Comparison of MLCC and X2Y® Technology for Use in Decoupling Circuits

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1. ABSTRACT

Technology for multiple layer ceramic capacitors (MLCC) has primarily focused on better dielectric materials, size reduction, or integrating passive devices (IPD's) to reduce inductance at higher frequencies in decoupling applications. X2Y® Technology is an emerging technology with a low-inductance solution for broadband decoupling due to its unique internal electrode structure. This paper investigates the performance of several MLCC technologies/configurations and compares them against the X2Y® Technology to determine their usefulness in decoupling circuits.

2. INTRODUCTION – What is X2Y® Technology?

The unique structure of the X2Y® Technology is a combination of a standard bypass capacitor and a parallel reference electrode structure that forms a quasi Faraday Cage. The packaged component has the regular A and B terminals of a bypass capacitor with two additional side terminations called G1 and G2 (Figure 1). [1] (NOTE: X2Y® components are applied in bypass and should not be confused as feedthrough capacitors.)

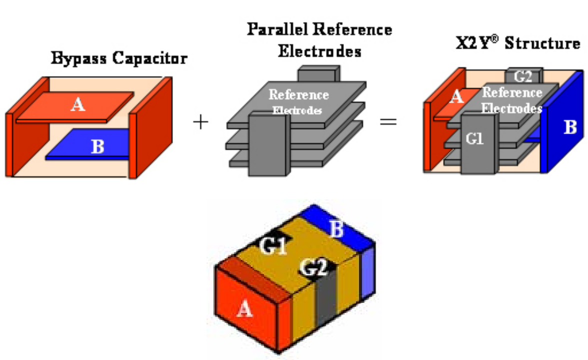

Figure 1. *Depiction of the X2Y® structure.*

The parallel reference electrode structure (Faraday Cage) creates a symmetrically balanced capacitive circuit with two capacitive halves. The capacitive rating is a line-to-ground measurement (A or B–to–G1 or G2, Figure 2), thus the total capacitance that an X2Y® can supply is double the capacitive rating. Capacitive tolerance from half-to-half (A-to-G1/G2 and B-to-G1/G2) is 1-2.5% or less. In addition, tolerance is maintained over temperature and time (aging) due to the shared dielectric. [1]

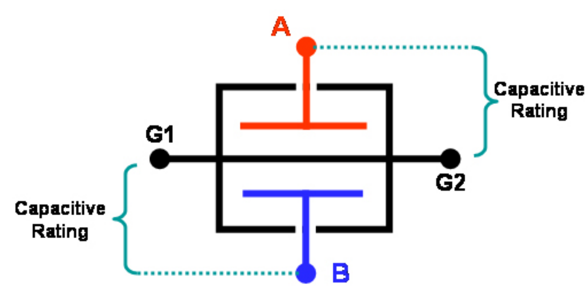

Figure 2. *Illustration of the X2Y® capacitive rating.*

X2Y® components should be viewed as a capacitive circuit because different connection configurations change the component's structure orientation with respect to the load. The two configurations explored in this paper are Circuit 1 and Circuit 2. Both configurations take advantage of the structure for E- and H- field cancellation.

The Circuit 1 configuration is a differential application that utilizes three independent conductors. Two examples of a Circuit 1 application are (1) attachment between a signal and return with respect to ground/image plane [2], or (2) attachment between 2 power planes (example: 5v and 3.3v planes) with respect to a ground/image plane (Figure 3).

The Circuit 2 configuration is a single ended application that utilizes two independent conductors. The A and B terminations share a common voltage potential and the G1 and G2 terminations share a common but separate potential from A and B. Two examples of a Circuit 2 application are (1) attachment between a signal and return, or (2) attachment between a power and ground plane (Figure 4).

