"New X2Y Filter Technology Emerges as Single Component Solution For Noise Suppression”

Presentation: approx. 60 min

**Introduction:**

“A new capacitive technology introduced by X2Y Attenuators LLC, Erie, Pa., can overcome the limitations of currently available signal-integrity solutions by reducing parts count while enhancing performance. It also opens the door to multi-sourced solutions. The X2Y technology is not a capacitor per se, but rather an architecture that can be used to manufacture a variety of devices, including capacitors, decouplers, transient voltage suppressors, and filters.”

*Quote from “Capacitive Technology Filters And Decouples With Fewer Parts” by David Morrison, Electronic Design Magazine, February 7, 2000*
**Topics Covered:**

- An update on the U.S. and European IC standards for Emissions and Immunity.

- Real world applications and test results of X2Y technology. A single X2Y device is used to suppress noise in small DC motors, replacing up to seven components currently used for EMI, including inductors, ferrites and standard capacitors.

- RJ 45 Connectors. Higher operating frequencies are bringing to light many of the shortfalls in today’s filter components, the broadband characteristics of X2Y Technology are offered as a possible solution.

**Speaker:** Jim Muccioli
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SUB-COMMITTEE NO. 47A: INTEGRATED CIRCUITS

Participants by Country:
- France
- Japan
- Poland
- Netherlands
- United Kingdom
- USA

Participants by Company:
- Hitachi
- Infineon
- ITE
- Motorola
- NEC
- Okayama University
- Philips
- Politecnico di Torino
- Siemens Automotive
- Texas Instrument
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Seattle & Oregon Chapters

Windshield Washer Pump DC Motor with Current Filter Arrangements

Typical Filtering in Current DC Motors

Presentation by X2Y Attenuators, LLC.
Windshield Washer Pump DC Motor with X2Y Filter

X2Y in a (2) Wire Motor Application
Windshield Washer Pump Radiated Comparison Test
X2Y vs Multi-Component

IFR AN820 Spectrum Analyzer
Sweep: 8*20 ms
Bandwidth: 120 kHz
Video Band: none
Frequency Range: 100kHz to 1 GHz
Measurement: dBuV

- No Filter
- Tef Ccl Ambient
- X2Y 0.44uf
- 0.1uf + 7.5mh y chokes + 0.47uf
Windshield Washer Pump Motor
Improved Performance with X2Y & Enhanced Shielding
Additional Small Motor Filter Approaches
Radiated Test Comparison X2Y vs. Various Prior Art

Radiated Emissions of DC Motor - 150 kHz to 1000 MHz - 10 Point Moving Avg.

- No Filters Dose Line Motor
- Fig. 5-(2) Inductors + (2) Caps + (2) Beads + (1) Cap Varistor
- Fig. 6-(2) Beads + (1) Cap Varistor + (2) Caps
- Fig. 7-(1) Cap + (2) Inductors + (1) Cap

IFR ANDO Spectrum Analyzer
Sweep: 8 * 20 ms
Bandwidth: 120 kHz
Video Band: none
Frequency Range: 100kHz to 1GHz
Measurement: dBuV

KuTEM Cell Ambient

Fig. 8-X2Y @ .44 uF

Windshield Washer Motor with X2Y & Enhanced Shielding

November 27, 2000

Presentation by X2Y Attenuators, LLC.
Technology in Balance
Basic Structure Comparison

Regular capacitors have two plates or electrodes surrounded by a dielectric material. There is capacitance between the two conductive plates within the component.
Basic Structure Comparison

As we begin to build the X2Y structure, a ground electrode or shield is added between the two active electrodes within the component and terminated to opposite sides. After adding an additional plate, there is now capacitance between each conductive electrode (electrodes are colored for clarity) and the central shield.
Basic Structure Comparison

However, parasitic capacitance can couple outside the component from the outer unshielded electrodes.
**Basic Structure Comparison**

By adding two additional shields or plates, top and bottom, Faraday cages surround the electrodes and parasitics are trapped within the component. X2Y uses capacitive coupling to charge the internal ground electrodes of the component with opposite charges. This gives a zero potential low impedance path to ground for noise which cancels on the internal image ground plane within the device.
Basic Structure Comparison

When the lines of flux are mapped on a regular capacitor, they protrude off the edges of the capacitor plates, which makes placement to other PC board trace signals critical at high frequencies.

