X2Y® Technology

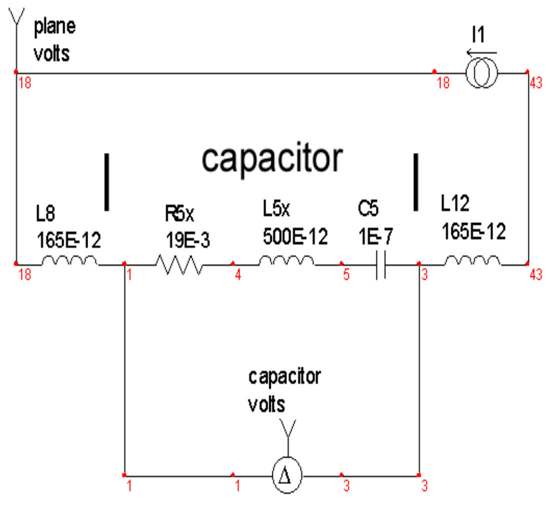
X2Y Comparative Decoupling Performance in 4 Layer PCBs

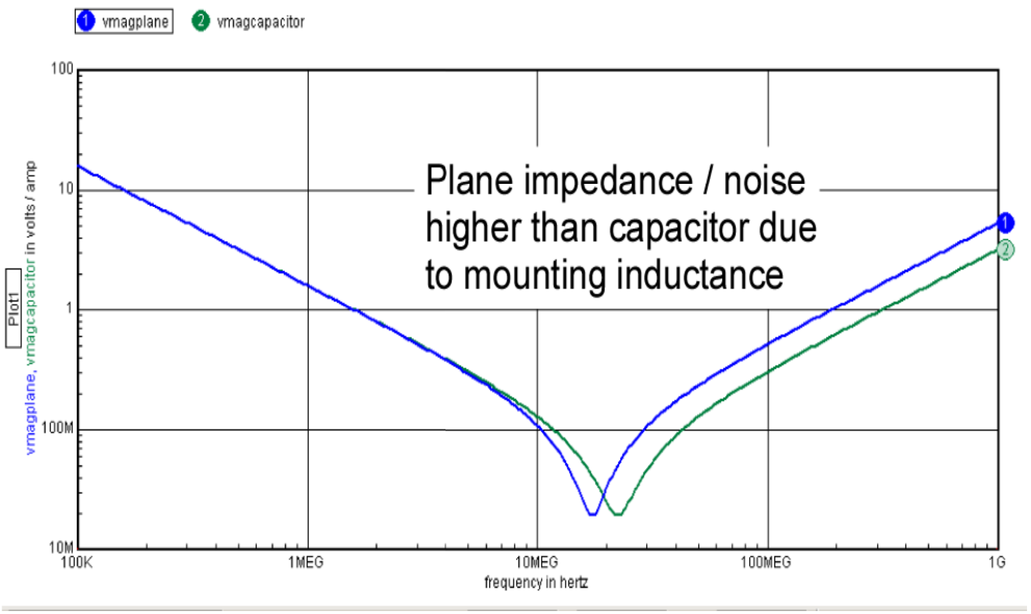
Four / Six Layer PCB Decoupling Challenges

- Cost and area are always major factors.
- Decoupling performance is determined by the transfer impedance ***at the IC attachment to the planes.***
- Long average distance to planes yields high attachment inductance. This requires more vias and more decoupling capacitors to hit a given target Z.
- Wide plane separation yields high plane inductance. Capacitors must be closer to the ICs they support to yield target Z at the ICs.

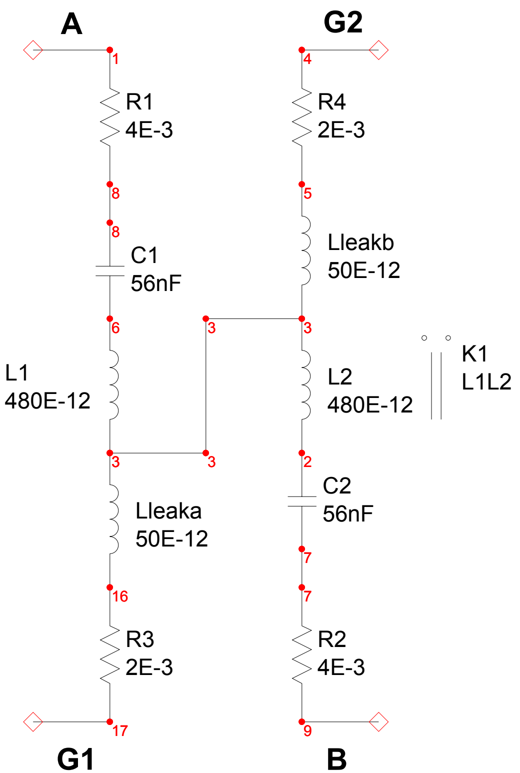
Mounted vs. Unmounted Decoupling Performance

- Decoupling performance is limited by the ESL of the capacitor, and the partial inductance of the attachment.
- Noise voltage at the planes is significantly higher than that measured at any decoupling capacitor.
- At high frequency insertion loss ≈ Zs / jw(ESL + Lattach)
- A high ESL defeats a low Lattach, and vice-versa





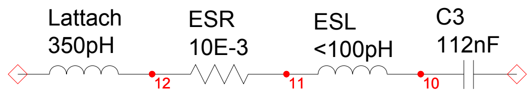
X2Y®, An Integrated Passive Circuit



Simplified 56nF
X2Y capacitor model.

- X2Y capacitors are complex four terminal devices that combine two capacitors with an embedded, transformer.
- A and B terminals each couple to opposing transformer ends.
- When A and B terminals are connected for decoupling, the apparent inductance is limited to leakage from imperfect coupling.
- Materials and dimensions support effective operation into the GHz.

X2Y® Circuit 2, Versus Ordinary Capacitors



X2Y 0603 Capacitor on 4 Layer PCB

Typical 0603 Capacitor on 4 Layer PCB

- The apparent ESL of an X2Y® capacitor is a small fraction of the ESL of an ordinary 0603 capacitor.
- Mounted ESL for an X2Y® on a 4/6 layer PCB is completely dominated by the attachment inductance, but still remains far below that of an ordinary 0603 capacitor.

