Internal Model of X2Y® Chip Technology

Summary

At high frequencies, traditional discrete components are significantly limited in performance by their parasitics, which are inherent in the design. For example, a standard capacitor is capacitive until self-resonant frequency, beyond that it becomes inductive. The inductive parasitic degrades circuit performance and is undesired.

X2Y® is the next generation in capacitors. X2Y®'s patented internal architecture significantly reduces parasitics at high frequency. The behavior at high frequency is coaxial, which is more desired for filtering and decoupling. This application note explains how the internal structure of X2Y® works and how it can be modeled.

Introduction

To understand the source of the coaxial effect, an understanding of the physical structure is important. A standard bypass capacitor consists of alternating electrode plates that are attached to opposing end terminations[1]. X2Y® combines the standard bypass capacitor with parallel reference electrode structure, similar to a Faraday Cage. This structure isolates end terminals, A and B, and adds two new side terminations known as G1 and G2 (Figure 1).

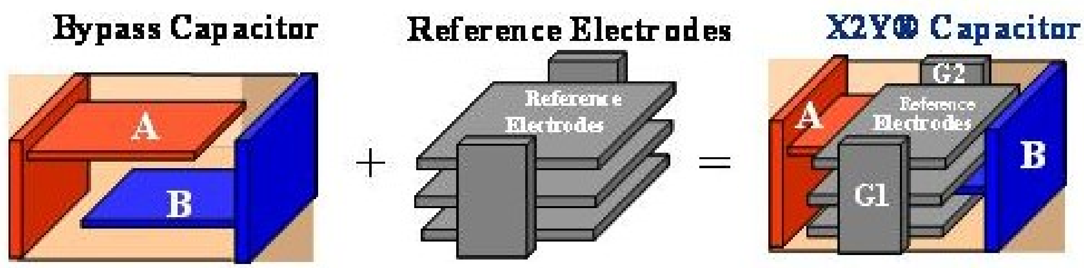


Figure 1. *X2Y® component's structure is made up of a bypass capacitor in conjunction with reference electrodes.*

The parallel reference electrodes change an unbalanced, single ended capacitor into a dual balanced capacitive circuit. When G1 and G2 are at equal potential and that potential is less then A and B's potential, the result is two capacitive tight potentials in each half of the structure. Typically X2Y® components have a tolerance of 1-3% or less (Figure 2). The balance is maintained over temperature and time (aging) because of the shared dielectric.

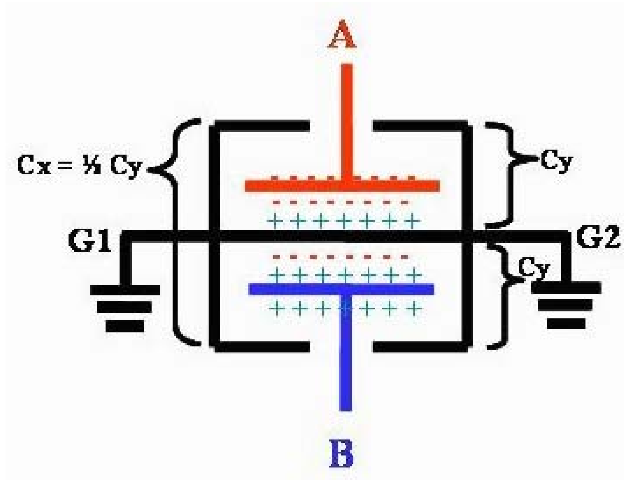


Figure 2. *The reference electrodes create two tightly matched potentials*.

To demonstrate this balance, a Vector Network Analyzer (VNA) and a microwave test fixture is used to make s11 and s22 (reflection) measurements from 30 kHz to 6 GHz. Figure 3 shows the magnitude and phase plots of this test.