Regular Capacitor Flux Lines
Flux Containment

The X2Y architecture utilizes internal ground planes (shields) to minimize the flux lines from protruding beyond the sides of the device. When the flux lines stay internal to the capacitor, the placement of the X2Y device near other PC board trace signals is not critical at high frequencies.

X2Y Architecture
Basic Structure Comparison

This component has the same disadvantages of a regular capacitor because parasitic capacitance is not eliminated. In an attempt to increase coupling, both hot electrodes are on the same plane, however, cancellation is inefficient because current loops are in series to ground, not 180 degrees out of phase.
Basic Structure Comparison

This feed-thru device has some advantages at higher frequencies at a narrow band because parasitics are minimized, however, feed-thru devices are current limited. Inductance is in series to ground and one device is needed for each line when used for common mode noise.

Surface Mount Chip Feed-Thru

Schematic

Component Layers

Gnd

A

Gnd
**Basic Structure Comparison**

The AVX Lica® current flowing out of the positive plate, returns in the opposite direction along the adjacent negative plate - this reduces the mutual inductance.¹ This device still has stray parasitics because electrodes are unshielded. Furthermore, this device is still in series to ground which hinders further reduction of inductance.

¹ Source: AVX Low Inductance Chip Capacitor Catalog
The X2Y Circuit has many structural advantages:

- Shielding of parasitics.
- Flux containment
- In Bypass, X2Y is not current limited.
- Inductance cancellation (180 degrees out of phase).
- Simultaneous dual line conditioning.
- Common mode and Differential mode filtering
Impedance

When two regular capacitors are placed in parallel, the capacitance adds and the impedance of the PC board ground between the two capacitors will have an effect on their self-resonant frequency.

Two Capacitors In Parallel

\[ \text{PCB Board Ground} \]

C1
C2
**Impedance**

In the X2Y architecture, the ground plates are connected in parallel to each other on either side of the internal image plane to reduce the internal image plane impedance before the device is connected to the PC board ground. The impedance of the internal image plane is in parallel with the PC board ground. Therefore, the impedance of the image plane and the PC board ground is reduced by one half of the smallest value. By reducing the impedance between the two capacitors in parallel, the self-resonance frequency is improved.
Impedance

Impedance models of two standard capacitors in parallel vs. one X2Y circuit.
Grounding Physics

Proper placement of an unbroken ground pad under the device will provide even lower impedance and further reduce noise in the circuit.

Solder Pad Recommendations for X2Y
Grounding Physics

Circuit Test Procedure - (Parallel)

NOTE: injected noise starts from tracking generator to power divider, then is split ½ to A, B to the 1 ohm resistor.

1 ohm OR 50 ohm Resistor Can be used
Grounding Physics

The following graphs will illustrate various ground attachments of an X2Y capacitor. Below are test results showing insertion loss. When X2Y is not grounded there is no effect to the circuit as shown below.
**Grounding Physics**

When only one of the ground terminals (G1) is connected, the X2Y component has a resonant frequency of 300 MHz. Ground electrodes within the component are in parallel, but are in series to the main circuit ground (like a regular cap).
Grounding Physics

When both G1 and G2 are connected, all the ground electrodes of the component are in parallel to each other and the main circuit ground. This effect moves the resonant frequency out approximately 80 MHz. This grounding shows optimum circuit performance on both sides of resonance.

![Diagram of Grounding Physics](image-url)
Grounding Physics

This graph shows that the X2Y component stays capacitive to the circuit well beyond what is normally expected compared to regular capacitors. Power is provided over a broad frequency range well into the microwave band (this test setup was limited to 1200 MHz). Navy tests on a discoidal with X2Y architecture have shown the component to be effective out to 40GHz.
TEM Cell

“The Dual TEM Cell is a Three-Conductor System Which Supports a Pair of Degenerate TEM Modules” *

X2Y Expressed as Two Rectangular Coaxial Transmission Lines (RCTL)

**TEM Cell**

**Model of X2Y Using Two TEM Cells**

(Assume two TEM cells stacked one above the other with the common ground as the image plane)

Common Mode Noise Coupling
- Note: Common mode noise cancels at image plane when capacitors go into self-resonant frequency

Differential Mode Noise Coupling
- Note: Differential mode noise cancels at image plane when currents of IA and IB are 180 degrees out of phase

\[ X2Y = 1 + 2 \]
**TEM Cell**

X2Y modeled as a stacked, dual TEM cell. In this cross section of an X2Y component there are 30 capacitors in parallel within the component but only four terminals on the outside of the component. G1 and G2 are a short to ground when connected (very low inductance mount) and in parallel line to line with the board ground.

