Title : X2Y® Integrated Passive Devices : A Breakthrough in High Speed Decoupling and Broadband Filtering.

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Introduction

Faster, Smaller, Better

The nearly insatiable need for faster computers has led to an ever increasing speed for microprocessors and busses. Today processor and clock speeds have surpassed the 1.5 Ghz for mainstream applications and further speed increases even up to a factor 2-7 have been forecasted by NEMI for the coming decade. The faster switching of circuits and the increased number of simultaneously switching circuits has led to a need for continously improved decoupling performance. In the past decade, surface mount ceramic multilayer capacitors (MLCC) have become the preferred choice of designers, by continuously meeting the need for improved performance. One of the major advantages of MLCC's is that size reduction in general is accompanied by improved decoupling performance, since the smaller sized component has a lower inductance, a lower ESR and a higher self resonance frequency. Size reduction alone, however, has not been enough to meet the designers decoupling demand. Specially designed low inductance MLCC's, location of the low inductance MLCC's as close as possible to the microprocessor and drastic reduction of interconnect path inductance have also been implemented to improve decoupling performance.
The increased number of simultaneously switching circuits has led to the need for higher capacitance values to serve as a local energy buffer. The current trends in multilayer technology are to reduce the dielectric layer thicknesses to enable both the availability of higher capacitance values and a better decoupling performance as a result of their low mOhm ESR levels. Another important factor leading to the need for better performance of components is the lowering supply voltage of CMOS IC's. Reductions in noise levels, created by the fast switching of the IC's, are not decreasing as fast as the supply voltages, so they become an increasing threat to supply voltage stability and signal integrity. The need to supply current at a higher speed and the resulting steeper transients have also led to a need for lower impedance, mainly at higher frequencies. Increasing data transmission speeds and concerns about signal integrity are also fueling the drive of the electronic industry for stricter conformance with EMI emission limits. As a result, the need for more broad band and better high frequency filtering continues to increase.
As current consumption in amps continues to rise along with the increasing switching speeds of the microprocessor, low inductance designs in capacitors become crucial for reduction in ripple voltage, as low inductance reduces the needed capacitance Minimization of parasitic inductance and resistance in a design is the only way for this to hold true[5][6]

Introduction to the X2Y® IPD

X2Y: An integrated passive device featuring extreme low inductance and balancing

<u>The basic structure of the X2Y® IPD</u>
The X2Y® structure begins with a standard two-electrode surface mount capacitor as the base for its internal design. For this description, we will refer to each of the two original electrodes as A and B respectively. X2Y® then adds three commonly attached shielding electrodes between and surrounding the A and B electrodes. The newly added shield electrodes are then attached to two opposing side terminations (called "G1" and "G2")

of the capacitor body, forming a new type of four terminal intgrated passive device (Figure 1).

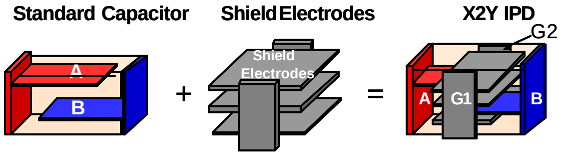
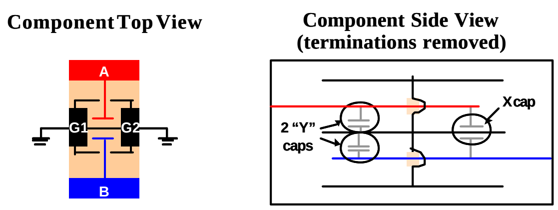


Figure 1. 3D views of X2Y? Integrated passive device.

The electrode shields are positioned to provide electrostatic containment and suppression of energy parasitics that would normally emanate from either A or B electrodes.

Just like a standard capacitor, repeating the core structure will increase the capacitance value of the device by increasing the effective electrode area. The A and B electrodes create, with their opposing shield electrodes, a pair of symmetrically balanced capacitors called Y caps, which are analogous to two standard MLCC's to a ground when attached in a circuit. Electrodes A and B across the shared center electrode (Fig. 2) also form an X capacitor. Hence the IPD consists of one X and 2 Y caps resulting in the name X2Y? . The capacitance value for each Y capacitor (both are equal) is "C" and the single X capacitor value is "1/2C" when measured.



X2Y circuit schematic overlaid on component surface

Internal view of the single X and two balanced Y capacitors inside X2Y.

Figure 2. X2Y®-IPD schematic and internal circuit arrangement.

Ultra Low Inductance

The three internal shielding electrodes of an X2Y IPD are used to lower the inductance of the component. The following example will illustrate how this is done.

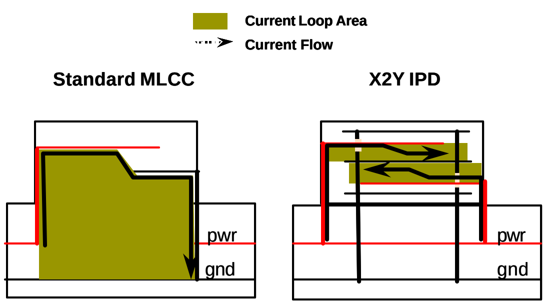


Figure 3. Comparison of current loop area and current flow in a standard MLCC and a X2Y® IPD.

In a standard capacitor connected to a standard two-layer board with a ground (gnd) and power (pwr) plane, the current travels from the powerplane through the connected via's terminal and electrode A, through the dielectric, electrode B, terminal B and connecting via to the ground plane on its way to the load. This results in a large current loop (figure 3) which means large inductance[4]. In the X2Y component both the A and B electrodes are attached to the pwr plane. The G1 and G2 terminations are connected to the ground (gnd) plane by vias. In this way the shield electrodes act to form a parallel extension of the board gnd plane (figure 3.). This "extension" of the board ground plane enables a major reduction of the current loop size. If we focus on one half of the capacitor connection, current from the pwr plane travels up through the via, capacitor A termination and electrode, back to the parallel gnd plane extension inside the X2Y®. The current loop size inside the X2Y® is now determined by the thickness of the dielectric layer. By dramatically reducing the loop area in this fashion, a significant reduction in inductance is realized.

The shield electrodes then allow a further reduction of inductance by utilizing opposition of magnetic flux (B field). In a standard MLCC current flows from the pwr plane and through the component's "A" electrode in one direction through the dielectric and leaves the capacitor via the opposed "B" electrode to return through the ground plane. The current flow results in a magnetic field with a direction derived from the right hand rule.

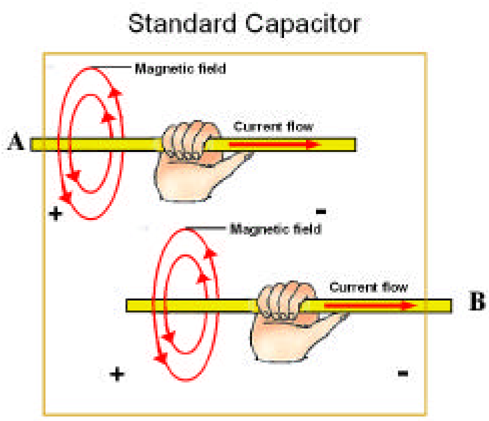


Figure 4. Depiction of magnetic field in a standard MLCC.