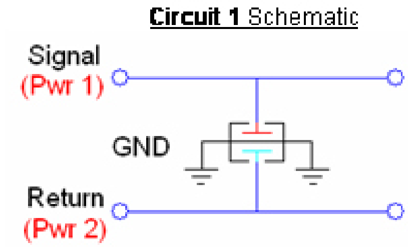

Figure 3. *Schematic of the X2Y® Circuit 1 configuration.*

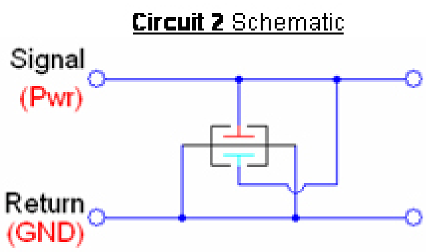

Figure 4. *Schematic of the X2Y® Circuit 2 configuration.*

3. EVALUATION #1 – Flux Containment

Previous work, [3] and [4], has shown that the performance characteristic of MLCCs in parallel are dependent on the mutual inductance exhibited between each other. The amount of mutual inductance between the capacitors is the result of magnetic flux extending beyond the physical boundary of the capacitor's body and the physical distance between them. Work in [3] characterized a 6dB improvement beyond self-resonant frequency in which (2) standard MLCC in parallel were spaced 10mm apart as compared to when the capacitors were spaced 2mm apart (Figure 5).

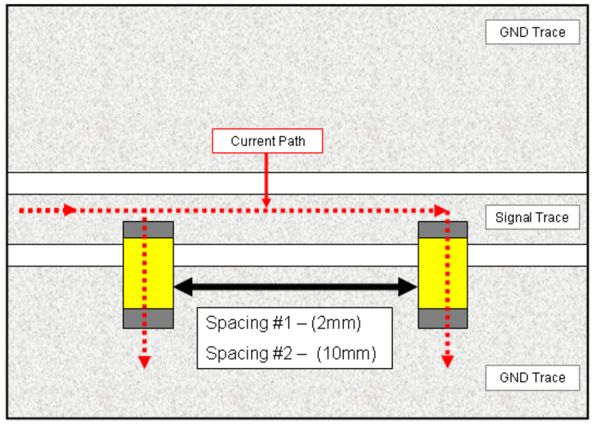

Figure 5. *Layout of component spacing.*

This evaluation investigates if the X2Y® Technology offers any advantage in spacing requirements over standard MLCC capacitors.

A test PCB with the layout similar to [3] was constructed with an overall dimension of 28mm x 28mm with a FR-4 substrate. The PCB is double layered, 1.0688mm thick, with a relative permittivity of 4.6. The signal trace is 1.345mm and the ground trace widths are 12.9475mm. SMA connectors were soldered at each end of the signal trace.

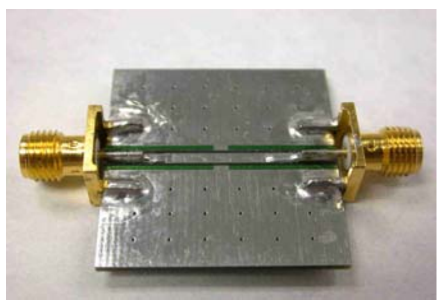

Figure 6. *Test PCB used for Evaluation #1.*

S21 measurements were taken with a Hewlett Packard 2-port Vector Network Analyzer (VNA) model HP 8753E with HP 11857D test set cables. The VNA setup parameters are shown in Table 1.

Points:	801
Start/Stop:	30kHz - 6GHz
IF Bandwidth:	100Hz
Span:	30kHz - 6GHz
Format:	Log Mag
Measurement:	S21
Data:	Log Scale

Table 1. *VNA setup for Evaluation #1.*

Note that due to layout configuration of the PCB a modified-Circuit 2 was used. The G1 and G2 terminals were connected to the signal trace while the A and B terminals were connected to the return (Figure 7). As mentioned in the previous section, the X2Y® structure is symmetrical; therefore, the difference in S21 measurements between the Circuit 2 configuration (Figure 4) and the modified-Circuit 2 configuration (Figure 7) is nominal (Figure 8).

