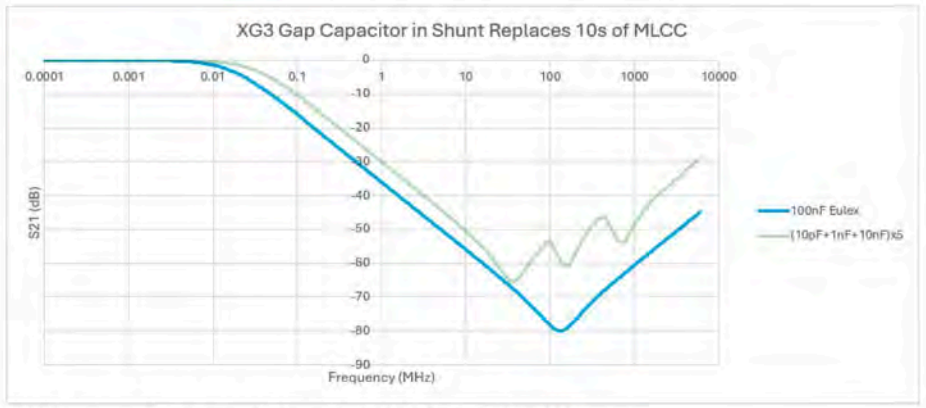
- Successful measurement of pico-Henry level inductance, demonstrating the capacitor's ultra-low inductance characteristics and validating accurate measurement at these levels.
- The significance of these results lies in demonstrating superior performance of the XG3 Eulex Gap Capacitor compared to traditional Multilayer Ceramic Capacitors (MLCCs). While typical MLCCs exhibit inductance values on the order of 200 pico-Henries, the XG3 Eulex Gap Capacitor exhibited significantly lower inductance, as low as 15 pico-Henries.

"Your capacitors exhibit remarkably low ESL, making them well-suited for coupling in microwave applications. They successfully passed 500 watts in testing."
Steve Sandler,
Managing Director
Picotest



This validation confirms the XG3 Eulex Gap Capacitor's suitability for applications in RF circuits, DC blocking, power integrity solutions, and high-reliability markets where minimizing inductance is paramount. The results provided independent confirmation of the XG3 Eulex Gap Capacitor's low inductance, underscoring its benefits for demanding high-frequency applications.

Further data indicates that approximately 20 MLCCs would be required to match the performance of a single XG3 Eulex Gap Capacitor.



XG3 Series Equivalent Circuit (XG3A1809Y104MGW)

Long-Term DC Life Testing: The Eulex Gap Capacitors have successfully passed over 7,000hr of life test at 2X rated voltage @ 125°C without failures.

Humidity Testing: 240 hours, no failures.

Dielectrics: Both the Eulex XG2 and XG3 use Class I dielectrics such as porcelain and NP0, chosen for their high stability, high Q, and low loss characteristics, with temperature coefficients (TCC) of negligible to 0 ±30ppm/°C, making them suitable for applications requiring minimal capacitance drift over temperature (-55 to +125°C) in high frequency.

Conclusion

The Eulex Gap Capacitor, in both its 2-terminal (XG2) and 3-terminal (XG3) variants, presents a substantive advancement in passive component design for high-frequency applications. By eliminating traditional sources of parasitic inductance—such as wire bonds and vias—and employing a coplanar, embedded electrode architecture, the XG Series achieves exceptionally low ESR and ESL, high capacitance density, and stable performance across temperature, voltage, and frequency extremes. Independent testing confirms its ability to operate effectively beyond 67 GHz, with consistent behavior under high power and bias conditions. These characteristics make the Eulex Gap Capacitor a technically robust solution for applications requiring precise impedance control, broadband filtering, and reliable power integrity, offering system-level advantages in performance, footprint reduction, and long-term reliability.