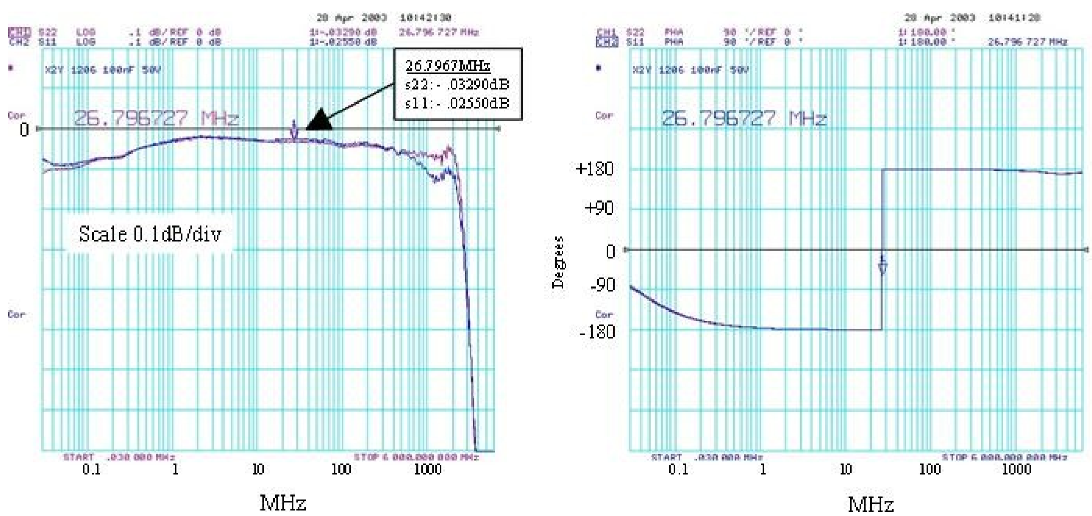


Figure 3. *s11 and s22 (reflection) measurements from 30 kHz to 6 GHz show X2Y® is tightly balanced component*.

The architecture of X2Y® can be compared to a dual rectangular coaxial structure that was studied and modeled by the National Institute of Standards and Technology (formerly the National Bureau of Standards)[2]. The internal Faraday cage forms a non-ideal shielded container for each conductor inside the capacitor. At high frequency, the unwanted noise in each capacitor will choose the path of least impedance, which are the reference electrodes. Since the reference electrodes are between opposite conductors and attached in parallel, an image plane[3] effect occurs. Common mode propagation cancels internally (Figure 4) of the component. The result is a Y-cap configuration effect.

It is important to note that the "shielding" is non-ideal. This also allows parasitic coupling between the A and B conductors. This results in an X-cap effect for differential mode propagation. Figure 4 shows that X2Y® can filter both common mode and differential mode noise current.

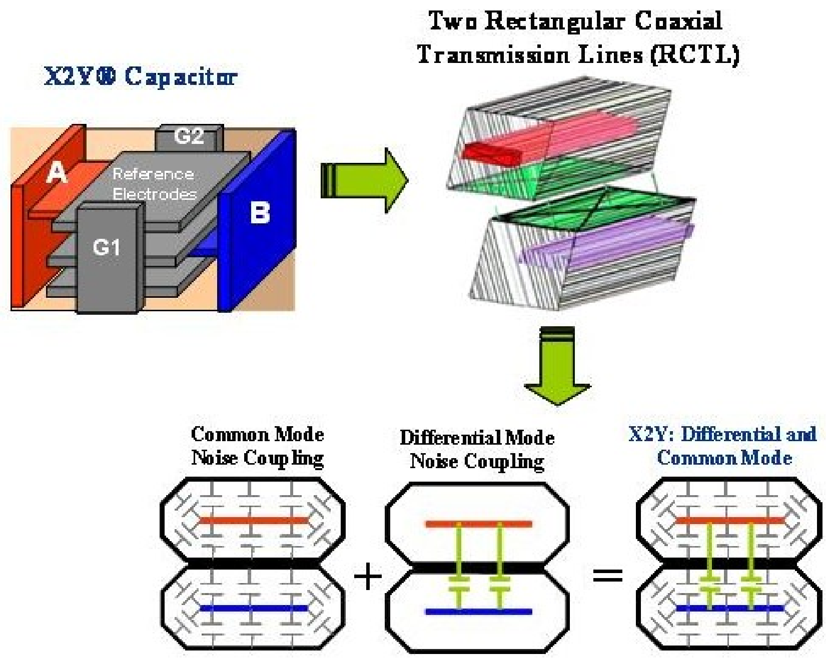


Figure 4. *X2Y® can be thought of as a dual rectangular coaxial structure. Because of this unique structure, X2Y® filters common mode and differential mode noise.*

Analytical Model

To further illustrate the dual rectangular transmission line effect and the internal canceling that occurs, consider the current loop in Figure 5. As current flows in the closed loop a magnetic field is created on the conductor and ground plane. Keep in mind that the strength of the magnetic field is proportional to the rate of change of the current (di/dt). The higher the frequency, the stronger the field is and the easier it radiates.