In a standard MLCC in all capacitor elements the current flows in the same direction. Hence all the resulting magnetic fields have the same direction. This causes the mutual inductance of each pair of plates to add.

In the X2Y® IPD, the shields divide the capacitor into two equal A and B capacitors that perform the same function, but the currents flows now in opposite directions! (figure 5). The two magnetic fields are 180 degrees out of phase and hence cancel, lowering mutual inductance.

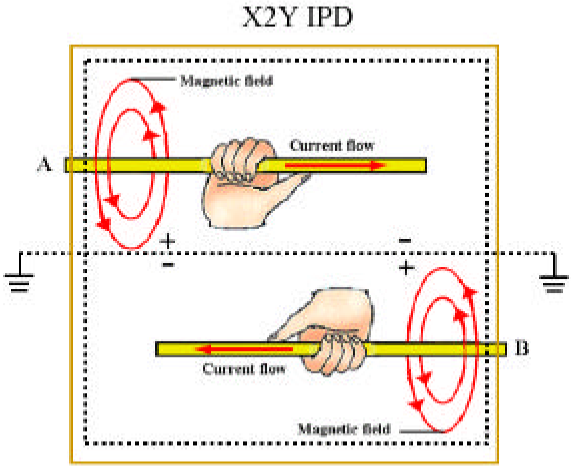


Figure 5. Depiction of magnetic field cancellation in an X2Y® IPD.

The closely spaced internal layering of an MLCC induces a high coefficient of coupling between the opposing capacitors and a significant reduction in the component inductance.

<u>Balance Through Process</u>

The manufacturing processes of making multilayer chip capacitors (MLCC's) involves an alternating, even layering of electrode prints and dielectric materials during the stack up process that ends with a plate. The end result of that process with standard capacitors is very closely matched layer thicknesses within a single component, layer thickness and electrode surfaces that can be well controlled.

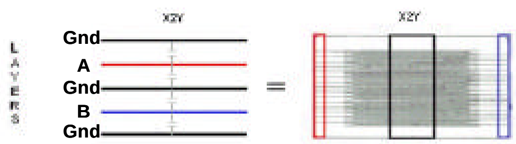


Figure 6. X2Y®-IPD has many even spaced layers which creates highly balanced Y capacitors.

Using this same manufacturing process to produce an X2Y® component results in two Y capacitors with a tight capacitance tolerance. Every A and B electrode pair shares a common seperating shield (gnd) electrode (figure 6) creating individual capacitors within a single component. Standard manufacturing tolerances during stack up ensure that each individual capacitor inside a single X2Y® component is spaced evenly. Components with lower capacitance values (less layers) typically have two Y caps with a 3-5% capacitance tolerance when each cap is measured line to gnd. Higher capacitance values that have more layers are balanced as close as 1%. The test data shown in figure 7 on 1206 200 nF X7R components shows the balance of the two Y caps is maintained throughout the frequency range tested.

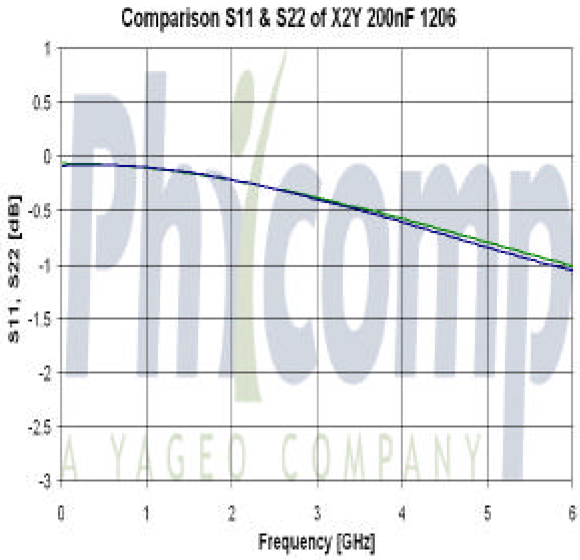


Figure 7. Suppression difference of the two Y caps of an X2Y® IPD is less than 0.1 db from 10 MHz to 6 GHz.

<u>Product Range</u>

The X2Y® product range is rapidly expanding. Devices are available in the standard EIA 0603-0805-1206-1210-1812 sizes , with capacitance values for the Y-caps from 10 pF up to µF's and voltages ranging from 10V to 100V.

Measurement data

Confirming the low inductance in both shunt and series feedthru measurements

<u>Shunt measurements</u>

To demonstrate the low inductance feature of the X2Y IPD, the performance of an X2Y 1812 470nF IPD has been compared with a parallel combination of two standard 1812 470 nF MLCC's (figure 8a). In case of the X2Y IPD measurements were done with 1 Y-cap and with 2 Y-capacitors (figure 8b) while in both cases the two grounds were connected. This shunt configuration is common for a single power line decoupling application.

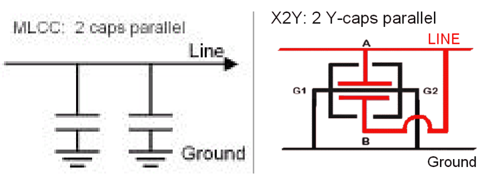


Fig. 8a Fig.8b

Figure 8. Test configurations of two parallel MLCC (8a) and one X2Y IPD Products for which both Y capacitors are connected to the line (8b).

The test samples are measured on a small substrate with a 50 Ohm microstrip line figure 9. The capacitors are connected between this line and ground.

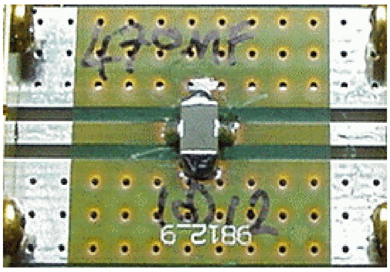


Figure 9: Testsubstrate for shunt measurements.

The substrate is mounted in a Wiltron Universal Fixture model 3680-20 (figure 10)

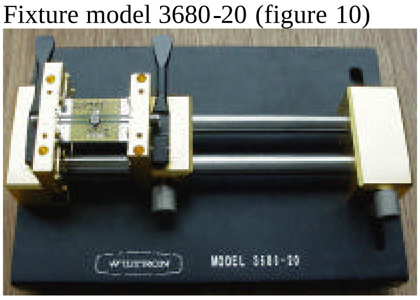


Figure 10. Wiltron Universal Fixture model 3680-20 with mounted substrate.

Measurement is carried out with a HP8753D 30 KHz - 6 GHz Network Analyzer.

