Common Mode and Differential Mode Noise Filtering

Summary

This application note gives a practical explanation of differential mode and common mode noise along with the traditional filtering approaches. In addition, an alternative method of filtering is shown using X2Y® components.

Introduction

In an ideal circuit, the signal from the source and load would require no filtering. Figure 1 represents the ideal circuit's current path. The signal current, I_S, flows on the positive conductor and signal's return current, I_r, flows on the negative conductor. The relationship between the current on the two conductors is $I_s = -I_r$. I_s and I_r have the same magnitude, but different polarity.

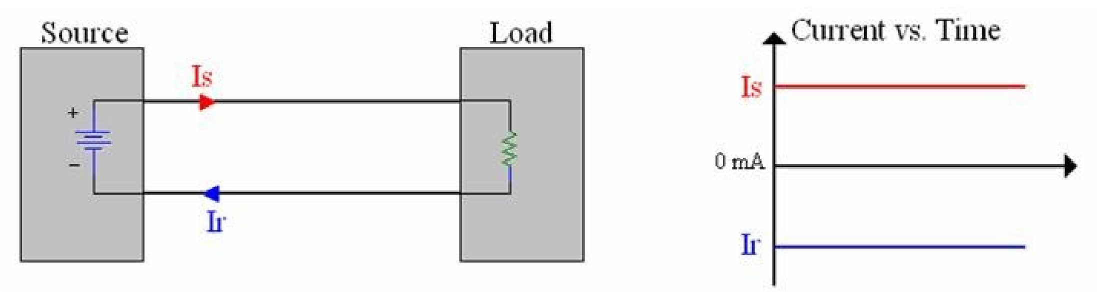

Figure 1. *The desired circuit's current path.*

Differential Mode Noise Current

Noise current that flows in the same directions as I_s and I_r is called <u>differential mode noise</u> or I_d, see Figure 2. The total current on the positive conductor is $I_{t\_pos} = I_s + I_d$. Conversely, the total current on the negative conductor is $I_{t\_neg} = I_r + I_d$. The relationship between I_{t_pos} and I_{t_neg} follows the same relationship, $I_{t\_pos} = -I_{t\_neg}$. The relationship between the current on the two conductors is $I_s = -I_r$. I_s and I_r have the same magnitude, but different polarity.

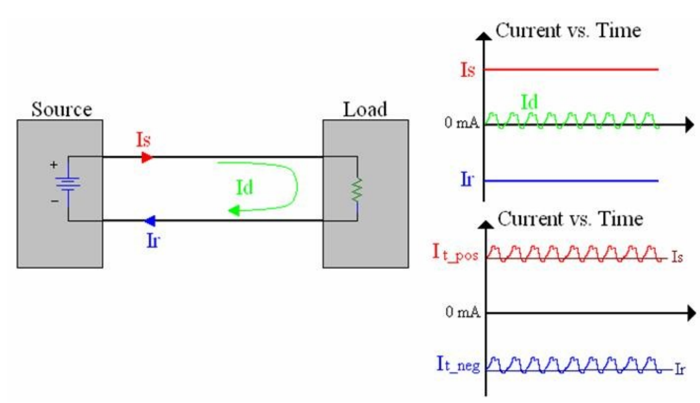

Figure 2. *The effects of differential mode current in a circuit.*

To attenuate differential mode current in a circuit, a standard capacitor is used in an x-cap configuration, Figure 3. The value of the capacitor is chosen by matching the frequency of I_d with the self-resonant frequency of the capacitor. At self-resonant frequency, the capacitor is at minimum impedance and provides an alternative return path to the source. By filtering out I_d, the load receives only the desired signal generated by the source.

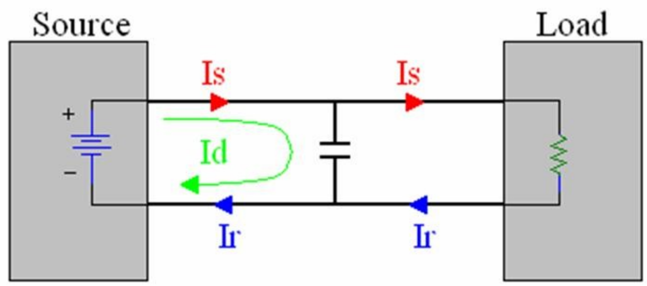

Figure 3. *x-cap configuration to minimize differential mode current.*

Common Mode Noise Current

Noise current that flows in the same directions on both the positive and negative conductors, as shown in Figure 4, is called common mode noise or I_c. The total current on the positive conductor is $I_{t\_pos} = I_s + I_c$. Conversely, the total current on the negative conductor is $I_{t\_neg} = I_r - I_c$. The relationship between I_{t_pos} and I_{t_neg} is no longer an equal magnitude with different polarities. The circuit has become unbalanced; the source and load impedance are no longer equivalent with respect to ground.[1]