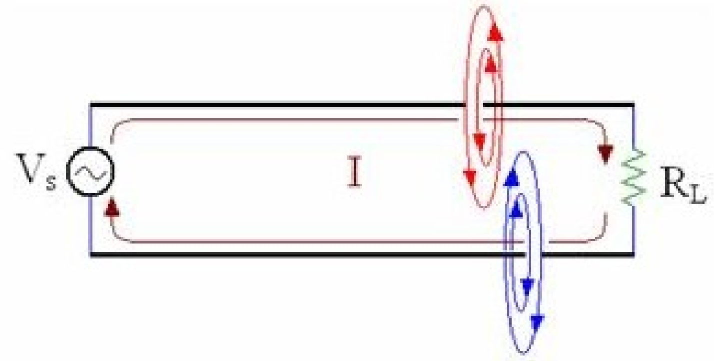


Figure 5. *Simple circuit showing magnetic fields created by current flow.*

Using the right-hand-rule, the direction of the magnetic fields on the conductor and the ground plane are in opposite directions. Mutual inductance occurs when these fields overlap or couple onto each other.[4] The coupled portion of the fields combine together effectively canceling each other because the magnitudes are the same but their polarities are opposites. Note, as the area between the conductors are minimized, mutual inductance increases causing a greater amount of canceling. To highlight the distinctiveness of X2Y®'s structure, consider the current loop of a standard capacitor to that of X2Y® (Figure 6).

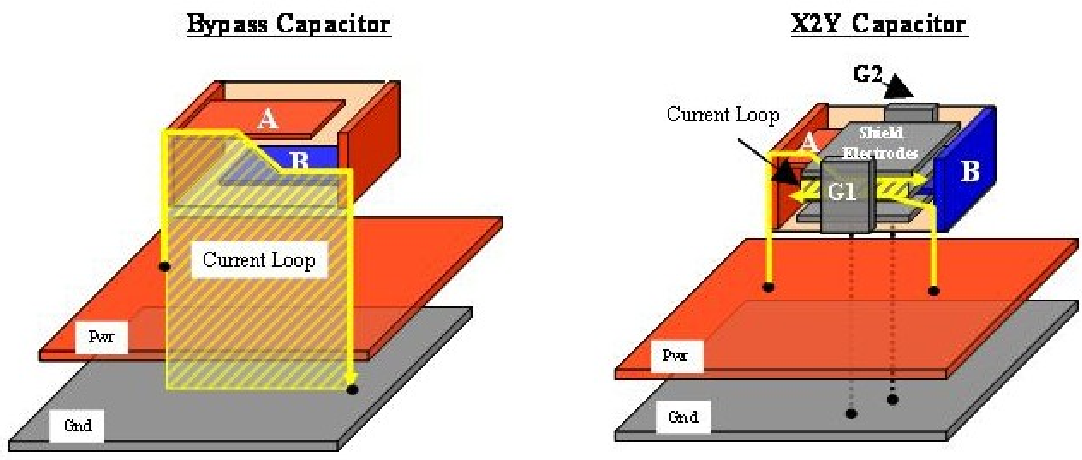


Figure 6. *Current loops of a standard bypass capacitor and an X2Y® capacitor*.

Now consider a coaxial cable connected as shown in Figure 7. Mutual inductance is utilized to cancel high frequency noise. A coaxial cable is a conductor encompassed by a braided shield. The shielding effectiveness is the cut-off frequency or ω_c. If the frequency becomes five times greater than ω_c, the braided shield becomes a lower impedance return path back to the source causing high frequency current to return on the shield[5]. Because the area between the conductor and the shield is small, the high frequency current (noise) cancels.