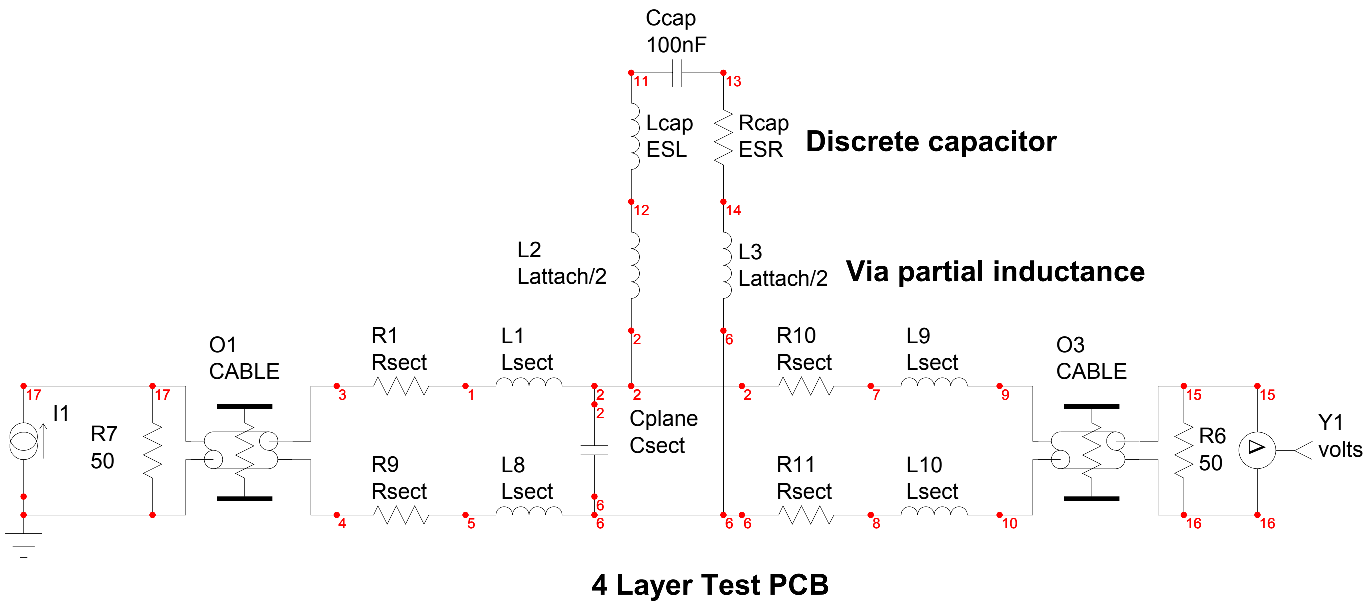
4 Layer PCB Test Setup

- Tests determine the **mounted decoupling performance** of X2Y and competing technologies on a representative 4 Layer PCB test section.
- The PCB is FR-4 with an overall thickness of 0.062“, with two inner layers (solid copper planes) that have a copper weight of 1 ounce, 0.012” and 0.050” from the component surface, and a nominal Er of 4.6 at 1MHz.
- The test PCB is small: 1.2” by 1.2” that allows capacitor evaluation to 400MHz and beyond.
- Capacitors are constrained to a small area to ensure position independence.
- SMAs connect to the PCB power and ground layers.
- s21 Loss Evaluated with an HP 8753E Vector Network Analyzer
- s21 measurements are converted to impedance with the following*:

$$s21 = 20_{\log_{10}} \frac{Z_{DUT}}{25\Omega} \longrightarrow Z_{DUT} = 25 \cdot 10^{\frac{s_{21}}{20}} \Omega$$

* David M.Pozar, Microwave Engineering, Addison-Wesley, (1990), p 236.

Decoupling Test Fixture Model

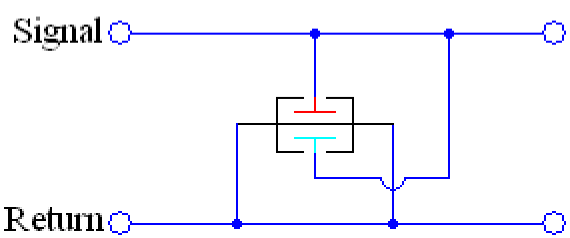


- Since Csect << Ccap, Ccap may be accurately derived from s21 loss at F << Ccap SRF.
- The combined Lattach and Lcap may be accurately determined from Ccap and the SRF.
- We derive Ccap from s21 loss at 2MHz.

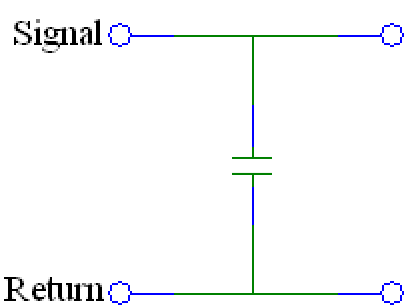
The 0603 test boards have 12 different via/land configurations to measure components using various mounting practices.

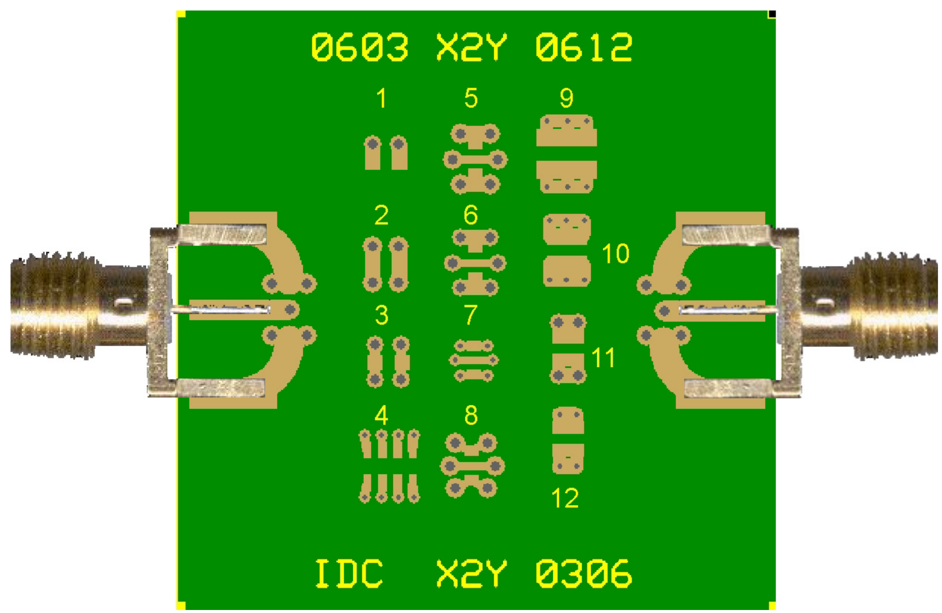
Note: best data results for X2Y® and normal capacitors is shown.

X2Y® Cap (circuit2)