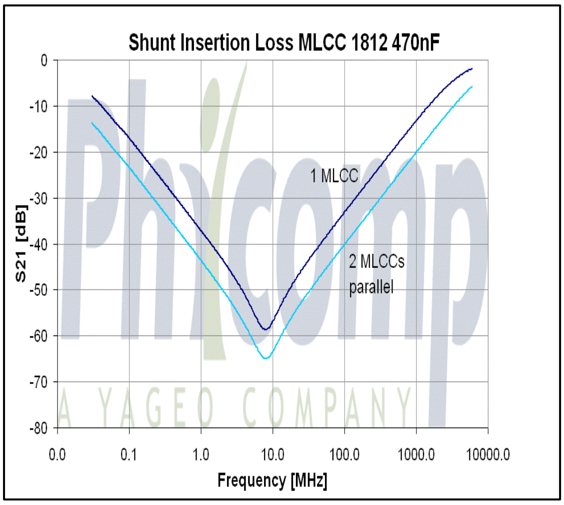


Figure 11a. Shunt insertion loss of one MLCC and two MLCCs in parallel.

A Parallel combination of 2 identical MLCCs gives the result one expects. The capacitance doubles while the equivalent series inductance (ESL) and equivalent series resistance (ESR) halve. Result is that the self resonant frequency (SRF) is the same as with one MLCC, but the notch is 6 dB deeper (see figure 11a). The overall insertion loss increases with 6 dB.

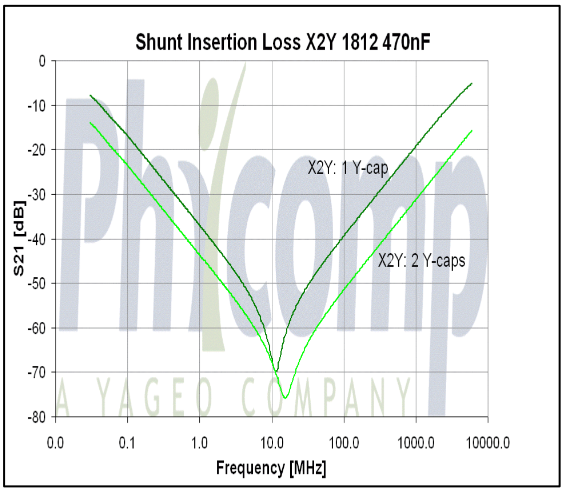


Figure 11b. Shunt insertion loss of one X2Y- IPD with one Y-cap and two Y-capacitors connected.

From figure 11b it can be concluded that for frequencies above a few MHz the insertion loss of 1 Y-capacitor of the X2Y (second Y-capacitor not connected) is already as good as the two parallel MLCCs, confirming the low inductance behaviour of the X2Y IPD. In the situation where both Y-caps are connected, it can be seen that the SRF-point shifts towards higher frequency. This means that the ESL value decreases with more than a factor 2 compared to the parallel combination of 2 MLCCs. This can only be explained by inductance cancellation inside the X2Y IPD. The insertion loss difference between one and two Ycaps connected is 6 db at and below SRF, but for frequencies above the SRF the gain in insertion loss is 12 dB. This is an additional 6 dB compared to the MLCC-situation shown in figure 11a.

In figure 11c the data of the 2 paralleled MLCCs of figure 11a and the X2Y-IPD with 2 Y-caps connected of figure 11b are compiled in one graph.

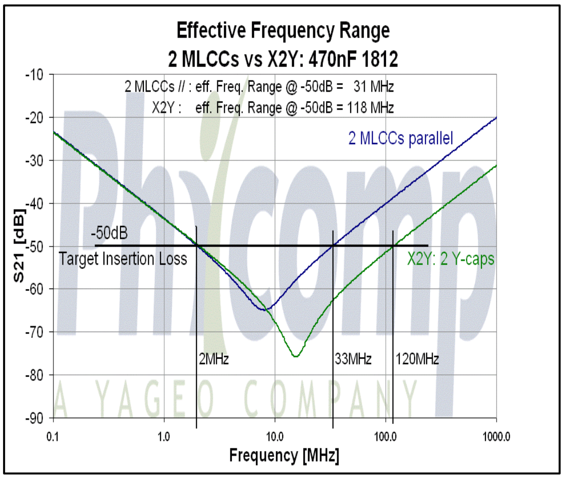


Figure 11c. Shunt insertion loss of two parallel MLCCs and one X2Y IPD with two Y-capacitors connected.

Below the SRF(capacitive) the insertion loss is equal for both graphs. Above SRF (inductive) the insertion loss of the X2Y IPD is about 12 dB better ! What this 12dB gain means in terms of bandwith is also illustrated in figure 11c. The effective frequency range is indicated for a desired attenuation of 50dB. The frequency range for which at least 50dB attenuation is achieved is almost 4 times larger in case of the X2Y IPD compared to the 2 parallel MLCCs.
Additional to this it should be noted that the X2Y IPD solution consumes about half the board space!

<u>Insertion Loss Measurement Data For Various X2Y® IPD in a Series Feed-thru Test Set Up.</u>

To verify the low inductance behaviour of the X2Y® device also series feed-thru measurements have been performed.

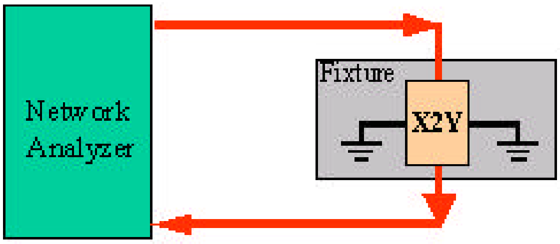


Figure 12 shows the set up for measuring the series feed-thru insertion loss of the X2Y-capacitors.

Besides a vector network analyzer with S-parameter test set a test fixture is used. This Inter-Continental Microwave Test Fixture [8] is designed for testing 4 terminal devices such as the X2Y® -IPD.
The fixture is designed to operate over a frequency range of DC-10 GHz at Room Temperature.
The fixture (figure 13) is made as a solution for making measurements in a series-thru test configuration.

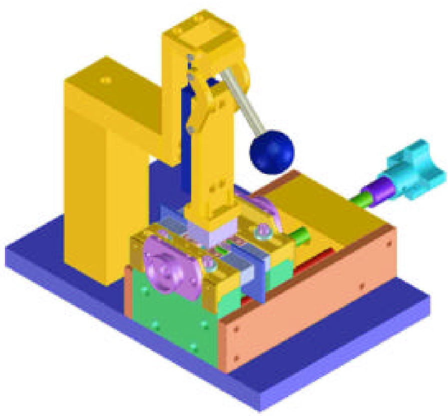


Figure 13. ICM Test fixture for DC-10GHz.

Input and Output launches are on microstrip material allowing selection of a material that will match the material used in the end application. Guides on the fixture ensure accurate and repeatable placement of the chip. De-embedding with TRL / LRM or TOSL Calibration Standards removes the effect of the test fixture from the measurements.
Measuring has been performed per MIL-STD-220 (25 ? 2°C, 50 ? system, no load).