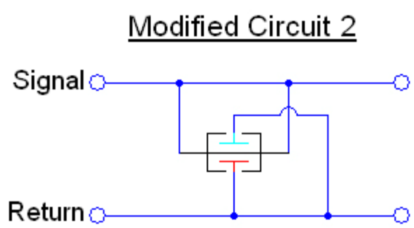

Figure 7. *Schematic of the X2Y® modified-Circuit 2 configuration.*

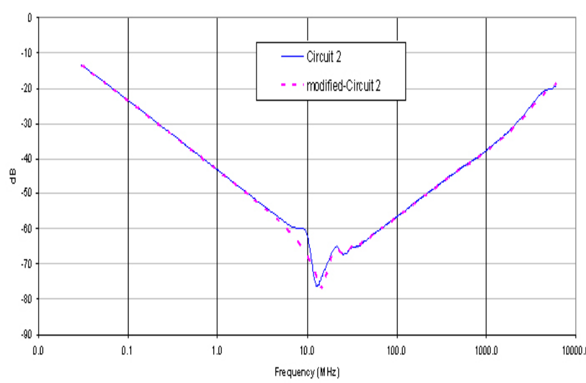

Figure 8. *S21 plot comparing X2Y® Circuit 2 to modified-Circuit 2 configuration. The component used here was a 1210 X2Y® 560nF.*

For the test comparison, S21 measurements were taken on (2) 1206 47nF X2Y® components and (2) 1206 100nF standard MLCC capacitors with spacing distance of 2mm and 10mm apart. (The capacitance rating of the X2Y® components is 47nF. The total capacitance supplied to the board is 94nF as explained in the previous section.)

The results (Figure 9) show nominal results between the X2Y® components spaced 2mm and 10mm apart. The difference seen at resonance is contributed to trace impedance of the PCB between the two components. For the standard MLCC capacitors a 6 - 7dB difference was seen which correlates with the results from [3].

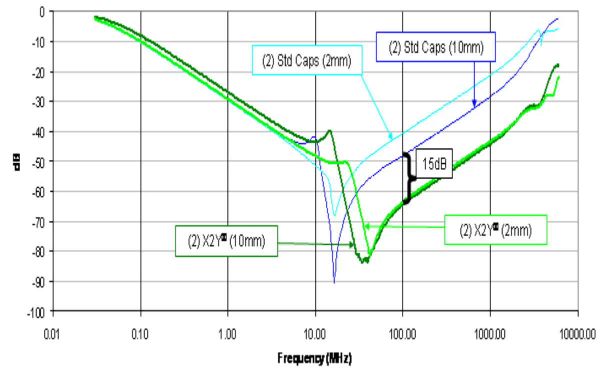

Figure 9. *S21 plot of (2) standard MLCC versus (2) X2Y® components spaced 2mm and 10mm apart.*

The following conclusions are drawn from this experiment:

i. Two X2Y® components exhibit a 15dB improvement beyond self-resonance over the best case MLCC spacing (10mm) recommendations in [3].

ii. X2Y® components are able to contain magnetic flux within the boundary of the component's body, thus reducing the mutual inductance between the two individual components.

4. EVALUATION #2 – X2Y® versus Low-Inductance Capacitors

The second evaluation examines the S21 (insertion loss) performance between the X2Y® Technology, standard MLCC, and low-inductance MLCC in a reversed geometry structure. Typically, reversing the electrode geometry and terminations yields a 50% reduction in package inductance.

Measurements for this experiment use a Wiltron Test Fixture model 3680-20. The setup for this fixture requires the device-under-test (DUT) to be soldered to a PCB made with a FR-4 substrate. The PCB has a 1mm thickness and a 50Ω microstrip line. The PCB is then mounted into the fixture. S21 measurements are taken with a HP 8753D, 2-port VNA. The VNA setup parameters are shown in Table 2.

Points:	443
Start/Stop:	30kHz - 6GHz
Span:	30kHz - 6GHz
Format:	Log Mag
Measurement:	S21
Data:	Log Scale

Table 2. *VNA setup for Evaluation #2.*

The DUT will be (1) 0603 220nF MLCC, (1) low-inductance 0306 220nF MLCC, and (1) 0603 100nF X2Y® component in a Circuit 2 configuration (Figure 4). (Note that the X2Y® 100nF supplies a total capacitance value of 200nF.)