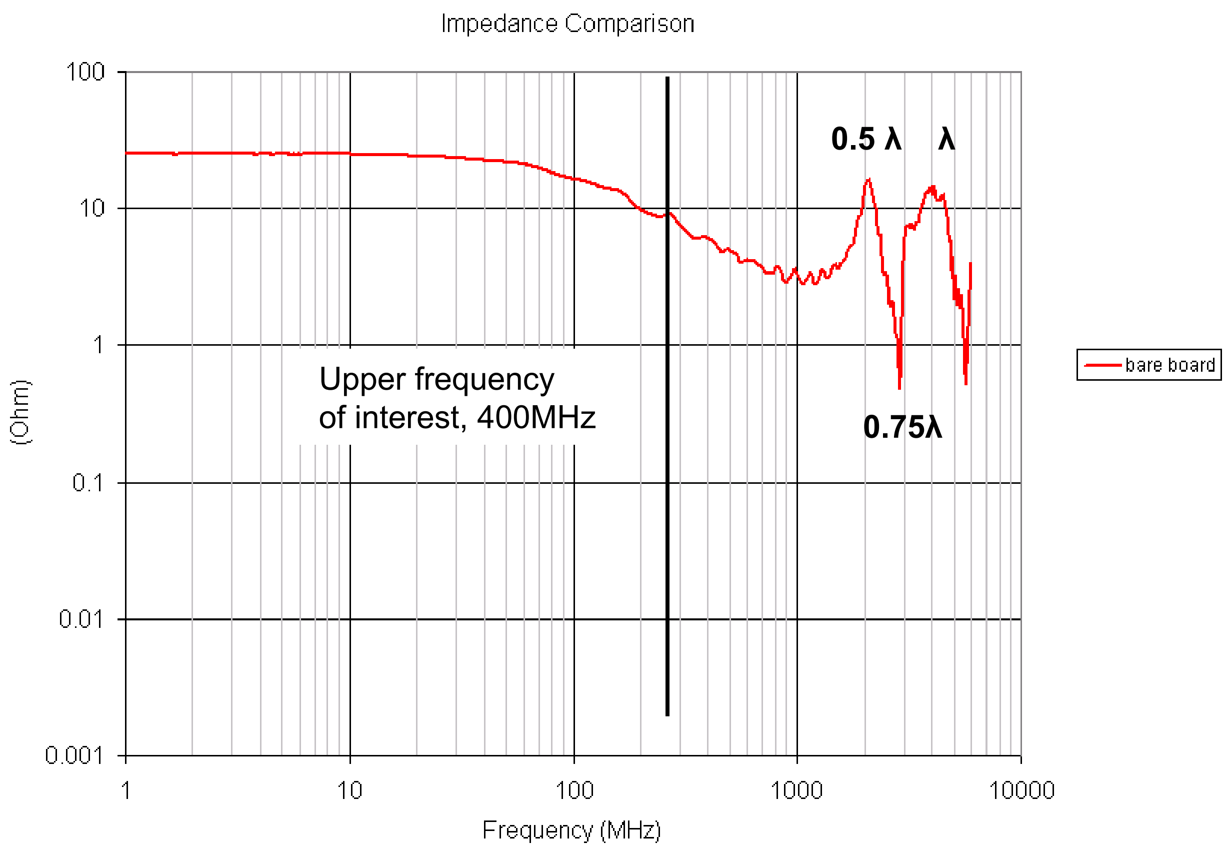
Normal Cap





* **A Transmission-Line Model for Ceramic Capacitors for CAD Tools Based on Measured Parameters,** Larry D Smith, David Hockanson, Krina Kothari, Published in Conference Record, Electrical Components Technology Conference (ECTC), San Diego, CA, pp. 331−336, May 2002.

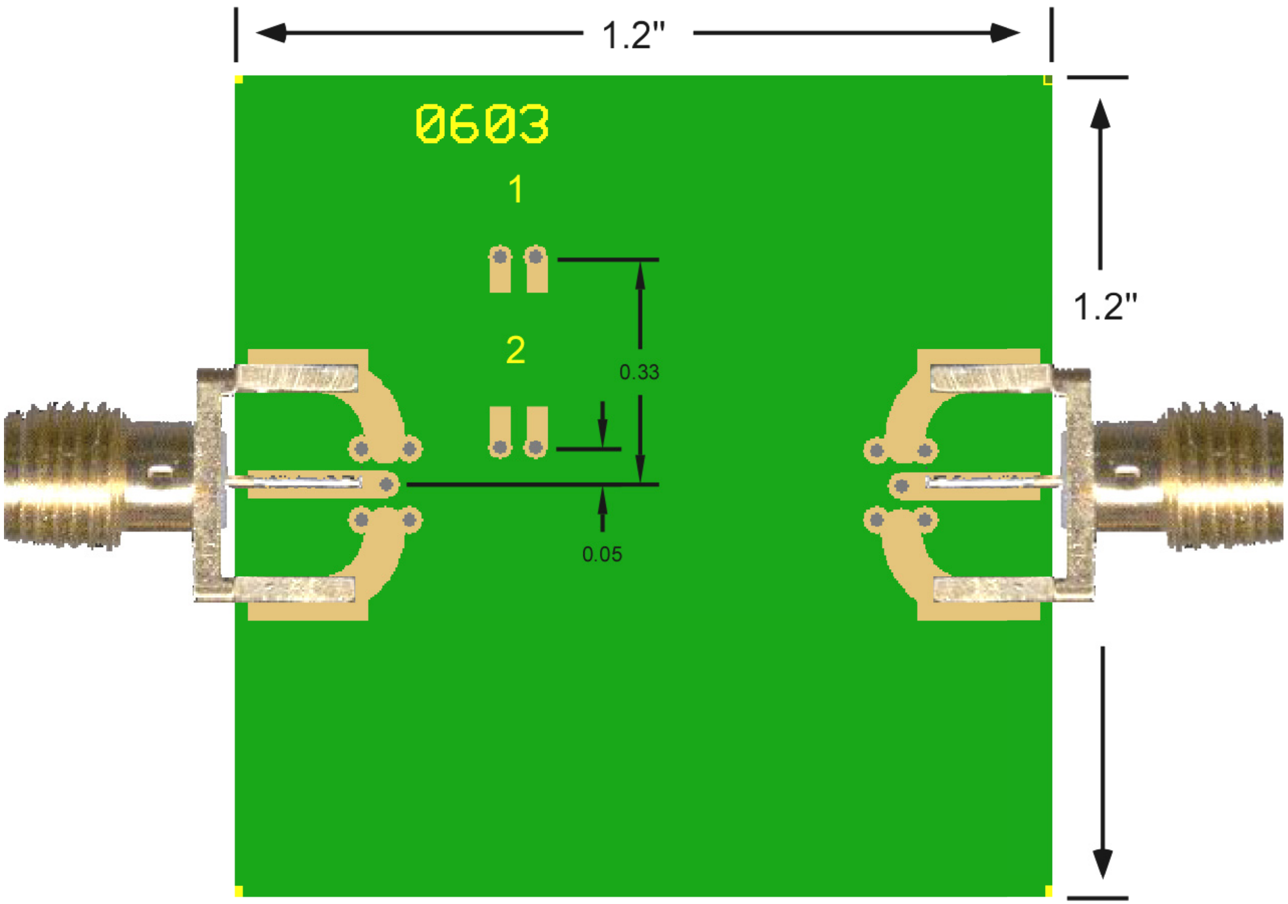
The 0603 test boards were developed to show accurate bypass capacitor performance to 400MHz



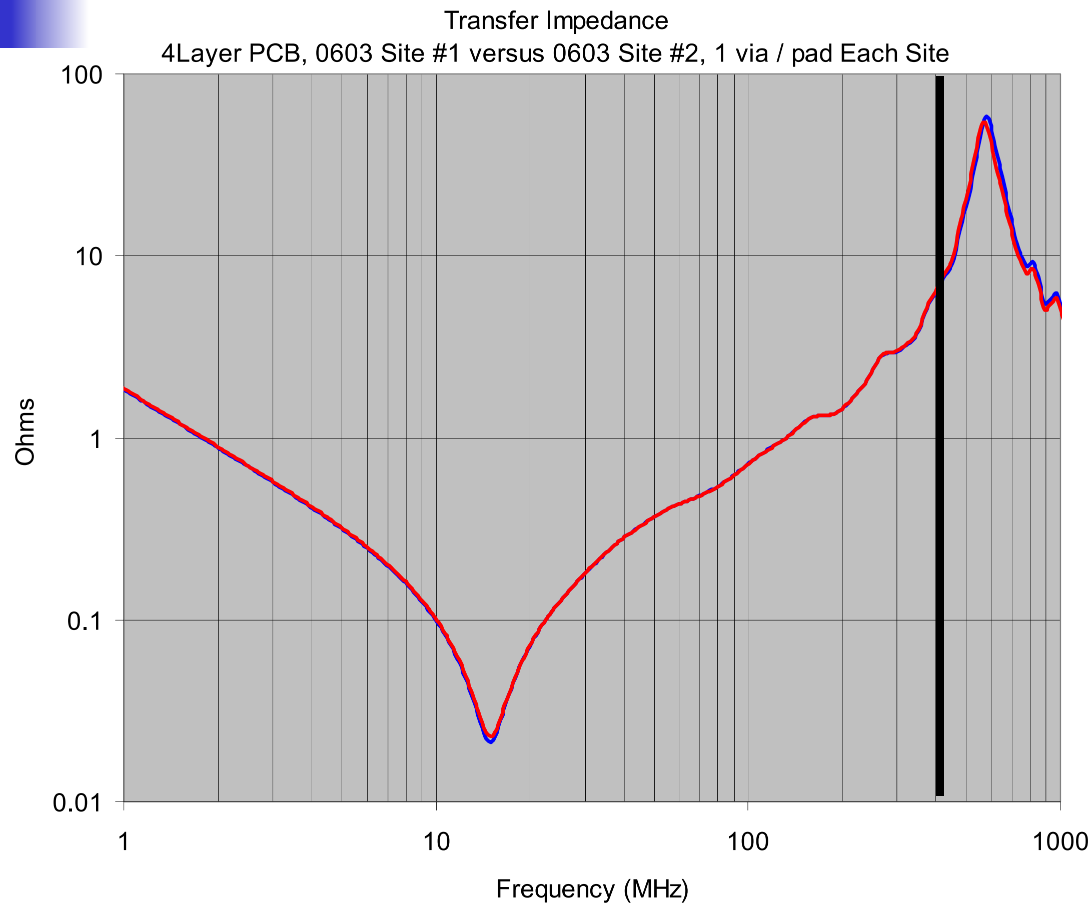
Board λ is approximately 1/(4 GHz) allowing accurate lumped approximations up to 400 MHz.