**X2Y .1uF**

15 “A” Electrodes

15 “B” Electrodes

31 Gnd electrodes

G1 shown here, G2 on other side
Cancellation of Fields

The X2Y architecture uses image planes (shields), which create rectangular current loops that share a common image plane. The X2Y plates A and B charge the image plane with opposing skin currents. When the currents are common on the image plane and 180° out-of-phase or oppositely charged they will cancel.

X2Y Architecture

![Image Plane (shield) with plates A and B charging the image plane with opposing currents](image.png)
Noise Cancellation

COMMON MODE NOISE

DEFINITION:
Common mode noise (longitudinal) (cable systems in power generating stations). The noise voltage which appears equally and in phase from each signal conductor to ground. Common mode noise will be caused by one or of the following: (1) Electrostatic induction. With equal capacitance between the signal wires and the surroundings, the noise voltage developed will be the same on both wires. (2) Electromagnetic induction. With the magnetic field linking the signal wires equally, the noise voltage developed will be the same on both signal wires. *

DIFFERENTIAL MODE NOISE

DEFINITION:
Interference, differential mode (signal transmission system). Interference that causes the potential of one side of the signal transmission path to be change relative to the other side. *

Common Mode Noise with Regular Capacitors

Two regular capacitors must be sorted for equal capacitance tolerance when manufactured (an extra cost). Two regular capacitors are mounted on the same side of a common ground, the inductance is in series and ground potential of each line can vary widely.


**Differential Mode**

**Differential Mode Noise with Regular Capacitors**

When a regular capacitor is used between lines A and B, filtering of differential mode noise is only effective to the resonant frequency of the capacitor used (narrow band). Additional capacitors of varying capacitance must be added to broaden effective resonant range.
Simultaneous Common & Differential Mode

A structure with X2Y circuitry contains 1 “X” capacitor and two “Y” capacitors in a single component, thereby replacing three regular capacitors with one component that can simultaneously filter common mode and differential mode noise.
**Balanced Capacitance**

Both X2Y and regular capacitors can vary in capacitance between components by as much as 20% when components have a 10% tolerance. However, only one X2Y is needed for two lines, saving a capacitor and capacitance between the Y capacitors within the single component have a very tight tolerance for exceptional balance in line to line applications.

**X2Y**

Capacitance between Internal Y caps varies, 1% - 2.9%

**Regular**

Capacitance between Components varies 20%
*To better understand how a monopole antenna works, let us approach it from this angle. Since the field propagating from a monopole is contained in the capacitance between the monopole element and the counterpoise, let us apply our understanding of capacitance and review what is occurring inside a parallel-plate capacitor.

* Ref: ‘An Intuitive Approach to EM Coupling’ by Vincent Greb  EMC Test & Design, December 1993
Antenna Theory with Regular Capacitors

*How does a capacitor work? Energy is transferred through a capacitor via an alternating electric field. One plate of the capacitor is given a net positive charge and the molecules in the intervening medium align themselves such that a net negative charge is established on the other plate. The first plate is then driven to a negative potential and this information is relayed to the other plate through the dielectric medium. The other plate responds by changing its’ net polarity to positive. This process is repeated periodically and the result is an AC circuit operating at some frequency.

* Ref: ‘An Intuitive Approach to EM Coupling’ by Vincent Greb  EMC Test & Design, December 1993
**Antenna Theory with X2Y**

In the X2Y the two opposite electrode plates A & B have shields around each side of both electrode plates, and are common between them. The counter-posed electrodes between and around the two ‘hot’ plates act as the other plate of a capacitor, creating three capacitors within the X2Y. In this manner, E fields are contained within the part and not allowed to exit into the free space from within the part.
“Dynamic Testing Of A Dual Line Filter For Common And Differential Mode Attenuation using a Spectrum Analyzer”
Seattle & Oregon Chapters

Presentation by X2Y Attenuators, LLC.
November 27, 2000

Seattle & Oregon Chapters

Presentation by X2Y Attenuators, LLC.
Seattle & Oregon Chapters

Presentation by X2Y Attenuators, LLC.