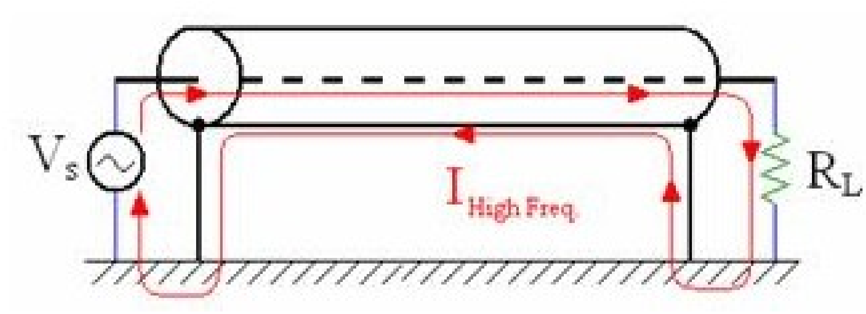


Figure 7. *High frequency current flow in a coaxial cable*.

Next consider two coaxial cables whose shields (non-ideal or non-homogeneous) are welded together and the signal is represented by A and its return is represented by B. Figure 8 depicts the distributive electric field, E-Field, coupling among the structure.[6]

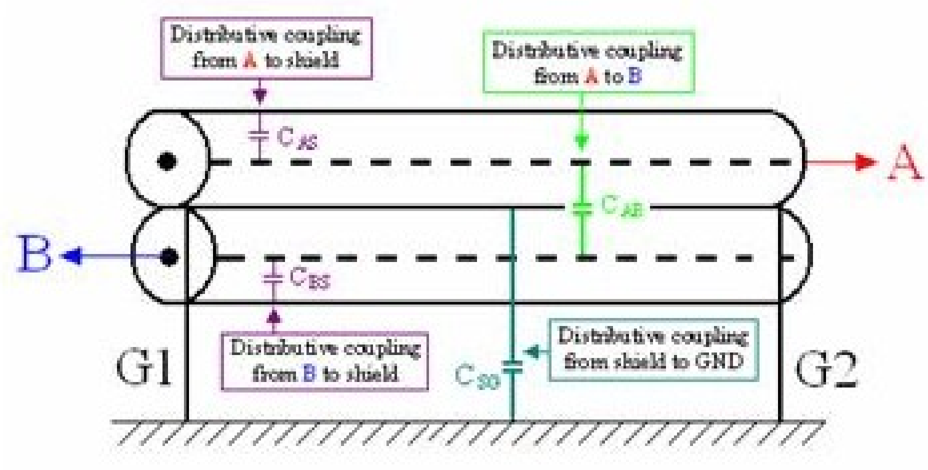


Figure 8. *The parasitics of two coaxial cables are similar to the parasitics of X2Y®.*

Figure 9 is a schematic representation of Figure 8 using non-ideal capacitors and lead parasitics for G1 and G2. The non-ideal capacitors incorporate the magnetic field, H-Field, in the inductors.