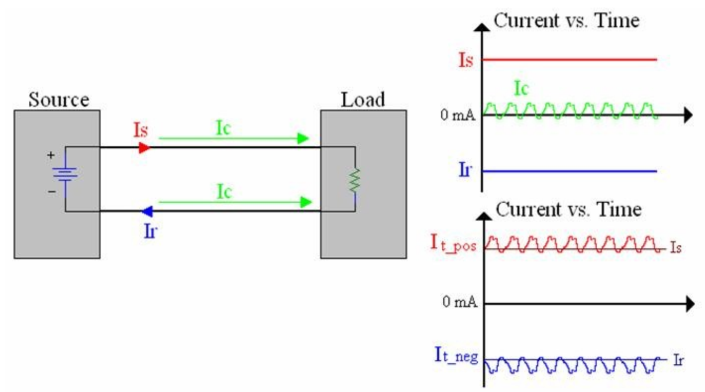

Figure 4. *The effects of common mode current in a circuit. Note I_{t_neg} and I_{t_pos} do not have the same magnitude.*

One approach to attenuate common mode current in a circuit is to use two standard capacitors in a y-cap configuration, Figure 5. Once again, the value of the capacitor is chosen by matching the frequency of I_c with the self-resonant frequency of the capacitor.

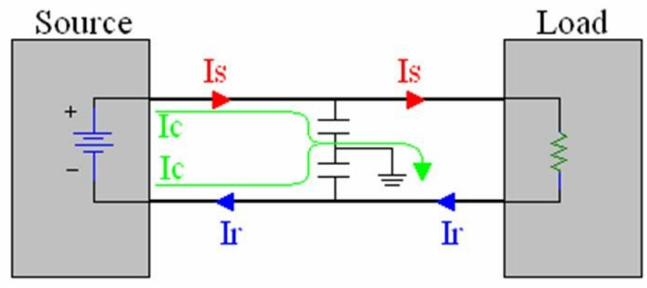

Figure 5. *y-cap configuration to reduce common mode noise current*.

Special care must be taken to ensure that the capacitors are as tightly matched as possible. For example, the goal of the y-cap configuration is to filter out I_c and match the magnitudes of I_s and I_r. If two capacitors are used that have a capacitance tolerance of ±10%, a 20% discrepancy can exist in the amount of attenuation performed between the two conductors.

A second approach to attenuate common mode current in a circuit is to use feedthrough capacitors, see Figure 6. Feedthrough capacitors are able to work at higher frequencies and are more broadband than standard capacitors. The disadvantage of feedthrough capacitors are higher cost and added impedance to the circuit of 0.2 to 0.6 ohms. In low voltage applications this could be an important consideration.

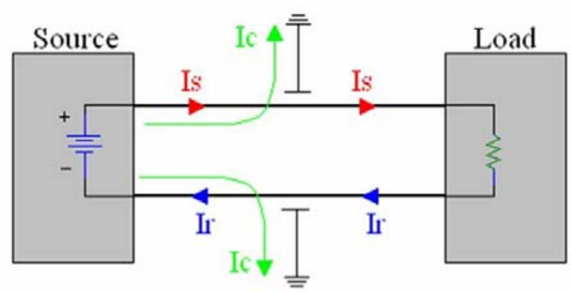

Figure 6. *Common mode filtering using feedthrough capacitors*.

A third approach to attenuate common mode current on a single conductor is to use an inductor, see Figure 7. An inductor in series acts like a short at DC and low frequencies. At high frequencies an inductor acts like an open. The voltage across an inductor is related to current by the rate of change in current.

$$V = -L\frac{di}{dt}$$

When current flows through the inductor magnetic flux is created. If the change in current is from a positive value, I_+, to a negative value, I_-, then the magnetic field will collapse and form magnetic flux in the opposite direction (use right-hand rule). At high frequencies the magnetic field cannot form because the rate of current change is too fast.