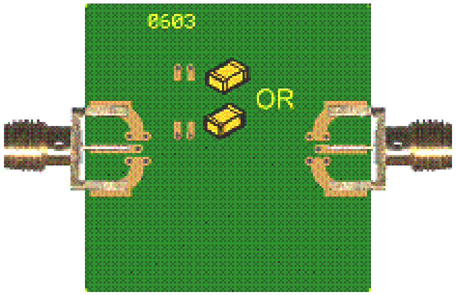
Location Dependency

To verify location independence. We compared results from a normal geometry 0603 capacitor in both center and outside locations on the PCB. Note that position #2 vias are almost directly in-line with the SMA connectors.



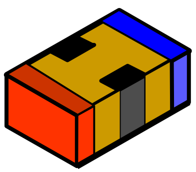
Location Dependency



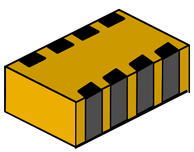


- Results from each location are almost indiscernible up to 400MHz.
- Test location does not impact measured results.

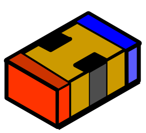
Decoupling Performance X2Y® vs. Conventional and Low Inductance Capacitors



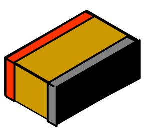
X2Y® – 1206 0.18uF*
(0.36uF total, circuit2)



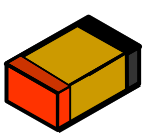
AVX IDC™ – 0612 0.47uF



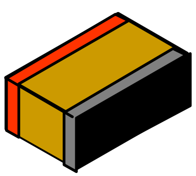
X2Y® – 0603 56nF*
(112nF total, circuit2)