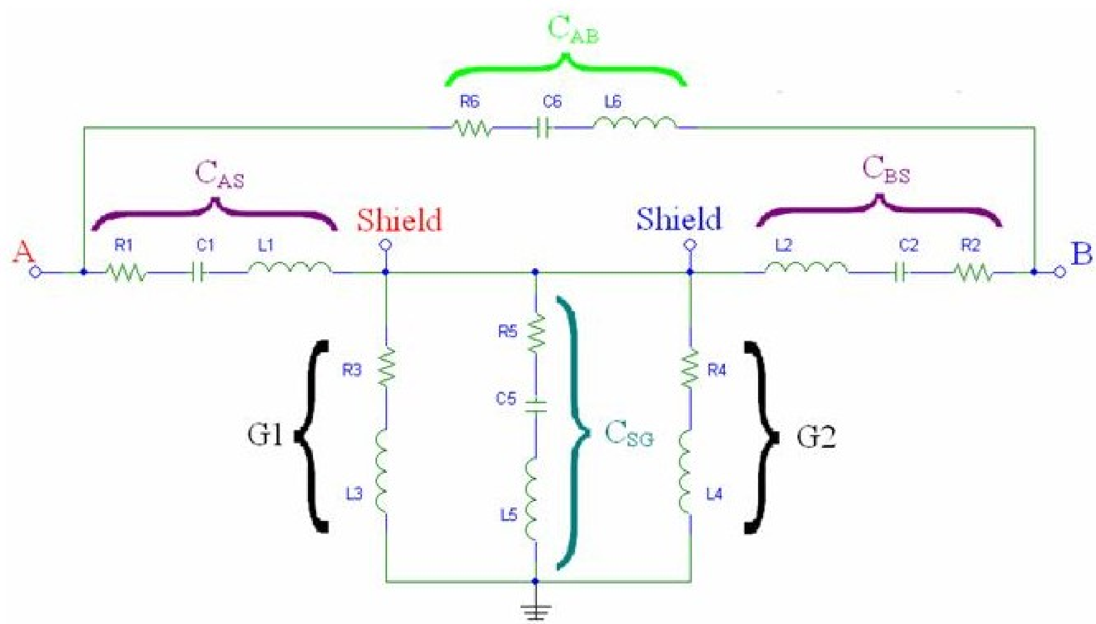


Figure 9. *Schematic of the internal parasitics of X2Y®.*

This schematic model can be used as a general representation of the dual rectangular coaxial mentioned before. Using this model, we can also define the internal model of an X2Y® component at high frequency. For a more accurate model of an X2Y® component, five assumptions can be made to reflect actual component behavior.

- The reference electrodes (Figure 10) are non-homogenous which allows coupling between the A and B electrodes (C_{AB} in Figure 9). Note: To contain magnetic flux internally to the component, an additional reference electrode is placed at each end of the structure. In addition the A and B electrodes are inset in the dielectric while the reference electrode plates are stretched.

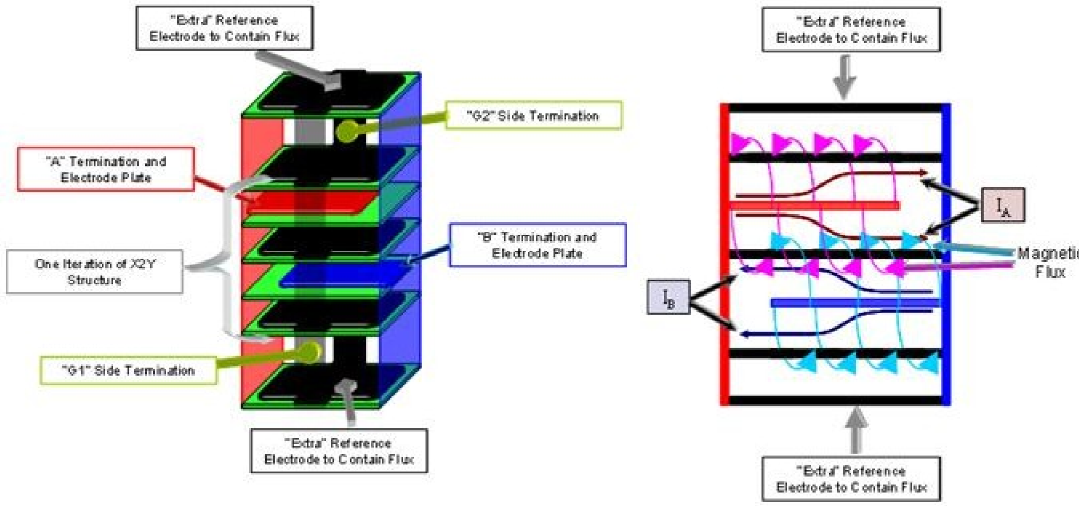


Figure 10. *Electrode plate structure of X2Y®.*

- C_{SG} (Figure 9) would have greater impedance than the side terminations G1 and G2 because R5 would ideally be infinitely large. Therefore C_{SG} can be neglected and the total impedance characteristic would be R3 and L3 in parallel with R4 and L4.

- Multiple repeating layering sequences (Figure 10) would place the A electrodes in parallel. Therefore the total impedance characteristic would primarily be capacitive. The same would be true for B electrodes. Therefore, R6 & L6 in Figure 9 would be nominal.

- The current direction of A and B are 180° out of phase (Figure 8). The magnetic field created by L1 & L2 in Figure 9 would cancel due to mutual inductance shown in Figure 10.

- The mutual inductance (Assumption ☐) and the capacitance from A to B (Assumption ☐) can be combined and modeled as a non-ideal transformer.

If these assumptions are incorporated into the schematic model in Figure 9, the model would now look like Figure 11.