Comparison - Common Mode Measurements - Lines A & B

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<tr>
<th>Frequency MHz</th>
<th>dBuV Insertion Loss</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>-5</td>
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<td>130</td>
<td>-65</td>
</tr>
<tr>
<td>140</td>
<td>-70</td>
</tr>
</tbody>
</table>

- (1) 0.47 uF "X-Cap"
- 7 AMP Dual Line Ferrite
- (2) 0.47 uF "Y-Caps"
- X2Y Chip @ 0.44 uF
- X2Y 0.22 uF Dual Line Discoidal
- Fair-Rite Balun
- (1) 0.47 Cap + (2) 7.5 Inductors

November 27, 2000
Comparison - Differential Mode Measurement - Line A

-55 -50 -45 -40 -35 -30 -25 -20 -15 -10 -5 0

0 100 200 300 400 500 600 700 800 900 1000 1100 1200

Frequency MHz

dBuV Insertion Loss

(1) 0.47 uF "X-Cap"  Fair-Rite Balun
7 AMP Dual Line Ferrite  (1) 0.47 Cap + (2) 7.5 Inductors
(2) 0.47 uF "Y-Caps"  X2Y Chip @ 0.44 uF
X2Y 0.22 uF Dual Line Discoidal
Comparison - Differential Mode Measurement - Line B

-55
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
0
100 200 300 400 500 600 700 800 900 1000 1100 1200
Frequency MHz
dBuV Insertion Loss

(1) 0.47 uF "X-Cap"
7 AMP Dual Line Ferrite
(2) 0.47 uF "Y-Caps"
X2Y 0.22 uF Dual Line Discoidal

Fair-Rite Balun
(1) 0.47 Cap + (2) 7.5 Inductors
X2Y Chip @ 0.44 uF
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- RJ 45 Connectors. Higher operating frequencies are bringing to light many of the shortfalls in today’s filter components, the broadband characteristics of X2Y Technology are offered as a possible solution.
## RJ 45 Connectors

X2Y in high frequency telecom applications meets or exceeds the specifications, the planar format is typically used for high voltage requirements.

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<th>Longitudinal</th>
<th>Metallic</th>
<th>Acceptance Criteria</th>
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<tr>
<td>10/560 mS</td>
<td>N/A</td>
<td>800 V</td>
<td>A</td>
</tr>
<tr>
<td>10/160 mS</td>
<td>1500V</td>
<td>N/A</td>
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<tr>
<td>10/1000 mS</td>
<td>600V</td>
<td>600V</td>
<td>A</td>
</tr>
<tr>
<td>10/360 mS</td>
<td>1000V</td>
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<td>10/1000 mS</td>
<td>1000V</td>
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<tr>
<td>2/10 mS</td>
<td>2500V</td>
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<tr>
<td>2/10 mS</td>
<td>5000V</td>
<td>N/A</td>
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<td>1.2/50 mS</td>
<td>4000V</td>
<td>2000V</td>
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</tr>
<tr>
<td>10/700 mS</td>
<td>4000V</td>
<td>2000V</td>
<td>A</td>
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Acceptance Criteria A: Equipment continues to operate after surge has passed;
Acceptance Criteria B: Equipment may suffer damage but not cause a fire or safety hazard.
RJ 45 Connectors

X2Y can offer three different levels of filtering, depending upon application requirements.
RJ45 Alternative Approaches

Solder Connection Perimeter
Ground on X2Y device to Chassis

RJ45 Metal Housing

50"

Housing Tabs (Ground Connect)

Snap Tabs Holes for Mounting

RJ45 Connector Shell Filtered with X2Y Planar and X2Y chip capacitor

Note: The X2Y Chip devices could easily be mounted inside the shell of the RJ45 connector or on the PCB as shown above. Other interconnect configurations can be accommodated in either the chip or the planar design.

PCB Layout With 0805 X2Y Chip Capacitors

Holes for housing tabs

(.062")

Holes for mounting tabs

165"

Drwg # X2Y 2337
Issue 0
June 20, 2000

Presentation by X2Y Attenuators, LLC.