<u>Measurement results</u>
3 types of X2Y® - IPD's were measured.
0603 3.3 nF (figure 14a), 1206 0.2 µF (figure 14b) and 1210 6 µF (figure 14c).
Since the ultra-low inductance is best proved at frequencies in the GHz range data were taken in the frequency range from 10 MHz – 10GHz.

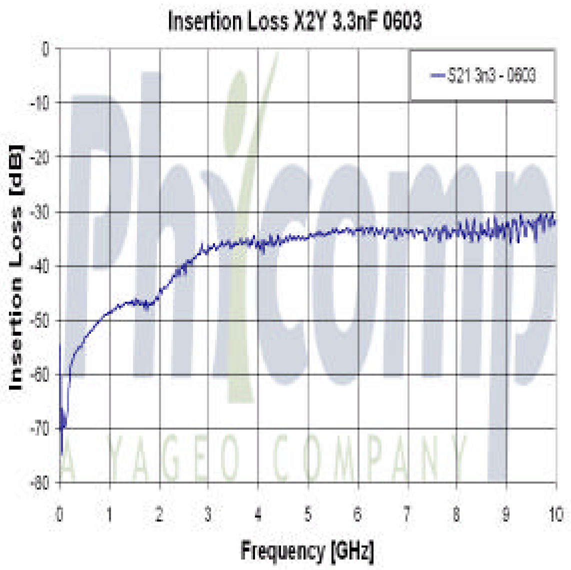


Figure 14a. Insertion loss (S21) of X2Y 0603 3.3 nF.

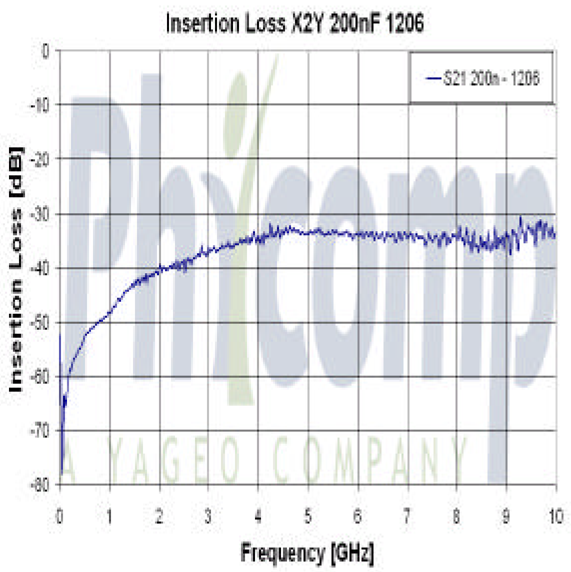


Figure 14b. Insertion loss (S21) of a X2Y 1206 200nF.

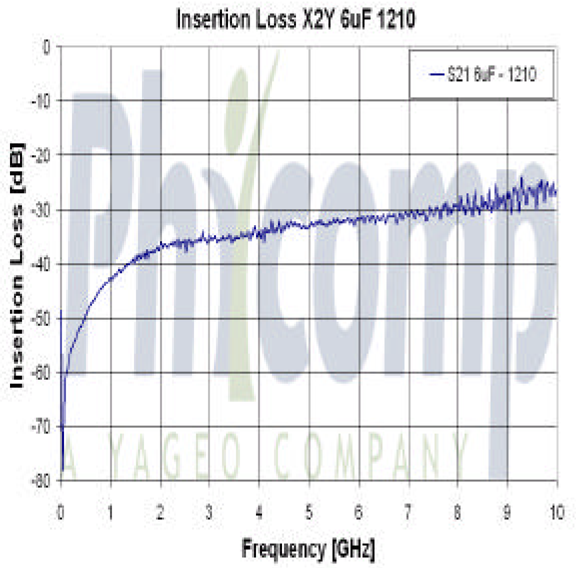


Figure 14c. Insertion loss (S21) of X2Y 1210 6 µF.

For all the 3 X2Y® IPD's very high suppression, typically 30 –40 db in the 1-10 GHz can be seen. The flat insertion loss versus frequency curve is also quite striking. It confirms the broadband performance expected from the ultra low inductance device.

Another striking result is the apparent small variation in the high frequency insertion loss with product size between an 0603 3.3 nF and a 1210 6 µF. This means that there is less scaling of inductance with size than normal with all standard MLCC. This makes the large capacitance X2Y® IPD , which has low frequency characteristics similar to standard high capacitance MLCC, an excellent candidate for broad band decoupling as explained in the section below.

Better broad band decoupling
How to do it in practice?

From low ESR to a parallel combination of low ESR and low ESL

Depending on currents and voltages there are many different forms of decoupling. The major application driving the need for improved decoupling in the past decade has been the decoupling of the power supply for high-speed microprocessors in electronic data processing applications. We will discuss below the approaches chosen in this particular decoupling application segment.

Power Systems for modern CMOS technology are becoming harder to design [4]. One design methodology is to identify a target impedance to be met across a broad frequency range and specify components to meet that impedance.

Given the voltage and power consumed, the current is calculated from Ohm's Law. Assuming that only a small percentage of the power supply voltage (e.g. 5%) is allowed as ripple voltage (noise), a target impedance for the PDS is calculated. The target impedance is falling at an alarming rate, 5X per computer generation and has now reached mOhm and sub mOhm levels.

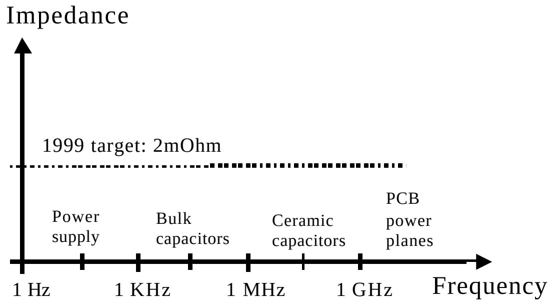


Figure 15. Low impedance in a broad frequency ranges requires different solutions in each frequency segment [4].

Good decoupling requires low imp edance over a broad frequency range. For the low end, the voltage regulator supplies the low impedance, for higher frequencies successively higher valued caps are used and low value caps and powerplanes provide the low impedance at higher frequencies. To achieve the extremely low target impedance, circuit designers have to continously improve circuit layout and refine component selection. Capacitor manufacturers join the battle to lower system inductance by developing components with lower inductance.