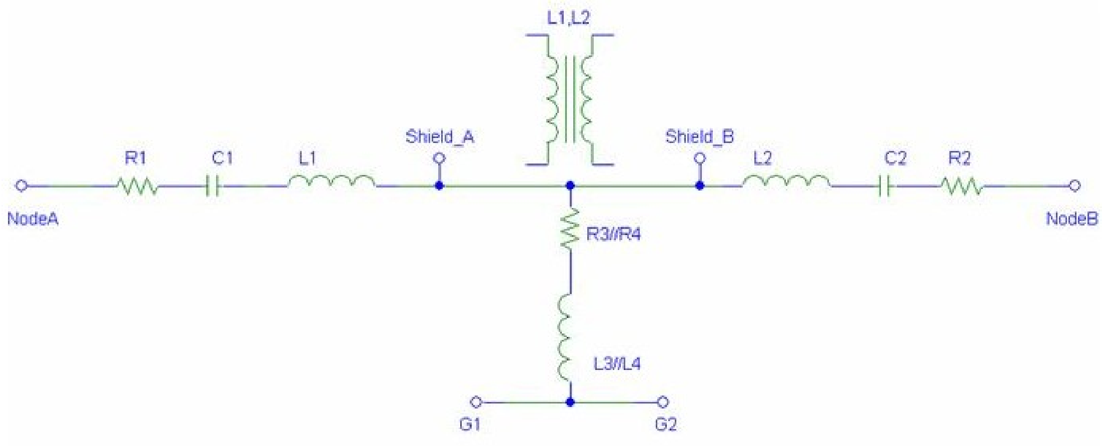


Figure 11. *Schematic model of X2Y® with the above assumptions*.

X2Y® Quantitative Data Taken in the Lab

To validate this model quantitatively, a laboratory setup to measure the insertion loss of an X2Y® component is shown in Figure 12. A test fixture from Inter-Continental Microwave (ICM) and a HP8753E Network Analyzer are used to measure from 30 kHz-6 GHz.

Figure 12. *Validation test set-up*.

A standard capacitor has one circuit configuration, thus one curve to show insertion loss. X2Y®, on the other hand is a multi-port device, which can be attached in a circuit three different ways. The result is three different curves for insertion loss depending on how X2Y® is attached. Figure 13 shows the three attachment configurations and the placement in the test fixture to measure insertion loss. Figure 14 shows the insertion loss curves.