Reverse Aspect ratio – 0508 100nF



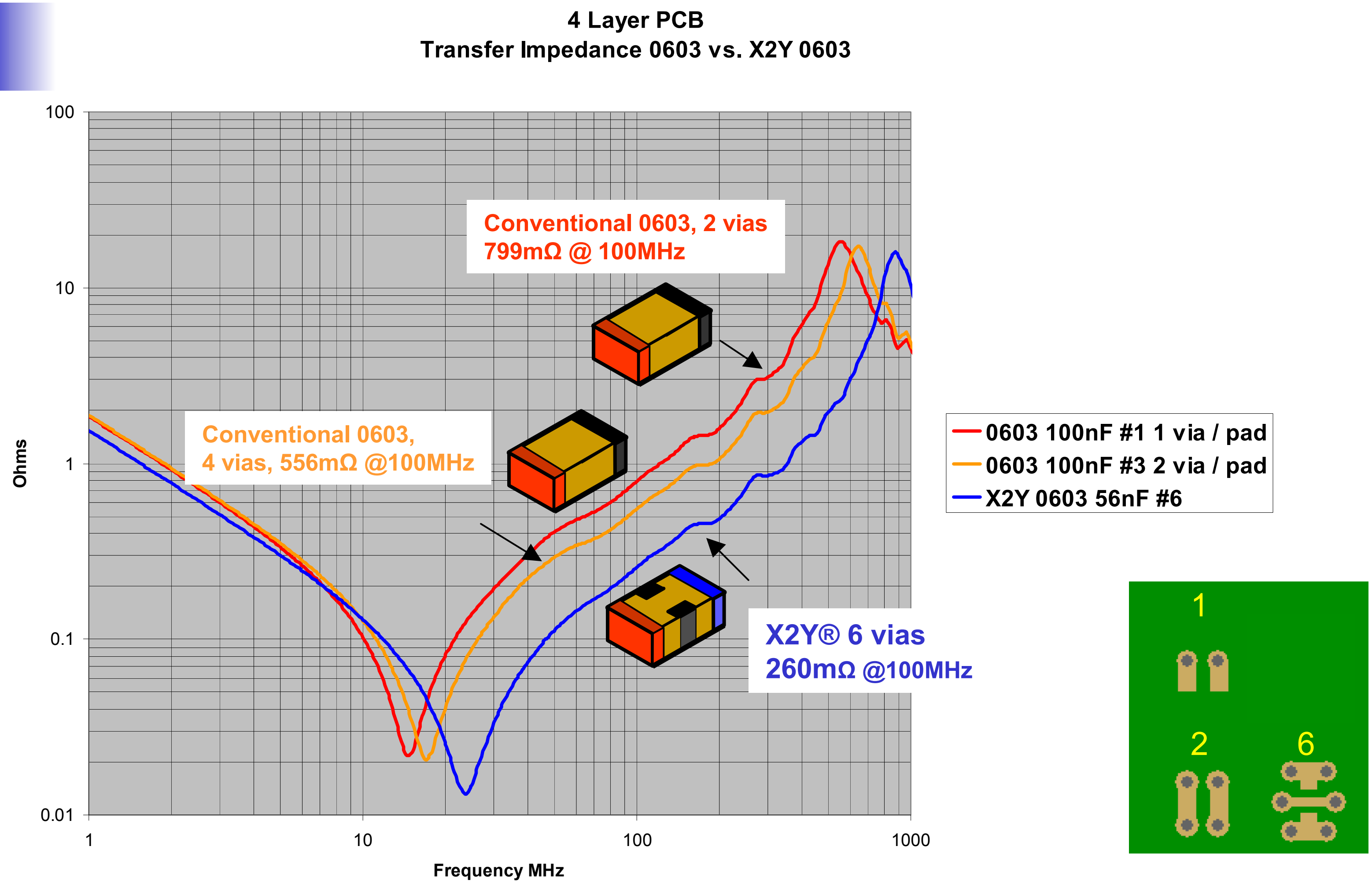
Normal – 0603 100nF



Reverse Aspect ratio – 0612 100nF

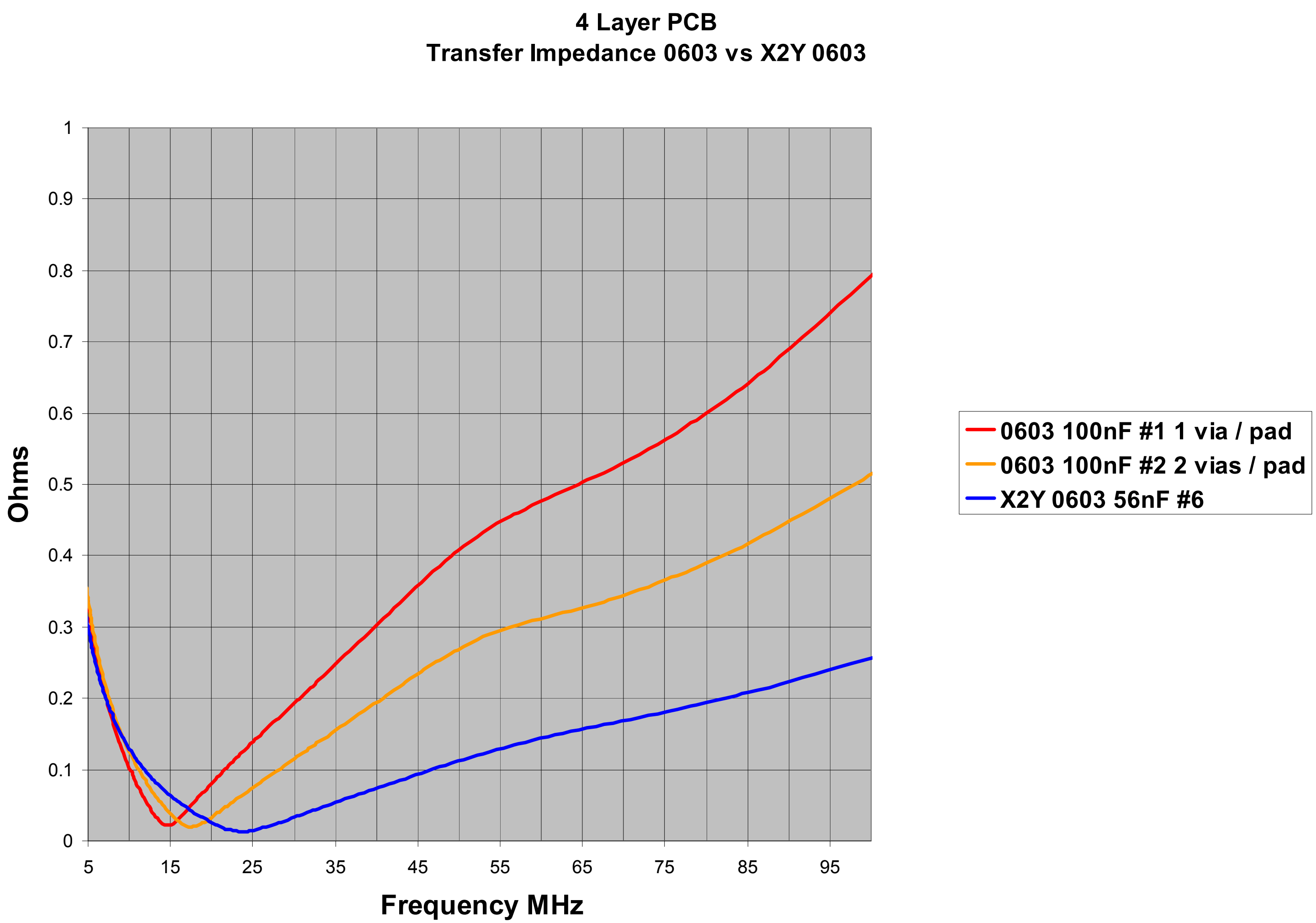
***Note: X2Y capacitors consist of two Y capacitors, and are rated based on the capacitance of a single Y capacitor. When used for decoupling, both Y caps appear in parallel, yielding a capacitor with 2X the single Y capacitor value..**

X2Y 0603 vs. Conventional 0603 Capacitors



A single X2Y 0603 capacitor exhibits a **mounted transfer impedance** of just **260mΩ at 100MHz** compared to 799mΩ for a conventional 0603.

Transfer Impedance, Linear Scale

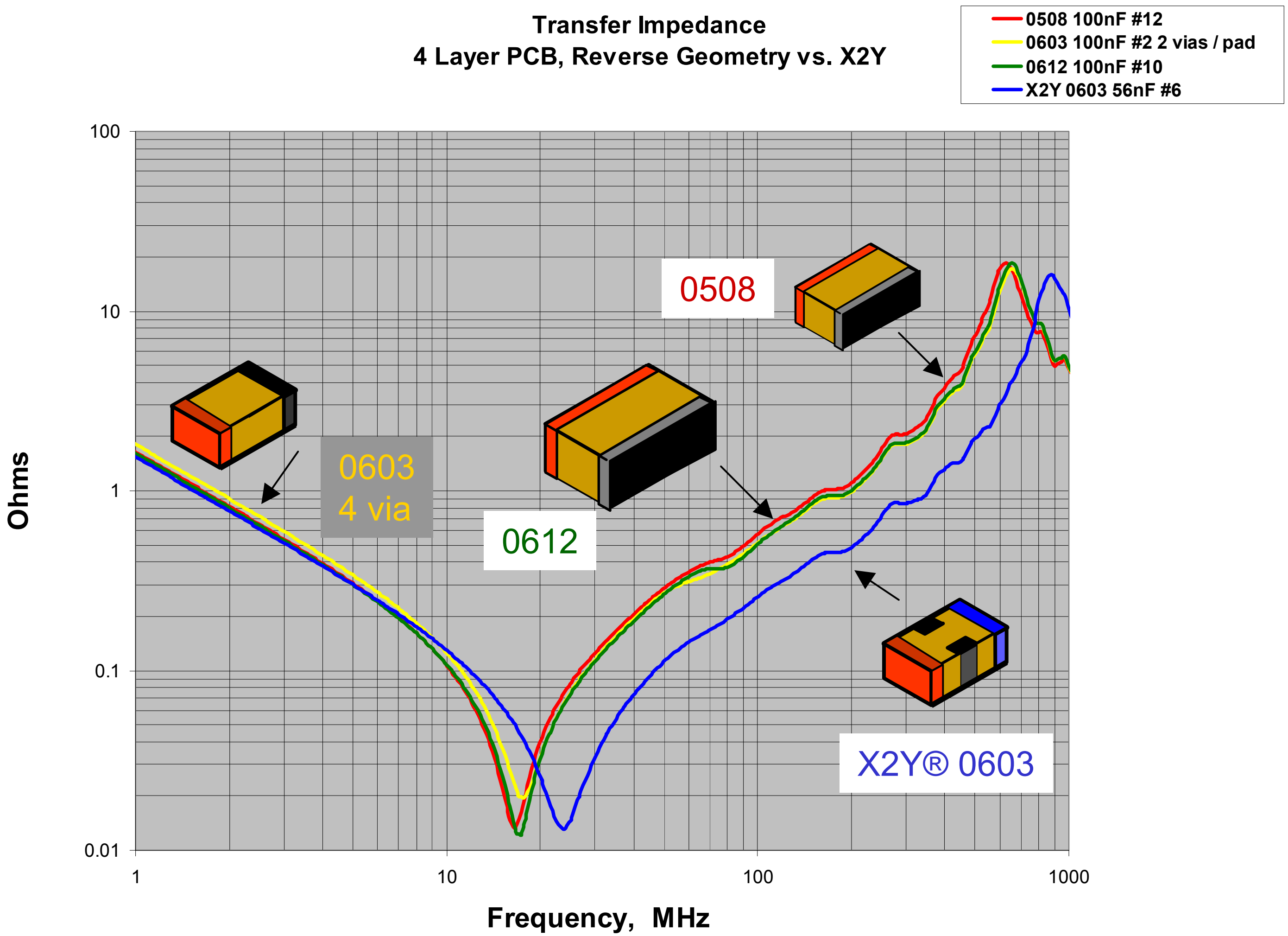


Linear scale representation indicates noise level in volts, and underscores the 3X mounted bandwidth of an X2Y® versus conventional capacitors.