<u>Choosing the right combination of capacitors.</u>

<u>1. Basic effects of capacitance and inductance of a single capacitor on decoupling performance.</u>
At high frequencies -above SRF- the term Xl determined by the cap's ESL is the major factor, but not the only contribution to the capacitors impedance. Example: a typical MLCC has an inductance of aprox. 1nH, this inductance will give an impedance of 62.8 ohm at 10 GHz. Both ESR and Xc are quite well below 1 Ohm.
To achieve low impedance the capacitors need to be used close to their self resonance frequency. To achieve decoupling at high frequency, capacitors with low capacitance values are suggested. In figure 16 it is shown that given a certain component size, by decreasing the capacitance value, the self resonant frequency (SRF) can be shifted towards higher frequencies. But because the inductance still has the same value, one can see that at frequencies just above the SRF, the insertion loss rapidly approaches the value of the capacitor with the higher cap-value. In fact this approach results in lower impedance at higher frequencies, but the frequency range in which

effective decoupling takes place is reduced. This solution is only effective over a small bandwidth.

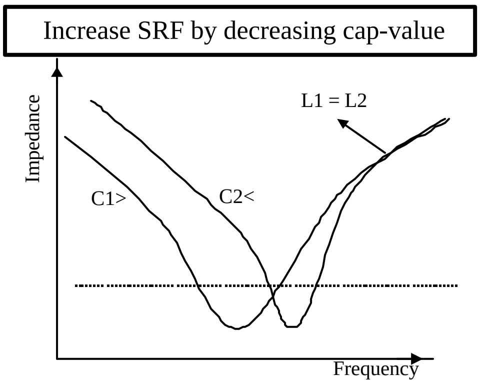


Figure 16. lower cap values->higher resonance freq.

As shown in figure 17 it is more effective to decrease the inductance of the capacitor. The SRF shifts towards higher frequencies and at the same time the effective frequency range increases.

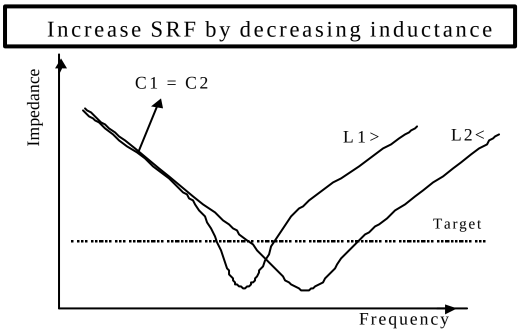


Figure 17. Low inductance shifts the resonance frequency and increases the low impedance range.

<u>2 . Using capacitors in parallel to achieve low impedance in a small frequency band.</u>

Since single components often cannot provide low enough impedance, parallel combinations of capacitors with the same capacitance value are used to drive down the impedance in a small frequency band around the self resonance frequency of the capacitor (figure 18).

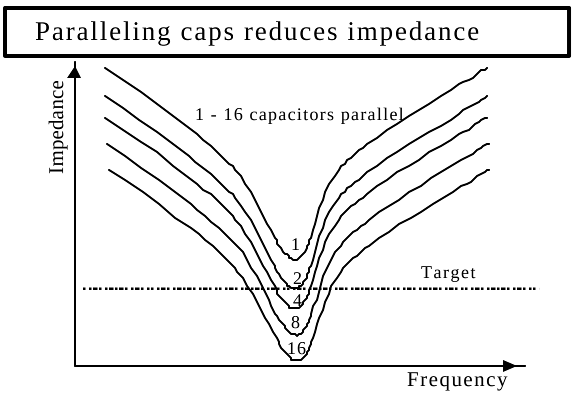


Figure 18. Effect of using parallel capacitors.

Of course this approach works best if the impedance of the capacitor at resonance frequency is minimized. Since the level at resonance is usually the minimum of the Equivalent Series Resistance of the capacitor (ESR), attention must be given to select capacitor types with low ESR levels. To reach the mOhm levels or even fractions of mOhm levels[4] required in modern processor, decoupling only capacitors with only mOhm level of ESR can be used. For this reason high capacitance MLCC's replaced electrolytic capacitors and tantalum capacitors based on the inherent extreme low ESR, resulting from the hundreds of electrode layers in parallel and their ability to effectively deliver energy in the very short cycles.

Even if there would be enough space on the board the efficiency of using this method decreases with the number of capacitors put in parallel, because the number of capacitors used, has to be doubled to reduce the impedance by half.

Using a parallel combination of capacitors around their self resonance frequency becomes even more effective, when as shown in figure 19, a combination of devices with low inductance and low ESR – is used. In this case, less capacitors are needed and the frequency range in which the impedance is below the target impedance is increased.

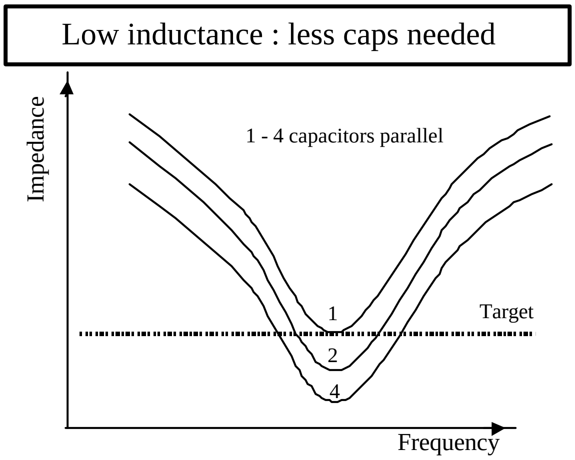


Figure 19. Effect of using a parallel combination of low inductance caps.

In addition to being an effective tool to reach low impedance, a low ESL level is also needed to prevent the generation of voltage spikes.

Not only do the fast switching currents flowing through the trace with inductance L generate voltage spikes, but also current delivered by the local energy source -the decoupling capacitor- with parasitic inductance can generate spikes [5][6].

The only way to reduce these voltage spikes is to reduce the inductance.

Besides this, the growing concern on deterioration of signals by voltage spikes generated by high speed decoupling provides a third argument to drive down the inductance of decoupling capacitors.

3. Using parallel combinations of different cap values to improve the decoupling bandwith.
As depicted in figure 20 two different valued capacitors in parallel will give a wider effective frequency range but produce an unwanted "anti-resonance". A peaking between the two minimums will appear.

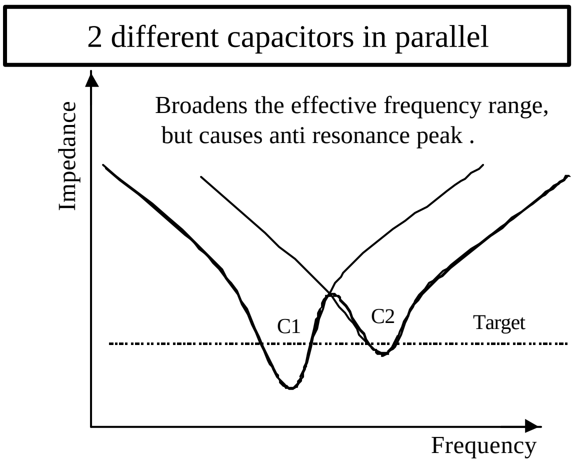


Figure 20. Effect of using two different cap values in parallel.
The most effective way to reduce the height of this peaking is to reduce the inductance of the total circuit, so minimizing the inductance of the caps and the inductance related to the pads and the connecting tracks is important as well.