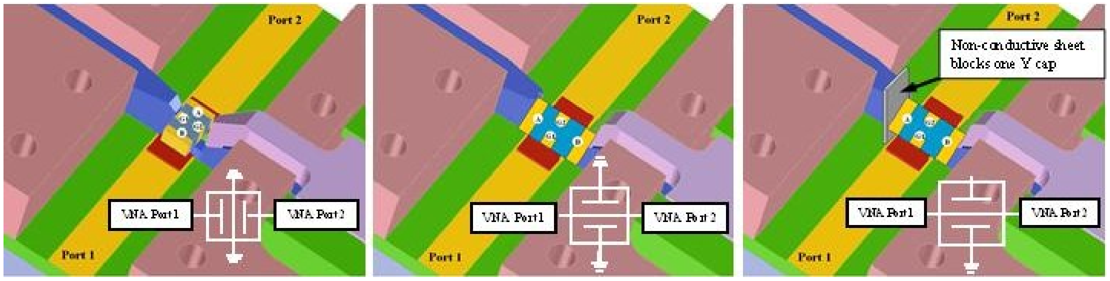


Figure 13. *Component placement in test fixture.*

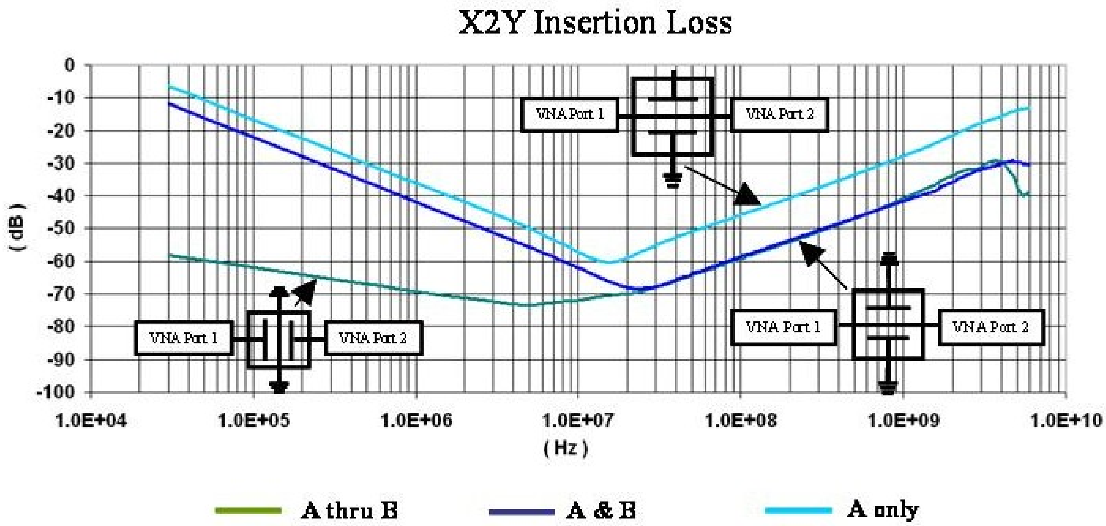


Figure 14. *The insertion loss plot of an X2Y® component. Unlike standard capacitors, X2Y® has three different insertion loss plots depending on how X2Y® is connected in the circuit.*

SPICE Simulations of the Analytical Model

Yageo/Phycomp, a licensed manufacturer of X2Y® components, has developed the following models in Figure 15 based on the measured S-parameter data. 0 is the plot of the simulated model.

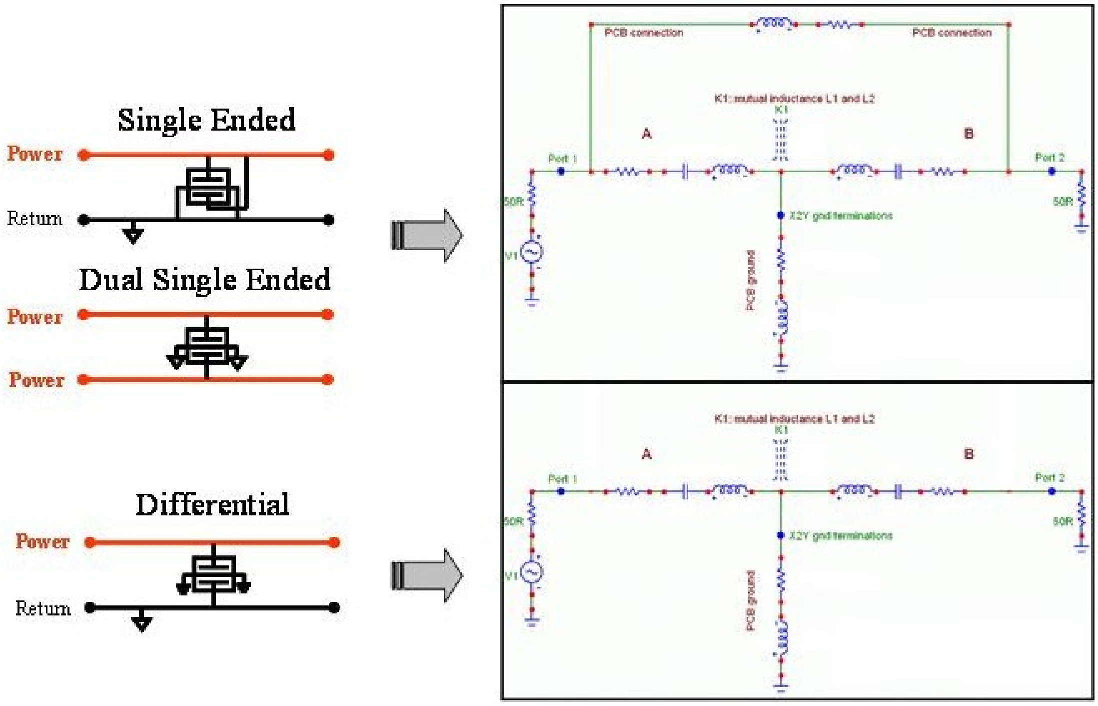
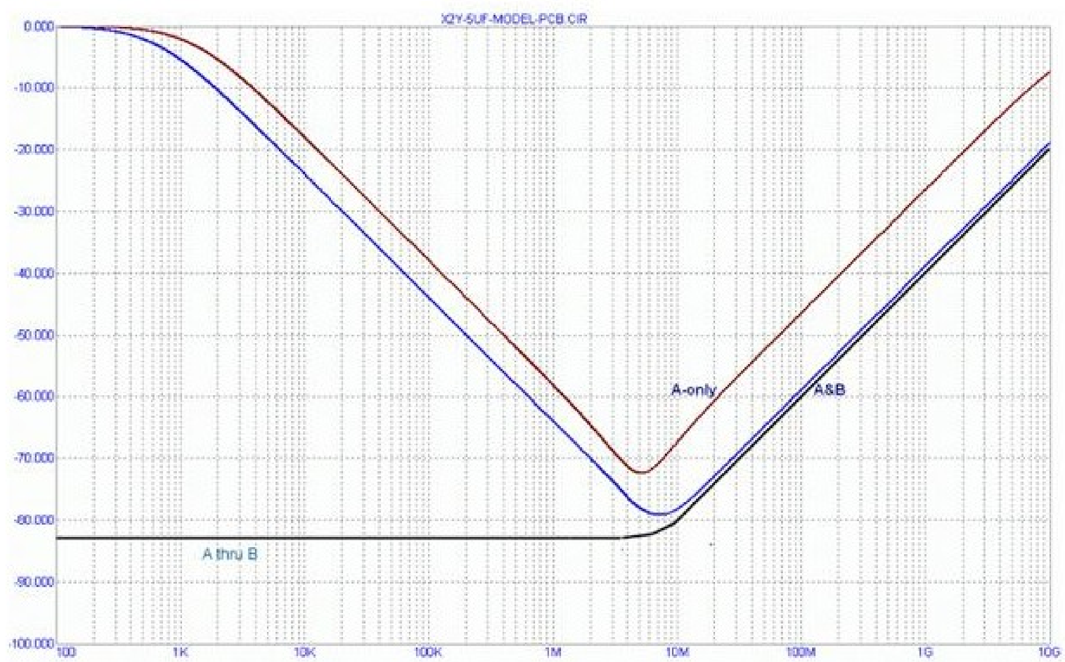