November 27, 2000
**RJ 45 Connectors**

For lower voltage requirements, such as Ethernet, X2Y MLCC’s can be applied between the pins of a connector to gain better Performance and filtering characteristics while using half of the components normally required.
USB Layout with X2Y Devices

Solder Pads
Insulator
Ground Surface
Connector Pins

Pin Diameter 0.032"
PCB Hole Diameter: 0.036" ± 0.004"
RJ 45 Connectors

A third alternative where lower frequencies are used and EMI problems are less likely to occur, standard MLCC’s can be used to filter on the board.
Filtering Applications – POWER SUPPLY

Here is an illustration of a “drop in” application for X2Y technology. A large ferrite noise suppressor is removed from power cord and replaced with single X2Y component mounted on the board.
Seattle & Oregon Chapters

Filtering Applications – POWER SUPPLY

Comparison - Common Mode Measurements - Lines A & B

ITEM 2000 - April 2000 - on Pg. 102 by Jim Muccioli & Tony Anthony
"Dynamic Testing Of A Dual Line Filter For Common And Differential Mode Attenuation"
“Filtering Capabilities of Various Devices Versus X2Y”
Seattle & Oregon Chapters

X2Y Various Values - Common Mode -
IN A "Real World" Circuit Attenuation Comparison "A+B" TO 1,000 MHZ

- X2Y MOV @ 1.0 nF E05138B
- X2Y X7R 1.0 nF
- X2Y X7R 2.4 nF
- X2Y X7R 10.0 nF
- (2) X2Y Stacked X7R 0.43 uF = 0.86 uF

Insertion Loss DB

Frequency MHz

November 27, 2000

Presentation by X2Y Attenuators, LLC.
Seattle & Oregon Chapters

X2Y Various Values - Common Mode -
IN A "Real World" Circuit Attenuation Comparison "A+B" TO 1,000 MHz

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<th>Insertion Loss (DB)</th>
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</tr>
<tr>
<td>X2Y X7R 2.4 nF</td>
<td>1.0</td>
</tr>
<tr>
<td>X2Y X7R 47 nF</td>
<td>10.0</td>
</tr>
<tr>
<td>X2Y X7R 100 nF</td>
<td>50.0</td>
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<tr>
<td>(2) X2Y Stacked X7R</td>
<td>0.43 μF = 0.86 μF</td>
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November 27, 2000

Presentation by X2Y Attenuators, LLC.
X2Y vs. Regular Film & Regular Electrolytics - Common Mode -
IN A "Real World" Circuit Insertion Loss Comparison "A+B" TO 1200 MHz

-10
-5
0
-100 200 300 400 500 600 700 800 900 1,000 1,100 1,200
Frequency MHz
Insertion Loss (DB)

(2) Std Film Cap - 1 uF
(2) Std Electrolytic Cap -10 uF
(2) Std Electrolytic Cap -100 uF
(2) X2Y Stacked X7R 0.43 uF = 0.86 uF
Seattle & Oregon Chapters

X2Y vs. Regular Film & Regular Electrolytics - Common Mode -
IN A "Real World" Circuit Insertion Loss Comparison "A+B" TO 1,000 MHz

![Graph showing insertion loss comparison between X2Y and regular components.](image)

**Legend:**
- (2) Std Film Cap - 1 uF
- (2) Std Electrolytic Cap -10 uF
- (2) Std Electrolytic Cap -100 uF
- X2Y X7R 100nF
- X2Y X7R 400 nF
- (2) X2Y Stacked X7R 0.43 uF = 0.86 uF

November 27, 2000

Presentation by X2Y Attenuators, LLC.
CAN BUS MECHANIZATION

CAN (ISO 11898 OR SAE J2284) NODE

PROTOCOL HANDLER

82C250/1 8-PIN

0 - 5 Volts
5 KHz to 2

Common Mode Choke**

*Two per bus

50 pF (nominal)
80 pF (MAX)

**S+M B82790-C0475-N240
50 Ohms TO Ground Insertion Loss Data

- X2Y 56 pF (A)
- X2Y 56 pF (B)
- X2Y 56 pF (A+B)
- STEWARD CC2824J502R-00 (A+B)
- STEWARD CC2824J502R-00 (A)
- STEWARD CC2824J502R-00 (B)
148 Ohms Across A +B Insertion Loss Data

Frequency MHz

dB

0 100 200 300 400 500 600 700 800 900 1000 1100 1200

0 5 10 15 20 25 30 35 40 45

STEWARD CC2824J502R-00 (148 ohms)  X2Y 56 pF (148 ohms)
Presented by X2Y Attenuators, LLC.

http://www.x2y.com