The results are shown in Figure 10.

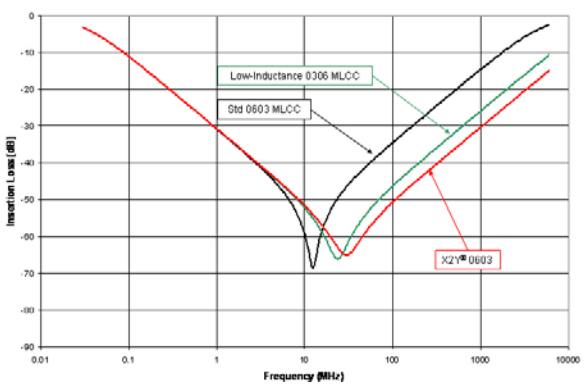

Figure 10. *S21 plot of standard 0603 MLCC, low-inductance 0306 MLCC, and 0603 X2Y® component. Data provided by Bart Bouma of Yageo-Phycomp.*

The following conclusions are drawn from this experiment:

i. A single X2Y® component exhibits a 16dB improvement beyond self-resonance over a single standard MLCC.

ii. A single X2Y® component exhibits a 3dB improvement beyond self-resonance over the low-inductance reverse geometry MLCC.

iii. The repeatability performance of X2Y® components is verified on a second test fixture/setup at a second laboratory. (Data was provided by Bart Bouma at Yageo-Phyomp.)

5. EVALUATION #3 – X2Y® Package Size and Inductance Correlation

The third evaluation examines the S21 (insertion loss) performance of different package sizes of the X2Y® Technology. It has been shown in [5] that there is a direct correlation of package size (the distance between terminations) to package inductance.

S21 measurements for this experiment will use the same test setup and equipment as described in Evaluation #2. The only exception is the number of points taken; this evaluation takes 801 points as shown in Table 3.

Points:	801
Start/Stop:	30kHz - 6GHz
Span:	30kHz - 6GHz
Format:	Log Mag
Measurement:	S21
Data:	Log Scale

Table 3. *VNA setup for Evaluation #3.*

The DUT will be (1) 1812 470nF X2Y® and (1) 1812 1uF X2Y®. Both DUTs are attached in a Circuit 2 (Figure 4) configuration. For reference, the 0603 100nF X2Y® component from Figure 10 is included.

The results are shown in Figure 11.

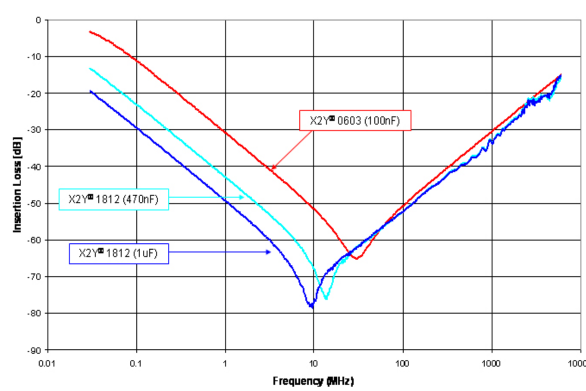

Figure 11. *S21 plot of 0603 (100nF) X2Y®, 1812 (470nF) X2Y®, and 1812 (1uF) X2Y®. Data provided by Bart Bouma of Yageo-Phycomp.*

The following conclusions are drawn from this experiment:

i. The larger X2Y® package size, 1812, has a 1 - 2dB performance improvement beyond self-resonance over the 0603 X2Y®, despite the fact that the physical distance between the terminations of the 1812 is much greater.

ii. The unexpected results seen are explained by the internal parallel structure of the X2Y® Technology and the internal mutual cancellation that occurs [1]. The larger the package size, the more parallel electrode layers exist. This results in a lower internal impedance and more mutual cancellation. This contradicts [5] that claims the inductance of MLCC is limited to its physical geometry (smaller is better). However, with the X2Y® Technology the internal parallel structure and passive cancellation are larger factors than physical geometry when calculating the internal inductance.