Figure 15. *SPICE model of X2Y® courtesy of Yageo/Phycomp*.



SPICE plot of insertion loss courtesy of Yageo/Phycomp.

Conclusion

The unique structure of an X2Y® component replaces inductive behavior that standard capacitors exhibit at frequencies above self-resonance with a more desirable coaxial one. Using the dual rectangular coaxial model, an analytical model of the internal parasitics of the X2Y® structure can be constructed.

Quantitative test data validates the analytical model from 30 kHz – 6 GHz for "A only" and "A & B" and from 1 MHz – 6 GHz for "A thru B" circuit configurations. For more information or further explanation of the valid range for the SPICE model contact X2Y® Attenuators (see Contact Information at the end of the Application Note).

Note: Performance results reported in this and other application notes can only be achieved with patented X2Y® components sourced from X2Y® licensed manufacturers or their authorized distribution channels.

References

[1] Stan Gibilisco, Electricity and Electronics, p205.

[2] "Theoretical and Experimental Analysis of Coupling Characteristics of Dual TEM Cells" by P.F. Wilson, D.C. Chang, Department of Electrical Engineering, University of Colorado & M.T.Ma, M.L. Crawford, Electromagnetic Fields Division, National Bureau of Standards, Boulder, CO 80303 © 1983 IEEE.

[3]German,Robert F, Ott, Henry W., and Paul, Clayton R., "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.

[4] Ott, Henry, "Noise Reduction Techniques in Electronic Systems", 2nd edition. Page 21, John Wiley & Sons, 1988.

[5] Ott, Henry, "Noise Reduction Techniques in Electronic Systems", 2nd edition. Pages 50-52, John Wiley & Sons, 1988.

[6] Ott, Henry, "Noise Reduction Techniques in Electronic Systems", 2nd edition. Pages 33-37, John Wiley & Sons, 1988.

Contact Information

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