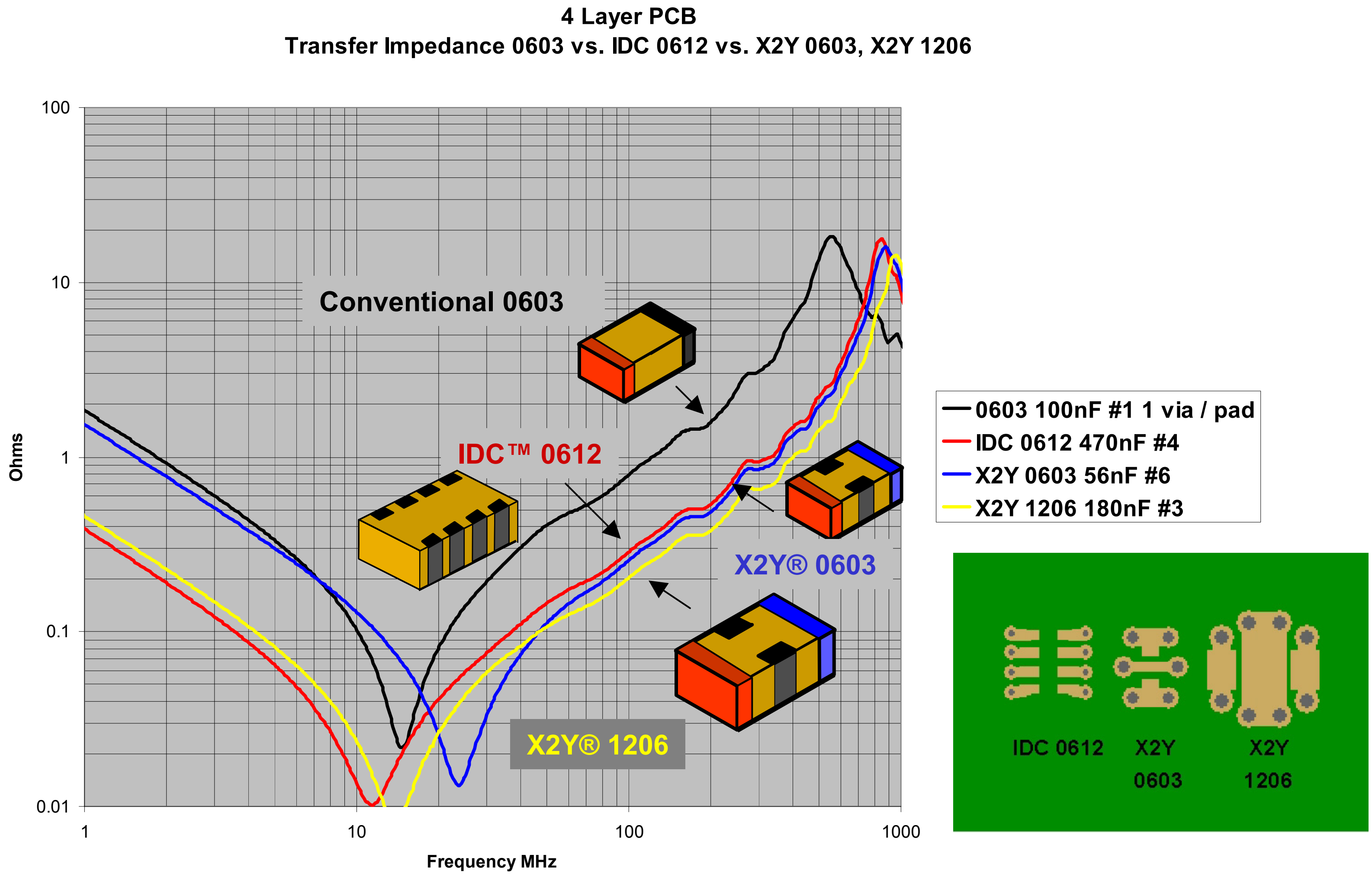
X2Y Advantages

- One X2Y® 0603 capacitor w/ 6 vias total = 260mΩ @ 100MHz, and outperform:
  - Three conventional 0603 capacitors w/ 6 vias total, 266mΩ @ 100MHz or
  - Two conventional 0603 capacitors w/ 8 vias total, 278mΩ @ 100MHz.
- X2Y® capacitors translate to:
  - Fewest Components
  - Fewest Vias
  - Best Decoupling Performance
- X2Y® concentrate attachment vias. This usually simplifies placement and signal routing.

X2Y vs. Reverse Aspect Ratio Capacitors

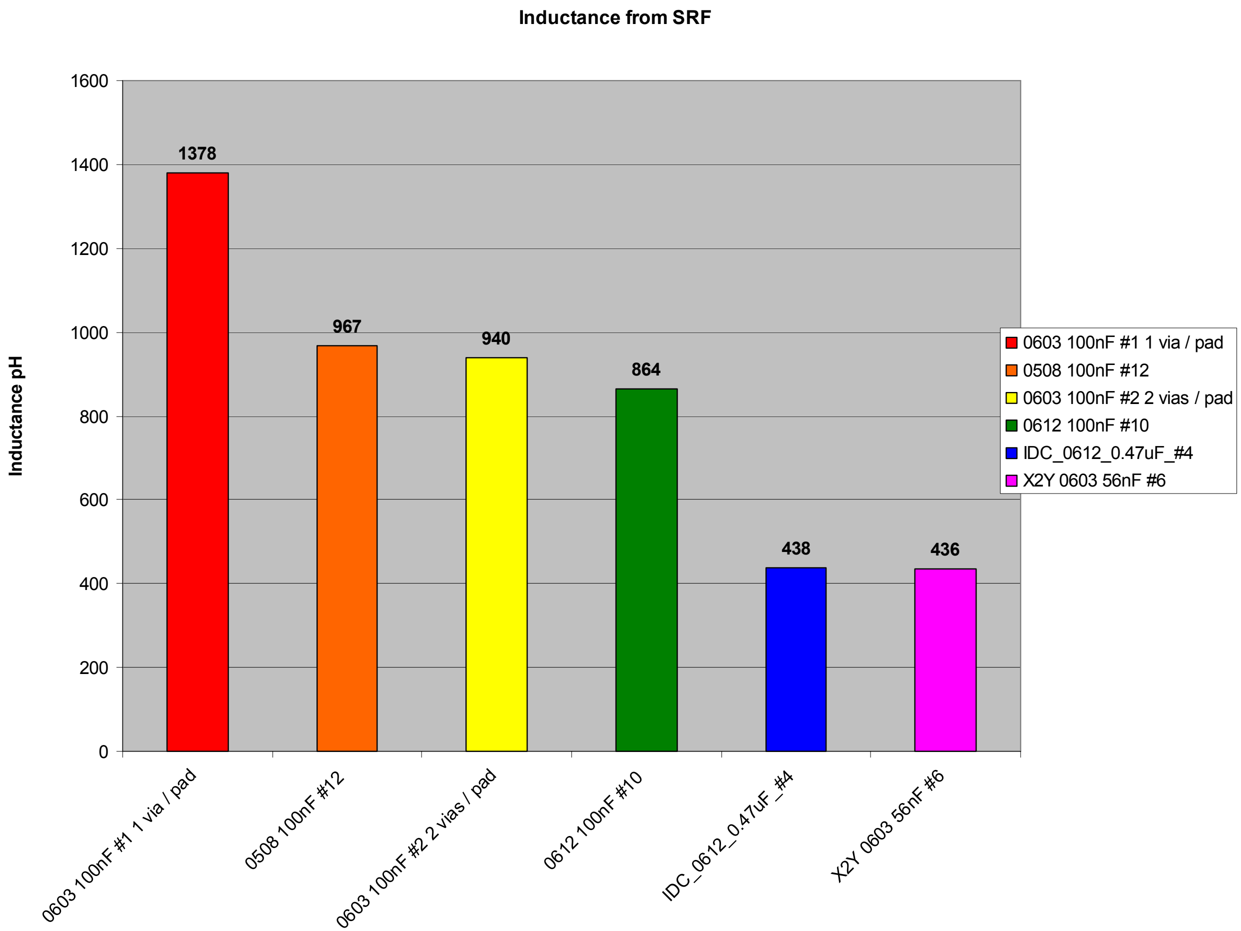


On a 4 layer PCB, reverse geometry capacitors even with 6 vias each perform similarly to an 0603 w/ only 4 vias. Reinforcing mutual inductance between adjacent vias impose diminishing returns and limit Lattach to relatively high values.



An X2Y® 0603 with 6 vias outperforms an IDC™ 0612 with 8 vias.
An X2Y® 1206 with 8 vias significantly outperforms an IDC™ 0612 with 8 vias.