6. EVALUATION #4 – X2Y® CIRCUIT 1 VERSUS CIRCUIT 2

The final evaluation compares the Circuit 1 configuration (Figure 3) to the modified-Circuit 2 configuration (Figure 7). Until this point, this paper has only shown performance results pertaining to Circuit 2/modified-Circuit 2 because it allows easier comparison to traditional MLCC. Circuit 1 utilizes the structure along with a three individual conductors to realize maximize the full potential of the X2Y® Technology.

The S21 measurements for this experiment will use a ICM Test Fixture A0134552A designed specifically for 4-port devices [6] and a Hewlett Packard 2-port Vector Network Analyzer (VNA) model HP 8753E with HP 11857D test set cables. The VNA setup parameters are shown in Table 4.

Points:	801
Start/Stop:	30kHz - 6GHz
IF Bandwidth:	100Hz
Span:	30kHz - 6GHz
Format:	Log Mag
Measurement:	S21
Data:	Log Scale

Table 4. *VNA setup for Evaluation #4.*

The results are shown in Figure 12.

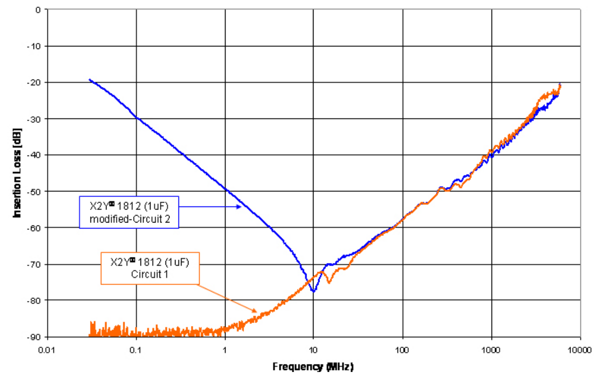

Figure 12. *S21 plot of X2Y® Circuit 1 and Circuit 2 configurations.*

The following conclusions are drawn from this experiment:

i. The inductance beyond self-resonant is the same between Circuit 1 and Circuit 2 configurations.

ii. The Circuit 1 configuration offers a more efficient transfer of energy at frequencies before self-resonance than the Circuit 2 configuration due to the parallel orientation to the load.

7. CONCLUSION

The X2Y® Technology shows great potential in the role of decoupling circuits. The unique structure gives it superior performance over standard and low-inductive MLCC. The performance results were correlated and verified using different equipment, fixtures, and laboratories.

In addition to superior performance, the different connection configurations give decoupling engineers greater flexibility for layout implementation in decoupling circuits.

8. REFERENCES

[1] Internal Model of X2Y®, Application Note #1004, www.x2y.com.

[2] Robert F. German, Henry W. Ott, and Clayton R. Paul, Effect of an Image Plane on Printed Circuit Board Radiation, IEEE International Symposium on Electromagnetic Compatibility, Washington, D.C., August 21-23, 1990. http://www.hottconsultants.com/pdf_files/image_plane.pdf.

[3] Hwan W. Shim, Theodore M. Zeeff, and Todd H. Hubing. "Decoupling Strategies for Printed Circuit Borards Without Power Planes," Vol 1, pages 258-261 of IEEE International Symposium on Electromagnetic Compatibility: Symposium Record. Minneapolis, Minnesota, August 19-23, 2002.

[4] Theodore M. Zeeff, Todd H. Hubing, Thomas P. Van Doren, and David Pommerenke. "Analysis of Simple Two-Capacitor Low-Pass Filters," Vol. 45, Number 4, pages 595-601 of IEEE Transactions on Electromagnetic Compatibility. November 2003.

[5] Howard Johnson. "Parasitic Inductance of Bypass Capacitor II," Vol. 6, Issue 9, High Speed Digital Design. http://www.sigcon.com/Pubs/news/6_09.htm

[6] User's Manual for ICM Test Fixture A0134552A, http://www.x2y.com/cube/x2y.nsf/(files)/FixtureOverview.pdf/$FILE/FixtureOverview.pdf