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Webeditorial February 2004

X2Y Capacitors Reduce EMI/RFI Susceptibility Of Computer Equipment

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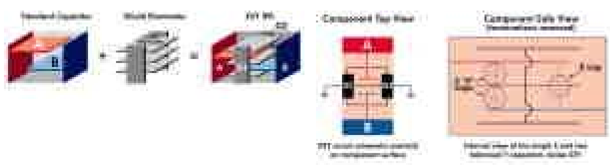
For today's high-frequency circuits, reducing noise susceptibility means reducing circuit impedance across a broad frequency band, and this in turn means reducing individual component inductance values. A new component, the X2Y capacitor, incorporates fundamental design improvements to reduce inductance to the 50 pH range while maintaining low ESR (Equivalent Series Resistance). The X2Y capacitor reduces the number of decoupling capacitors while improving performance by providing both common and differential-mode noise suppression for high-frequency signal-line filtering. Here we describe how.

X2Y Capacitors Reduce EMI/RFI Susceptibility Of Computer Equipment



The number of peripherals around a typical computer user is increasing steadily. Computers, keyboards, mice, monitors and video cards are being joined by modems and phones, printers and scanners. Faster CMOS circuits are switching larger currents, but with reduced voltage margins. As clock and data speeds increase, so does a circuit's sensitivity to noise. For different equipment to work together at all, strict conformity with EMI emission limits is essential, and this is placing correspondingly stricter requirements on filters and on other high-frequency components that surround ICs. On-board interference is contained by shielding the equipment case but the leads entering and leaving the case are still susceptible since they act (very efficiently, as it happens) as antennas for receiving/transmitting Common Mode interference. Any CM-interference due to stray inductances or capacitances from power and data leads is now generally mopped up by clipping a ferrite bead to one or both ends. The bead chokes the RFI at the point where it clips onto the lead, providing a high resistance path for the high-frequency interference (it sets up current loops that dissipate the energy as heat in the ferrite core, rather than being transmitted down the cable). On power lines, the ferrite bead prevents EMI and RFI from being transmitted, and on data lines it prevents any stray interference from being received.

Ferrite beads deal fairly effectively and easily with the problem (although the EMI suppression they can achieve is limited), but are a relatively expensive solution because they involve a separate assembly operation. A better approach is to suppress the noise on the circuit board itself. This demands low-inductance components, particularly capacitors, to isolate critical circuits from ripple and other high-frequency effects. Surface-mount ceramic multilayer capacitors (MLCC) have helped reduce interference by improving decoupling performance. More recently, MLCCs like e those from Yageo's Phycomp-branded low-inductance series have cut interference still further. They are located as close as possible to the microprocessor, and help keep interference manageable in circuits with process and clock speeds up to around 1GHz.

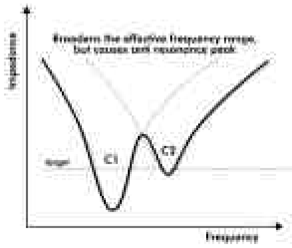
Above that frequency, the only successful approach is to minimize parasitic inductances and resistances of critical circuit elements. Low-inductance MLCCs must be accompanied, for critical circuits, by ultra-low-inductance X and Y capacitors to reduce interference on power and data lines. These were in the past discrete components, but there are huge advantages in integrating them. Using a patented breakthrough from X2Y Attenuators, Yageo is now mass manufacturing and marketing X2Y product series under its Phycomp brand.

The devices are integrated in a small four-pin surface-mount package, and feature extreme low inductance with balancing. They eliminate the need for the ferrite bead while also increasing noise margins for designers. The remarkably low inductance of 50pH (a factor 10 lower than the best discrete MLCC solutions) converts to a suppression of typically 30 to 40 dB across 1 to 10GHz. The strikingly flat insertion loss versus frequency curve gives the broadband performance needed from ultra low inductance devices.

Shielding electrodes suppress parasitics

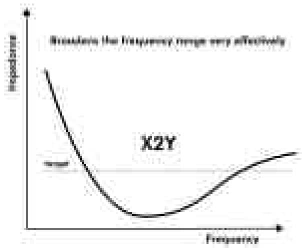
The X2Y design starts from a standard two-electrode (A and B) surface mount capacitor. Three commonly attached shielding electrodes surround the A/B electrodes, and connect to two opposing side terminations (G1 and G2) of the capacitor body. This forms a four-terminal Integrated Passive Device, IPD (Figure 1). The electrode shields contain the electrostatic fields, and suppress the energy parasitics normally transmitted from the A/B electrodes.

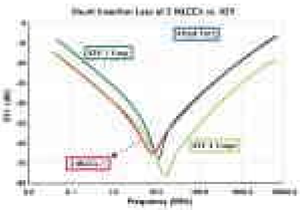
Together with their shield electrodes, the A/B electrodes create a pair of symmetrically balanced 'Y capacitors' which act like two standard MLCCs connected to ground. The same two electrodes also



form an 'X capacitor' across the shared center electrode, hence the name X2Y (Figure 2). Each Y capacitor has capacitance C, with X being C/2. As with standard capacitors, repeating the core structure increases the capacitance.
Conventional capacitors on standard two-layer boards with ground (gnd) and power (pwr) planes give large current loops and hence large inductance. With X2Y, the A/B electrodes are both attached to pwr, with G1/G2 connected to gnd by vias. The shield electrodes thus form a parallel extension of the board gnd, and current loop and hence inductance is determined only by the dielectric layer thickness. The shield electrodes further cut inductance by opposing the magnetic fields, since the X2Y currents through A and B flow in opposite directions and the two magnetic fields cancel.
The manufacturing process is similar to that of an MLCC, with closely spaced internal layers giving close matching of the two Y capacitors (on request, even better than 1%). The devices come in standard EIA sizes (0603/0805/1206/1210/1812), with Y cap values from 10pF up to µF values, and from 10 to 100V.