Mounted Inductance Comparisons



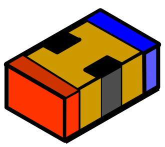
- Mounted inductance of one X2Y® 0603 is better than 3X ordinary 0603s with the same number of total vias.
- Mounted inductance of X2Y® 0603 is better than IDC™ 0612, while consuming 25% fewer vias.

Summary of 0603 4 Layer Board Data

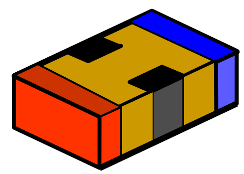
- Mounted inductance determines the high frequency performance of decoupling capacitors.
- **X2Y® capacitors provide the lowest mounted inductance of any capacitor type**.
- **X2Y® capacitors require the fewest total vias of any decoupling solution**.
- Just one X2Y® 0603 w/ 6 vias is a **better than replacement for any**:
  - 3) 0603 capacitors, 6 vias,
  - 2) 0603 capacitors, 2 vias / pad, 8 vias total,
  - 2) 0508, or 0612 reverse geometry capacitors, 8-12 vias, or
  - 1) 0612 IDC™ capacitor, 8 vias.
- The X2Y® performance advantage improves with higher layer count boards, allowing one X2Y® to replace even more conventional parts and vias.

Shunt Measurement
Larger X2Y® Capacitors

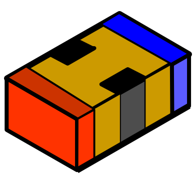
A set of test boards is used to show the performance of larger size X2Y components.



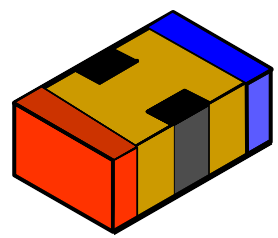
X2Y® – 0805 100nF
(200nF total, circuit2)



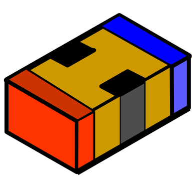
X2Y® – 1210 100nF
(200nF total, circuit2)



X2Y® – 1206 100nF
(200nF total, circuit2)



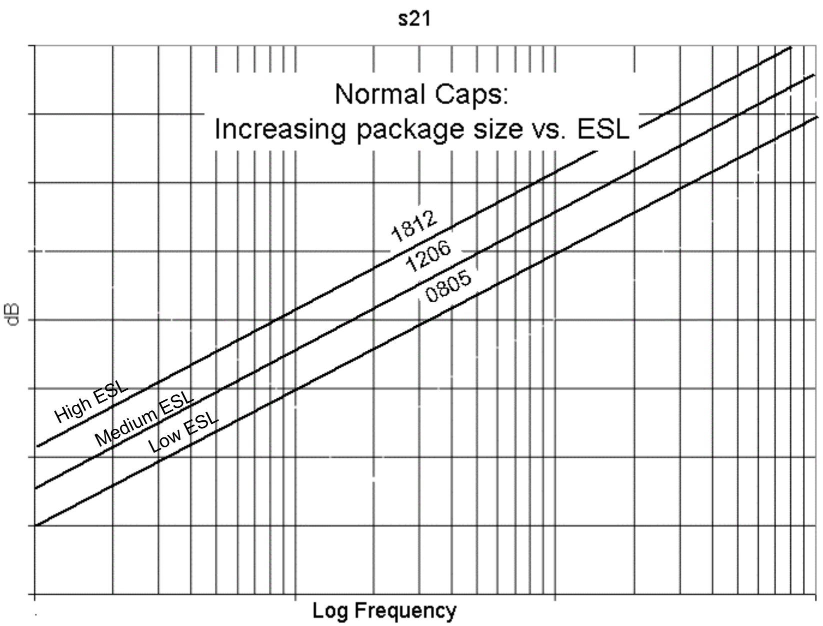
X2Y® – 1812 1uF
(2uF total, circuit2)

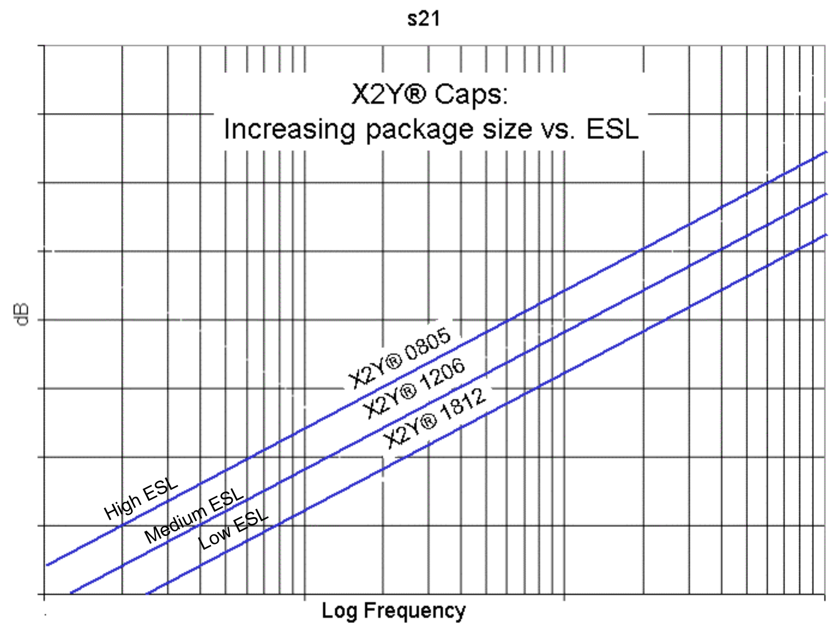


X2Y® – 1206 0.18uF
(0.36uF total, circuit2)

Inductance Versus Package Size

Whereas ESL increases with package size in ordinary capacitors, the X2Y integrated passive circuit, IPC™, ESL arises from leakage inductance and does not increase significantly with package size. Large body X2Y parts afford lower Lattach, resulting in lower mounted inductance than smaller devices.



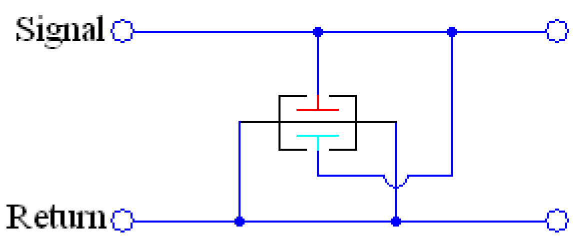


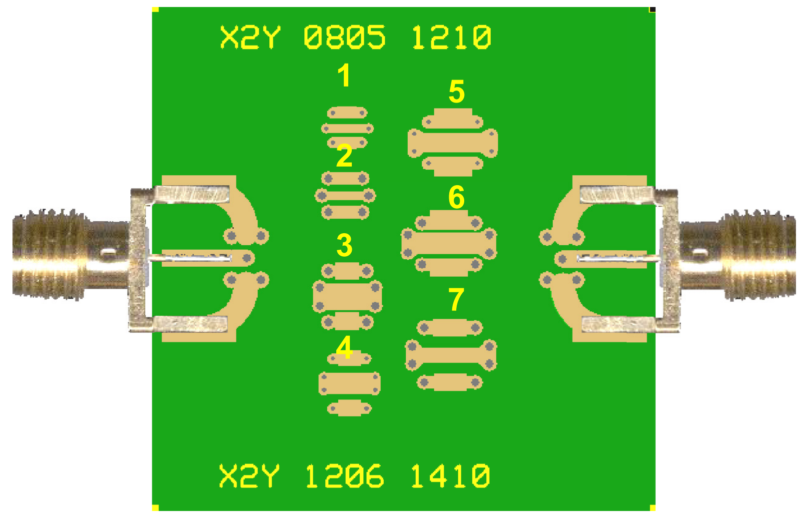
0805 / 1206 / 1210 / 1410 / 1812 / 2220 Test Boards

The test boards have 10 different via/land configurations to measure components using various mounting practices.