In figure 21 the impedance curve of two different very low inductance caps in parallel is shown. This gives a low impedance in a broad frequency range.

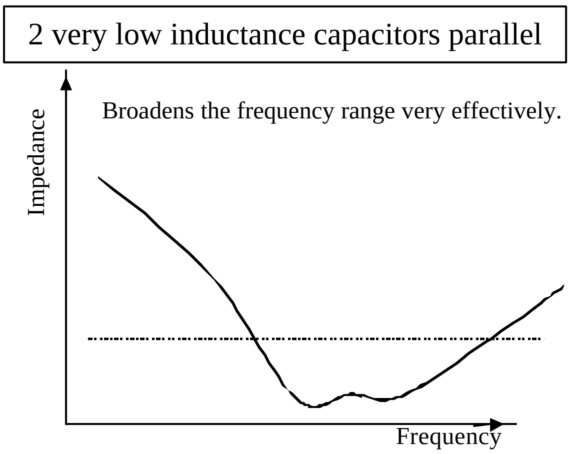


Figure 21. Effect of using a parallel combination of two low inductance caps with different cap values.

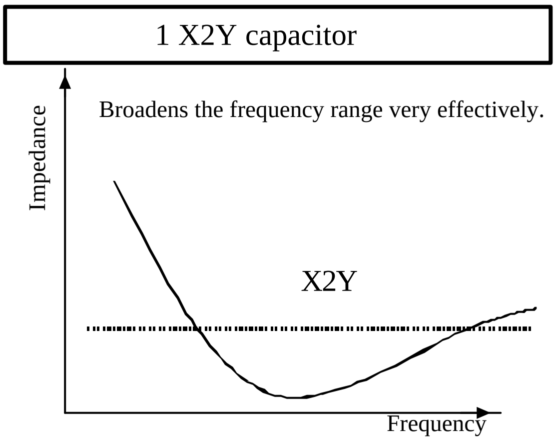


Figure 22. Impedance characteristic of a X2Y decoupler.
In figure 22 it is shown that a single X2Y® -device is also a very effective way to decouple in a wide frequency range because of the inductance cancellation inside the X2Y®-device.

4. Minimizing the Inductance in the Connections.

Even when carefully selecting the right parallel combination of (low inductance) capacitors the decoupling may turn out to be ineffective if the influence of the inductance of the connections and the power plane spreading inductance of the capacitors to the board is not reduced at the same level. As illustrated e.g. in [4] the industry succesfully decreased the inductance of the path and the via's from the 4-5 nH level to around the level of 1 nH. Further improvements are needed, to continue to benefit from lower inductance capacitors.

Developments in Lower inductance capacitors

Component manufacturers have contributed highly in lowering the inductance of capacitors. Design improvements have developed from leaded passive, MLCC, smaller MLCC, reverse aspect ratio MLCCs towards X2Y®-capacitors.

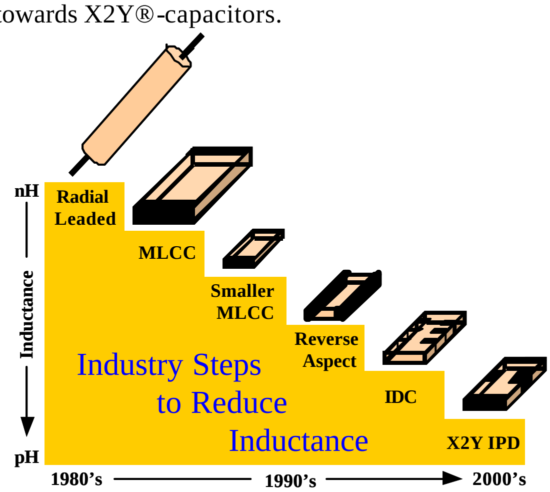


Figure 23. Developments in Low inductance caps.

The first big step was from leaded components to surface mount MLCC. The next step was the continuous development of smaller sized capacitors. In MLCC technology, smaller size results in lower inductance. A next step brought lower inductance by using capacitors with reversed aspect ratio with e.g. 0612 size. With these Low Inductance Caps an inductance of aprox. 300 pH can be obtained.
Further reduction of component inductance has been achieved e.g by the introduction of an integrated passive device consisting of 4 interdigitated capacitors in a 0612 and 0508 size, which reach 100-175 pH levels. Such inductance values still are too high and therefore multiple capacitors must be placed in parallel to achieve the low impedance necessary for modern high-frequency decoupling.
In this paper we introduce the X2Y® IPD as the next step in lowering component inductance well below the 50 pH level. In the X2Y® device the inductance reduction results from a principal new approach to inductance reduction (see "ultralow inductance").
Compared to the reverse aspect ratio and interdigitated capacitor array, the X2Y® device offers following principle advantages.
Compared to a standard low inductance MLCC, which benefits from the increased width/length ratio the X2Y® device offers a structurally lower inductance as a results of smaller current loops. Reduction of the mutual inductance of each capacitor element in the stack and cancellation of currents on the shared ground plane translate in lower inductance with the X2Y®, even when using a standard aspect ratio.
Compared to interdigitated low inductance solutions, the X2Y IPD provides shielding and much better mutual inductance cancellation.

<u>How to use the X2Y® IPD in decoupling ?</u>

In figure 24 a circuit is depicted which shows how several standard capacitors have been placed parallel in order to obtain a low impedance over a broad frequency range.

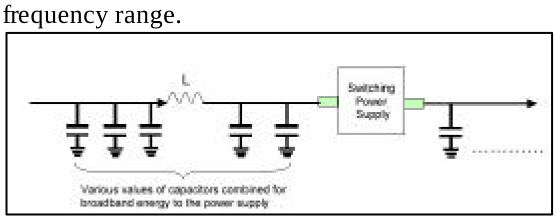


Figure 24. Approach of power supply decoupling using standard capacitors.

In figure 25 it is shown how the X2Y® device is connected in a decoupling application. The balanced pair of Y capacitors (A and B) work in parallel

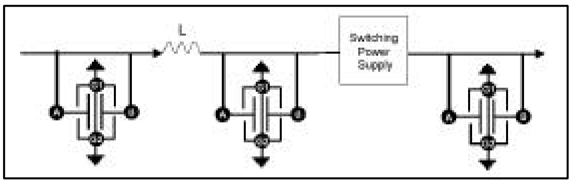


figure 25. Improved decoupling by using X2Y®.

to deliver energy. Each X2Y® device has two equal capacitors and therefore by default reduces the number of capacitors needed by a factor two. Thanks to its intrinsic low inductance, the amount of capacitors can be reduced even by more than a factor two, while as explained in figures 18 and 21 the decoupling performance improves.
It should be noted that the "X" cap of the X2Y is not used in this single power line decoupling application. E.g. in a dual power line decoupling application both the X and the two Y caps can be used.
To understand the full benefit of the X2Y® device in a decoupling application a closer comparison between a standard MLCC and a X2Y® device is needed.
The low inductance X2Y® device requires a four-port attachment to the printed circuit board as shown in Figure 25. The internal shield electrodes are bound together by opposing termination structures and create a parallel plate extension of the gnd plane. Besides providing a parallel extension of the ground, the shield electrodes are connected to the ground plane via two symmetrically placed connections (figure 26). The connections are in parallel so the the inductance of the capacitor terminations, path and via are reduced with a factor 2.