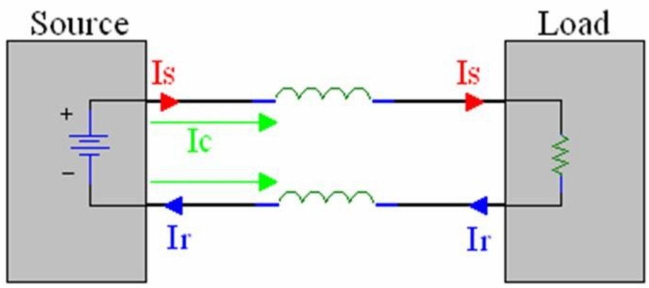

Figure 7. *Common mode filtering using inductors*.

A fourth approach to attenuate common mode current is to use a common mode choke, see Figure 8. Common mode chokes works like an inductor with an added feature. The common mode current creates a flux. Since the flux created by each conductor is in the same direction it adds. This field causes a large impedance thus "choking" the throughput of the common mode current on the conductors[2]. I_S and I_R are differential signals and the mutual inductance of each cancels with the inductance of the choke resulting in I_S and I_R passing through the choke onto the load.

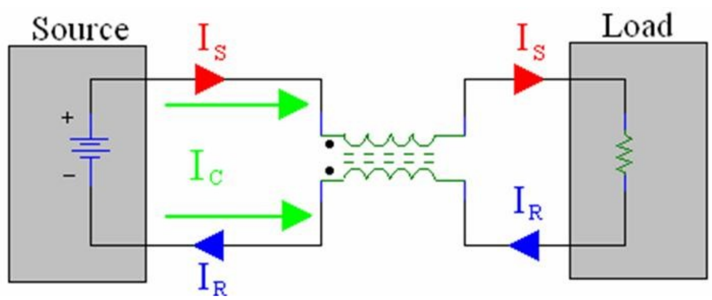

Figure 8. *Common mode filtering using a common mode choke*.

The fifth type of filter uses ferrite material that provides high impedance at the frequencies of the unwanted noise. The ferromagnetic material absorbs the noise and dissipates it as heat, due to a time varying magnetic field, see Figure 9.

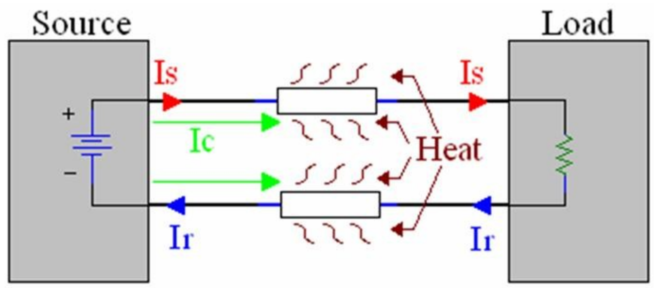

Figure 9. *Common mode filtering using ferrites*.

Common Mode and Differential Mode Current

To filter both common mode and differential mode noise current in a circuit, a combination of previous solutions can be used. Figure 10 - Figure 13 shows common filter configurations for both differential and common mode current.

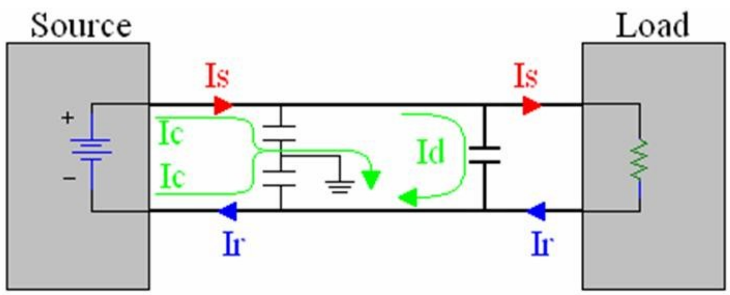

Figure 10. *x-cap and y-cap configuration for common mode and differential mode noise filtering*.