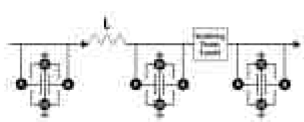
Decoupling broadband circuits (part 1)





Improvements in decoupling have largely been driven by power supplies for high-speed microprocessors, with CMOS power systems becoming particularly difficult to design. One approach identifies a target impedance across a broad frequency range and specifies components to meet that impedance. The required value is falling rapidly (5´ each computer generation), and is now down to sub mOhm levels. Up to about 1kHz the low impedance is provided by a system's voltage regulator, at higher frequencies by successively lower valued capacitors (bulk capacitors up to 1MHz, ceramic up to 1GHz), and above that by low value capacitors and power planes. Circuit designers are continuously tightening layout and component specifications to reduce the target impedance across the complete frequency range.
For a single capacitor, at frequencies above SRF (Self Resonant Frequency), the Xl (inductive) term has the largest contribution to impedance, and is determined by the ESL (Equivalent Series Inductance). Capacitors need to be close to SRF for low impedance, with low capacitance values for decoupling at high frequency. Given a certain component size, decreasing the capacitance value raises the SRF. The approach cuts impedances at higher frequencies, but also reduces the decoupling bandwidth. Decreasing the capacitor's inductance is more effective, increasing the SRF and the effective frequency range.
Parallel combinations of capacitors with the same capacitance are often used to reduce impedance in a narrow band around the SRF. The capacitors should have low ESR (mOhm for modern processors). Electrolytic and tantalum capacitors have therefore been replaced by MLCCs, where hundreds of parallel electrodes have inherently low ESRs. Halving the impedance, however, demands doubling the number of capacitors.
The effective frequency range is increased by using two different valued capacitors in parallel, but this produces unwanted "anti-resonance" (Figure 3), with a peak k between the two minima.

Decoupling broadband circuits (part 2)



The peaking can be reduced by minimizing the total circuit inductance including that of capacitors, pads and connecting tracks. Because of its internal cancellation of inductances, a single X2Y device decouples across a wide frequency range (Figure 4).

The performance of half the X2Y (one Y-cap, Figure 5) compares to two MLCCs connected in parallel. However, obtaining the full X2Y (two Y-caps) performance, increasing the effective frequency range by a factor four, would need a parallel connection of eight MLCCs.

Component design has improved from leaded passives through MLCCs, smaller MLCCs, reverse-aspect ratio MLCCs (down to 300pH), and IPDs (four interdigitated capacitors can reach 100 to 175pH). Again, though, multiple capacitors need to be paralleled for high-frequency decoupling. Conventionally, several standard capacitors are paralleled to reduce impedance across a broad frequency range (Figure 6).
For decoupling (Figure 7), the X2Y's balanced pair of Y capacitors (A/B) work in parallel to deliver energy.

Even discounting the inherently low-inductance design, the X2Y's two equal capacitors halve the number of devices required. The low inductance reduces the number required even further, while improving decoupling performance. X2Y® devices have a four-port attachment to the PCB (Figure 7). Attaching both G1/G2 terminations to the board can give a 15 dB attenuation increase between 45MHz and 6GHz.

Broadband filtering

Increasing transmission speeds, smaller signals, and more parallel data lines all demand more effective common- and differential-mode noise filtering. This means considering a combination of common-mode choke coils or ferrite-beads and/or capacitor/FTCs (feedthrough capacitors). The need for better filtering and lower EMI emission levels has also affected the location of filters. From putting a core round the cable, filters have been moved on board and (for very fast signals) into the connector. At higher frequencies, ferrite-beads are replaced by capacitive filters: one MLCC, two MLCCs in parallel, one FTC, two FTCs, and X2Y IPD in order of increasing performance.

Signal line filtering

Two MLCCs can act as shunt capacitors to give a low impedance noise path for high-speed signal filters (Figure 8), with a third MLCC between the two lines filtering differential noise. A single X2Y replaces all three MLCCs.

Feedthrough capacitors improve filtering by reducing parasitic inductance: two parallel paths shunt noise to ground. However, the signal current flows through the capacitor itself: traces, terminations and electrodes all add DC resistance to cause signal loss. The feedthrough capacitor also has larger parasitic inductance. The X2Y's A/B electrodes have a remarkable dual function: together they form the single X electrode and, with the shields, they form the two Y electrodes. This allows simultaneous operation as both a common- and differential-mode filter when connected between two opposing conductors and to ground. A lower inherent inductance improves suppression at higher frequencies, with broader bandwidth. The internal shield electrodes also provide cross-talk isolation between pins (line-to-line) for filtering connector lines.

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