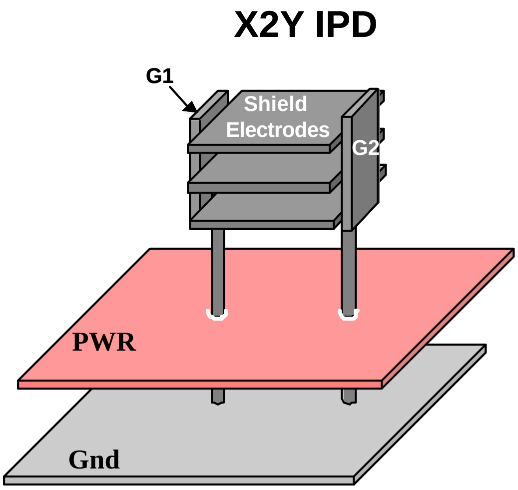


Figure 26. The double ground connection reduces the inductance in the current loop.

Note: actual mounting on the printed circuit board requires a continuous pad under the component's G1 and G2 terminations to optimize peformance.

To investigate the influence on the noise suppression performance of the ground connections of the X2Y® IPD a test has been performed. The X2Y® IPD was connected with one ground connect and with two ground connections.

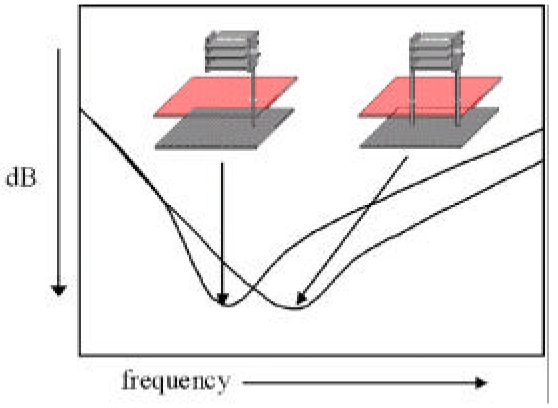


Figure 27. Graph showing the result on inductance of an X2Y® device connected with 3 and 4 terminations.

The graph 27 shows an increase in frequency effectiveness when both the G1 and G2 terminations are attached to the board. Actual measurement data show that when the second ground termination is attached to the board, the change in connection results in a 15 dB increase in attenuation from 30 kHz to 6 GHz (figure 28).

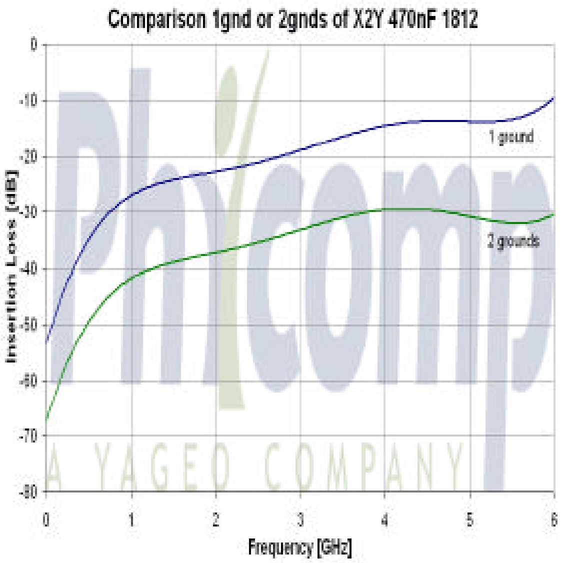


Figure 28. Comparison of X2Y® IPD with one and two grounds connected (S21 insertion loss).

Better Broadband Filtering with X2Y®.

Good high frequency decoupling capability automatically provides a good starting position for good filtering. Both applications require a low impedance and hence a low inductance.

For adequate fitering the capacitor normally is used around its self resonant frequency (SRF), so it is obvious that there is only a narrow frequency band in which the filtering is effective.
Strict conformance to EMI regulations has brought more demands for adequate filtering..
IC's generate normal mode noise along with the signal or the signal picks up normal mode noise on his way to the connector. External noise emission induces comon mode noise in the signal lines.
The need for both common and differential mode noise handling is increasing.
For effective filtering of both common mode noise and differential mode noise, a combination of common mode choke coils or ferrite-beads and/or capacitor/feedthrough-caps must be considered. In the section below we will explain how the unique combination of the 3 capacitors present in a single X2Y® device can significantly reduce the number of components needed in filtering, which also improves the performance.

Approaches to Improved Filtering by Choice of Filtering Location and Component.

In meeting the EMC emission requirements several approaches for filtering in high speed data transmission are chosen.

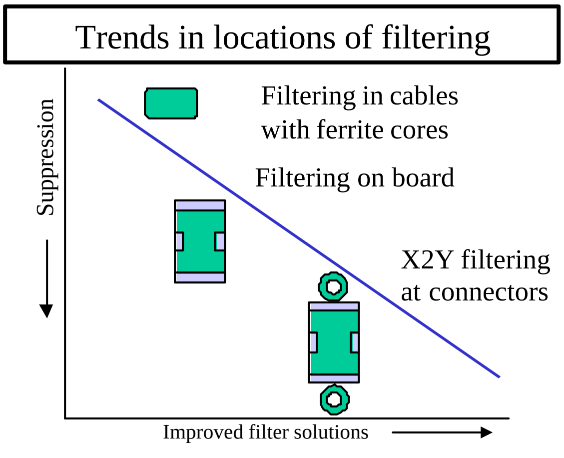


Figure 29. Trends in location of filtering.

The need for better filtering and lower EMC emission levels stimulated trends in the location of the filter solutions (figure 29). First solutions were putting a core around the cable, a better approach is to filter on the board, and for very fast signals it is better to filter in the connector.

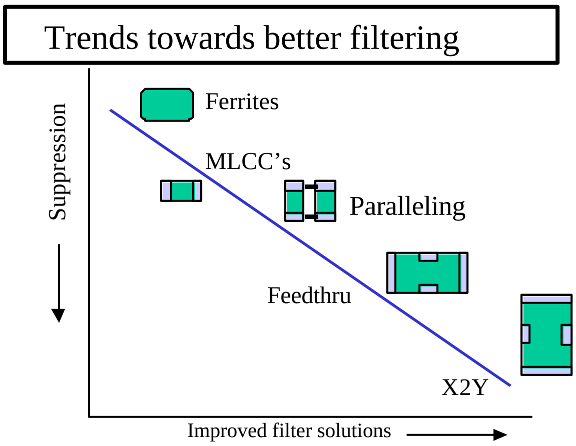


Figure 30. Trends in component selection for high speed signal line filtering.