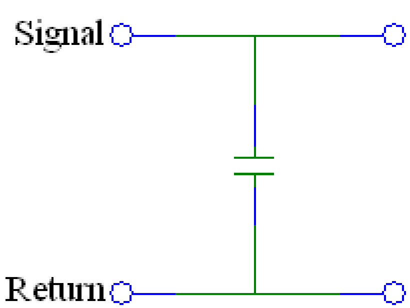
Note: best data results is shown.

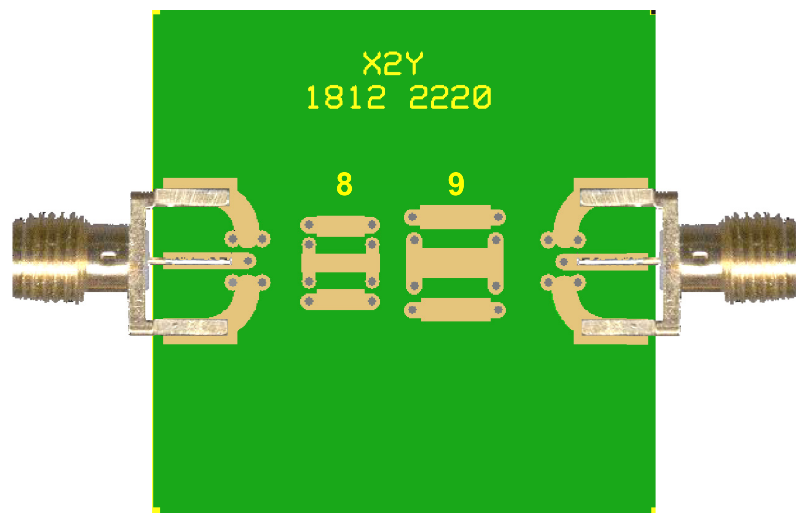
X2Y® Cap (circuit2)



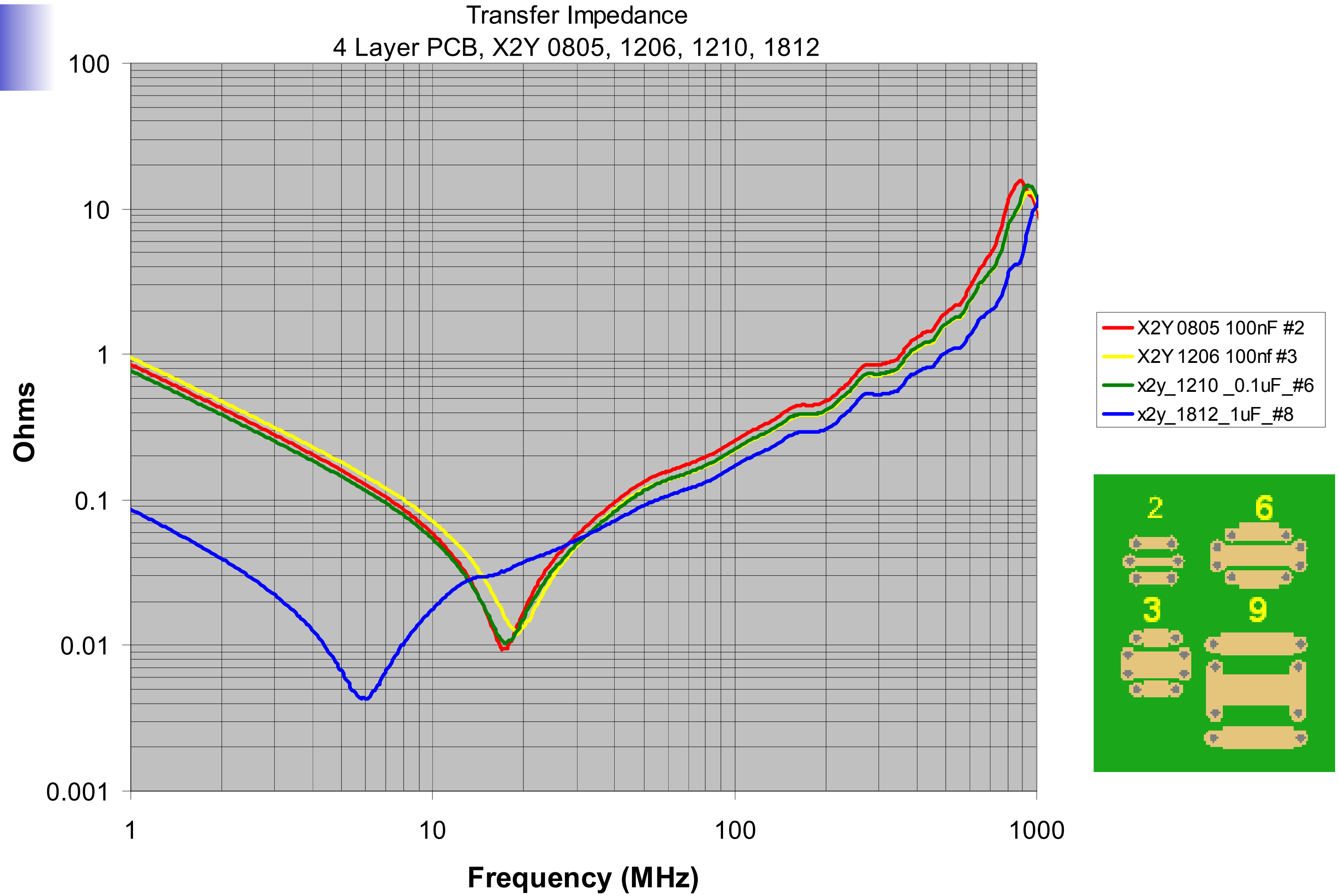


Normal Cap





X2Y 0805 / 1206 / 1210 / 1812



Even large X2Y devices exhibit very low impedance at high frequency.

Summary of large X2Y® data

- With proper via patterns, large X2Y capacitors exhibit equal or better mounted inductance as compared to industry leading 0603 X2Ys.
- An 1812 X2Y mounted on a 4 layer board demonstrates better high frequency performance than four ordinary 0603 capacitors in parallel.

Conclusions

- X2Y® capacitor's ultra-low inductance afford unmatched decoupling performance, even on 4/6 layer PCBs where Lattach strongly dominates.
- X2Y® capacitors for decoupling translate to:
  - Fewest decoupling capacitors,
  - Fewest decoupling capacitor vias,
  - Lowest component costs,
  - Lowest assembly costs,
  - Improved performance,
  - Improved reliability, from fewer parts and better decoupling.

Further Resources: Si_List

The tests were developed after comments about X2Y Technology in actual applications by an independent consultant Steve Weir on the signal integrity reflector si_list.

The full thread discussion is highlighted at the links below.

Thread Subjects:

1) Re: Bypass Capacitor Selection

2) Re: Power Supply Distribution/Filtering/Decoupling Guide

Post# Link:

10323 http://groups.yahoo.com/group/si-list/message/10323

10326 http://groups.yahoo.com/group/si-list/message/10326

10329 http://groups.yahoo.com/group/si-list/message/10329

10352 http://groups.yahoo.com/group/si-list/message/10352

10358 http://groups.yahoo.com/group/si-list/message/10358

Main Post Pages:

http://groups.yahoo.com/group/si-list/messages/10288

Information about the si_list:

http://www.si-list.org

Acknowledgements

X2Y Attenuators, LLC would like to thank Steve Weir of Steve Weir Design Engineering, Petaluma CA for the test board development and layouts shown in this presentation.

Steve has over 25 years industry experience, holds numerous patents, and is a frequent contributor to the si_list.

Steve may be contacted via e-mail at: weirspde@comcast.net.