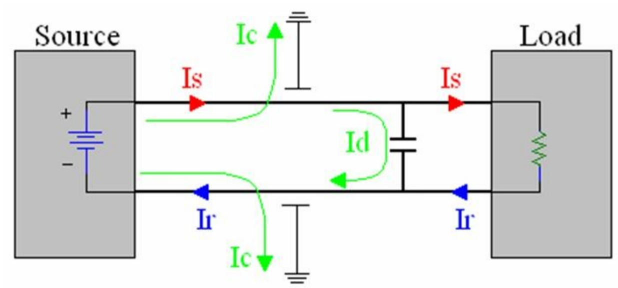

Figure 11. *Feedthrough capacitors and an x-cap configuration for common mode and differential mode noise filtering.*

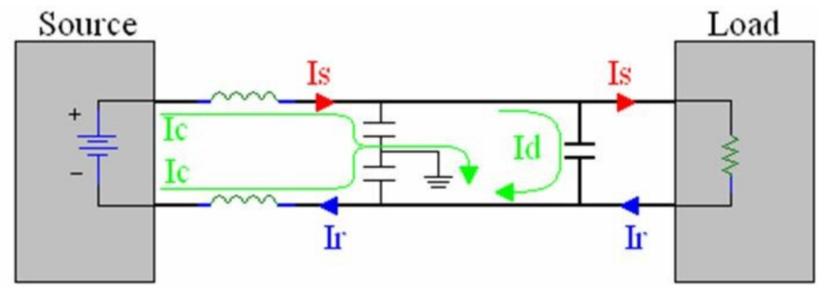

Figure 12. *x-cap, y-cap, and inductors for common mode and differential mode noise filtering. The inductors broaden the common mode filtering range*.

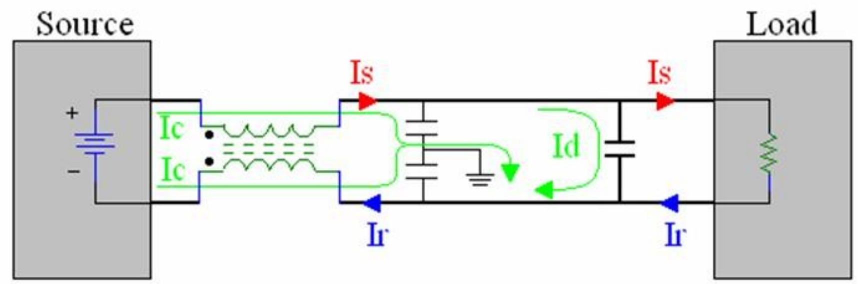

Figure 13. *x-cap, y-cap, and common mode choke for common mode and differential mode noise filtering. The common mode choke broadens the common mode filtering range*.

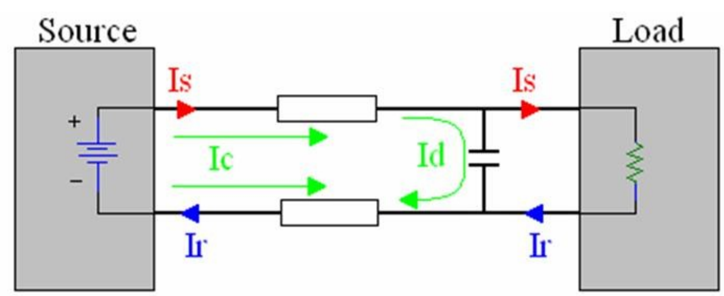

Figure 14. *x-cap and ferrites for common mode and differential mode noise filtering.*

New Technology in Noise Filtering

Typical filters for common mode and differential mode noise usually consist of 3-7 standard discrete components. This section introduces a new technology in noise filtering. An X2Y® component is a single component that performs the same function that the multiple traditional components do, Figure 15.

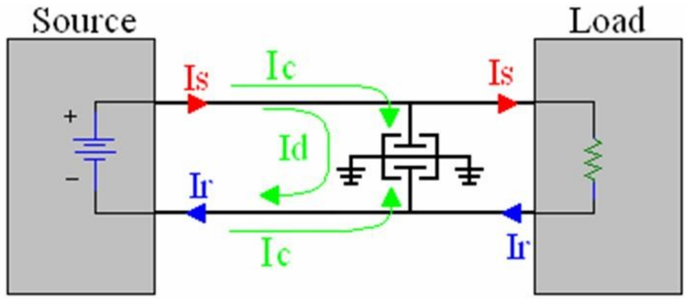

Figure 15. *X2Y® can easily replace 3-7 discrete components when used as a filter*.