Figure 30 shows trends in the components used for filtering. For higher frequencies ferrite-beads are not good enough and capacitive filtering is needed. Alternative solutions in sequence of increased performance are: MLCC, Two MLCC in parallel, FTC, or Two FTC, X2Y® IPD.

Electromagnetic Interference (EMI) or circuit noise can appear as either common mode or differential mode noise. Common mode noise is the noise voltage which appears equally and in phase from each signal conductor to ground. Differential mode noise is the noise which causes the potential of one side of the signal transmission path to be changed relative to the other side. With increased transmission speeds, smaller signals and more data lines in parallel, the requirements for more effective filtering of both common mode and differential mode noise continues to increase.

Alternative Solutions in Signal Line Filtering.

In the section below 3 different solutions in high speed signal filtering are compared. For filtering two lines a pair of MLCC's, a pair of Feedthru capacitors (FTC's) or one single X2Y® device can be used . The principle circuit configuration for these three solutions is as shown in figure 31.

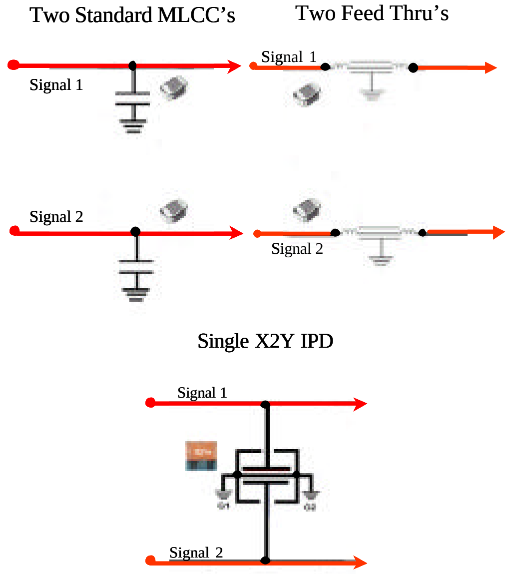


Figure 31. Principle circuits used in filtering of two datalines.

Two MLCC's.

A pair of two discrete capacitors, usually MLCC's are often used for filtering a pair of data signal lines. The two capacitors act as shunt capacitors, that provide a low impedance path for the noise to return to it's source. Common mode noise can be filtered with two MLCC's. The common mode noise suppression can be improved by using two closely matched capacitors because noise shunting would be equal from each line and magnetic flux cancellation is maximized. Standard capacitors that are applied to a circuit in pairs would require expensive sorting to achieve the same tight tolerance that is achieved by a single X2Y® capacitor during the normal manufacturing process.

To filter differential mode noise a third MLCC needs to be placed between the two lines(figure 32).

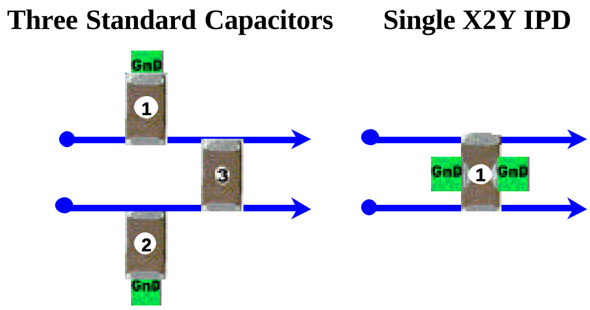


Figure 32. Common mode and differential mode noise with 3 MLCCs, or one X2Y®.

As with decoupling and illustrated in figure 17 a low inductance of the capacitor is both important for reaching a low impedance as well as for achieving a good broad band filtering.

Using two feedthru's

A improvement in filtering performance compared to a solution with MLCCs can be achieved by using feedthru capacitors[7]. The feedthrus have reduced parasitic inductance since two paths in parallel are available for the noise to shunt to ground. Investigations reported in [3] showed a difference of 15db between a 0805 10 nF two terminal MLCC and a 3 terminal FTC over a frequency range from 1-6 GHz. Compared to a X2Y® device however a feedthru principally has two significant disadvantages , which hinder reduction in attenuation. In a feedthru capacitor the signal current flows through the capacitor. The traces, terminations and electrodes carrying the signal, all add DC resistance to the circuit. This results in unwanted signal loss. A second disadvantage of a FTC compared to a X2Y® IPD is the larger parasitic inductance of the FTC. Like in an MLCC there is no reduction of mutual inductance between each pair of stacked electrodes, since the current flows in each electrode carrying the signal in the same direction.

Using one X2Y®-IPD

The dual function of the A and B electrodes, as both forming together the single X and with the shields two Y capacitor electrodes, allows the X2Y® device to function as both a common mode and differential mode filter simultaneously when attached between two opposing conductors and to ground in a circuit. By filtering both modes, X2Y prevents differential to common mode noise conversion. The built-in lower inductance of the X2Y® IPD provides the basis for more suppression at higher frequencies and a broader band width.

In addition, the internal shield electrodes of the X2Y also provide an additonal benefit for filtering connetor lines. As shown in [9], X2Y can provide cross talk isolation between pins (line-to-line).

The advantages of filtering 2 signal lines with one X2Y® IPD are summarized in table 1.

Filter Devices	Filter view	Common and Differential Mode noise suppression	Quantity needed for 2 lines	Common and Differential Mode noise suppression	Signal loss resulting from DC resistance	Noise suppression	Broadband Effectiveness
X2Y		both	1	Yes	No	++	++
STANDARD MLCC		common mode	2	No	No	+/-	+/-
		differential mode	1	No			
		both	3	Yes			
FEEDTHRU		common mode	2	No	Yes	+	+/-
		differential mode	1 MLCC	No			
		both	2 + 1 MLCC	Yes			

Table 1: Performance comparison of X2Y® device with standard MLCC's and Feed-thru capacitors.

Conclusions

1. To realize low impedance over a broad frequency band, reduction of component and circuit ESL is necessary.
2. The X2Y® IPD provides a fundamental new approach to reduce ESL, while maintaining the low ESR advantages of MLCC technology.
3. Compared to two MLCCs of the same capacitance value, one X2Y® IPD consumes half the board space, has two times higher self resonance frequency and provides 12 db more attenuation above the self resonance frequency.
4. X2Y® IPD's can reduce the number of decoupling capacitors needed, while improving the decoupling performance.
5. One single X2Y® IPD provides both common mode and differential mode noise suppression for two lines. The single X2Y® IPD outperforms existing solutions with MLCC's feedthru's for high frequency signal line filtering.

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