X2Y® outperforms discrete components because of its unique internal structure. The X2Y® design is similar to a dual rectangular coaxial structure that was studied and modeled by the National Bureau of Standards[3]. The internal Faraday cage forms a shielded container for each conductor inside the capacitor. At high frequency, the circuit noise in each capacitor will choose the low impedance path of the shield and opposing noise currents will cancel.

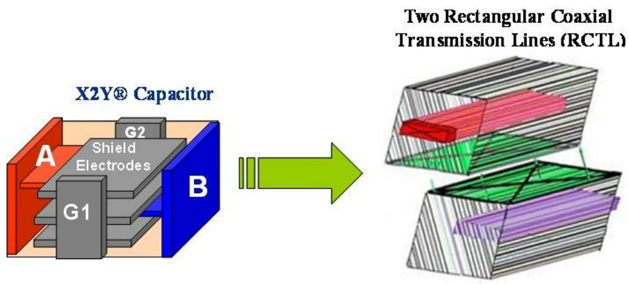

Figure 16. *X2Y® compared to a dual rectangular coaxial structure*.

X2Y® is a circuit inside a capacitor that can operate simultaneously in multi-modes. The unique internal electrode arrangement creates two tightly balanced capacitors. Typical capacitance tolerance is 1-3 %, when each capacitor is measured from A to G1 and B to G2.

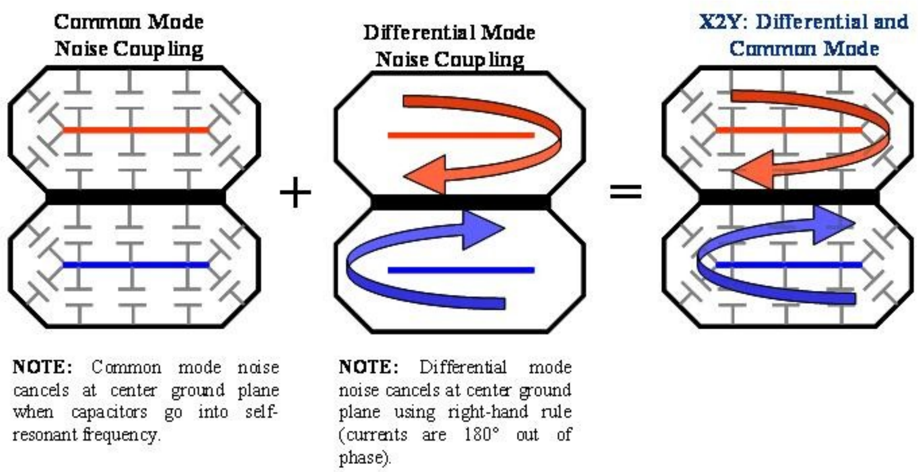

Figure 17. *Side view of dual Transverse Electromagnetic (TEM) model*.

Figure 18 depicts a measurement sequence of X2Y® versus a discrete x-cap and two y-capacitor configurations. Figure 19 plots the comparison data of the different measurements.

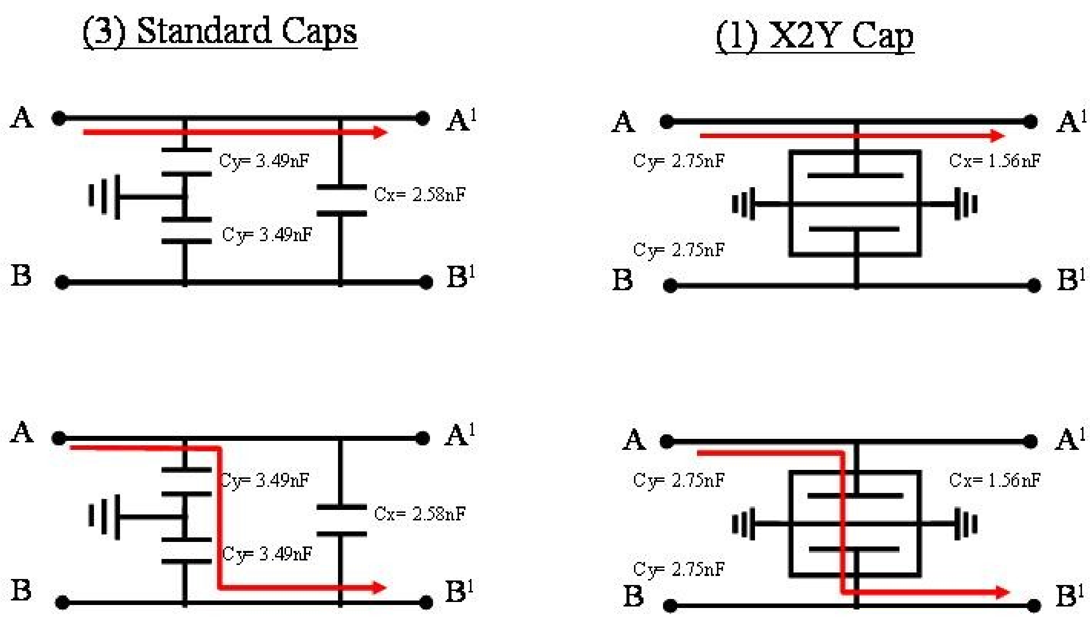

Figure 18. *Depiction of measurement sequence*.

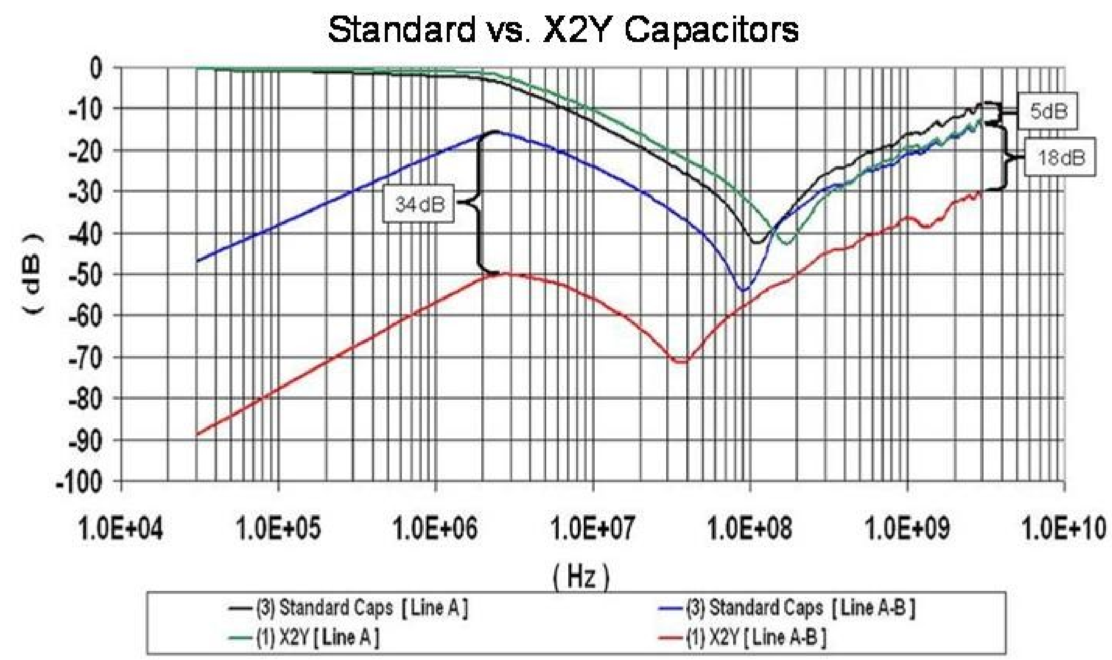

Figure 19. *Comparison data, X2Y® vs. discrete x-cap and 2 y-cap configurations.*

As shown in Figure 19, X2Y® has a 34dB improvement in insertion loss for differential mode at low frequency and 18dB at high frequency. Common mode has a 5 dB insertion loss improvement at high frequency.

Conclusion

X2Y® provides an alternative to standard components used to filter common mode and differential mode noise voltage. The advantages of a single X2Y® component are:

- Replaces 3-7 standard discrete components.
- Large improvement in attenuation.
- Reduction of PC board space.

Application Note#1003 - Internal Model of X2Y® Chip Technology will further explain how the X2Y® accomplishes the dramatic improvement in circuit performance. For this and other test results go to www.x2y.com.

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] Ott, Henry, “Noise Reduction Techniques in Electronic Systems”, 2nd edition. Page 116, John Wiley & Sons, 1988.

[2] Paul, Clayton R. "Introduction to Electromagnetic Compatibility", pages 301-304, John Wiley & Sons, 1992.

[3] "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.

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