X2Y®

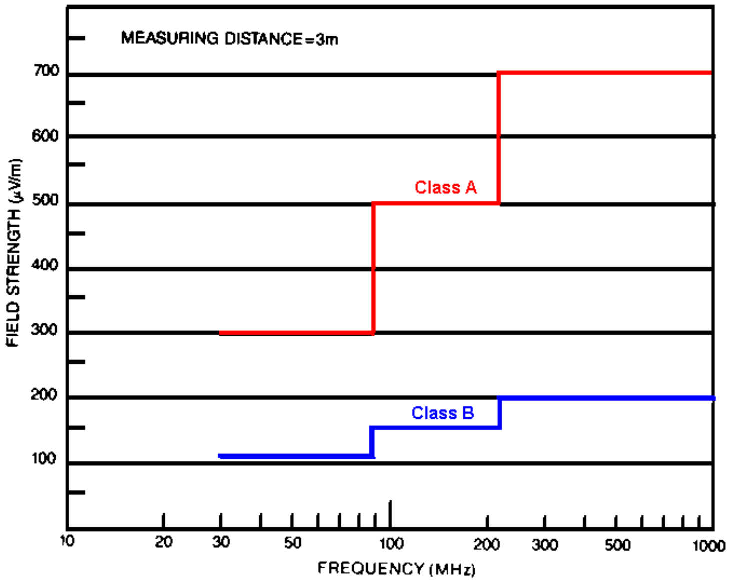
Technology In Balance

Common Mode Filters

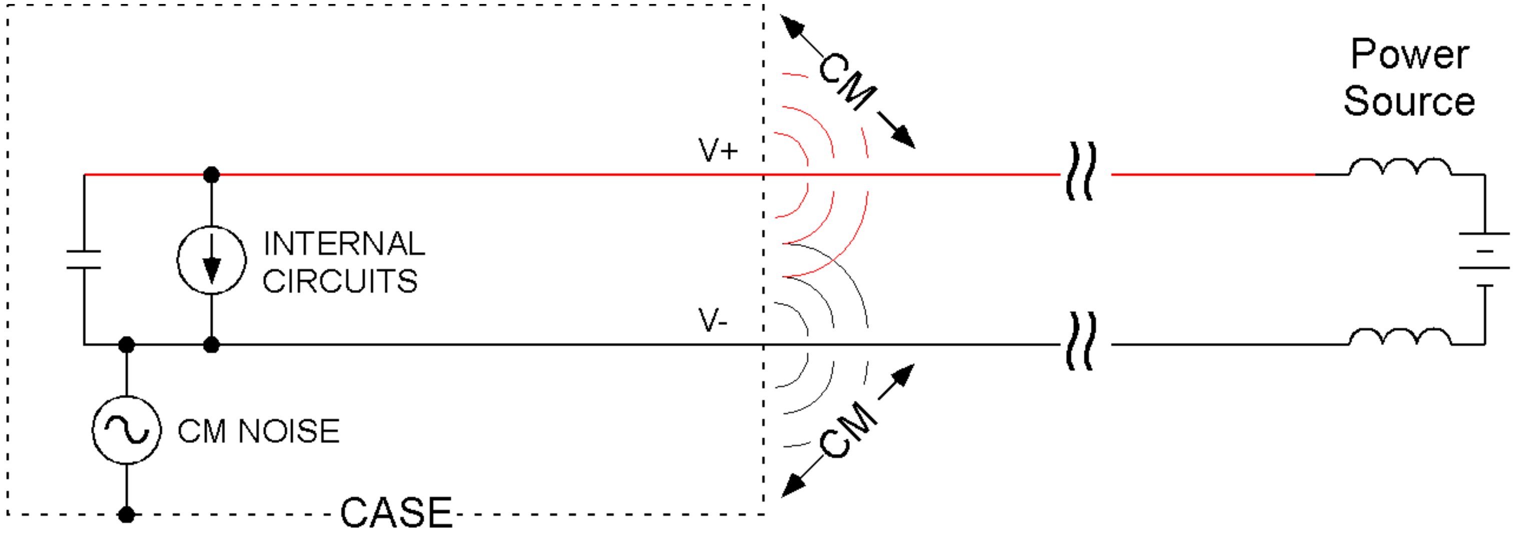
X2Y® versus CM Chokes and PI Filters

Common Mode and EMI

- Most EMI compliance problems are common mode emissions.
- Only 10's of uAs in external cables are enough to violate EMC standards.

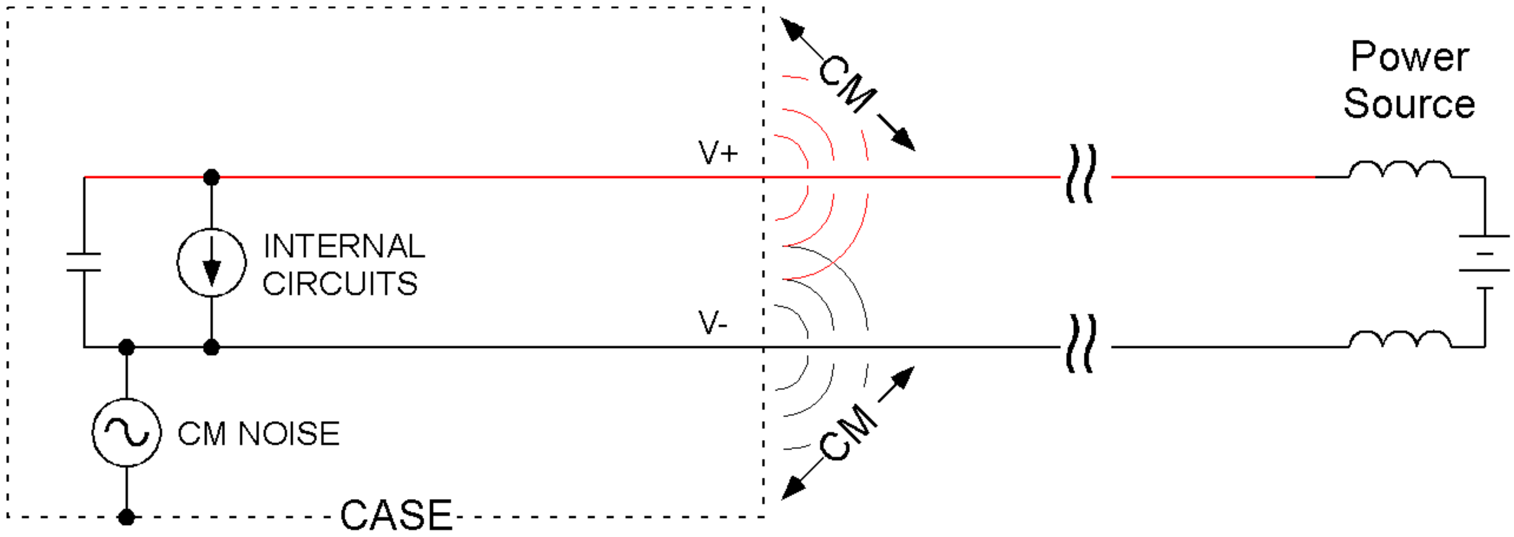


Common Mode Noise Model



- E field developed between any lead exiting a shielded enclosure and the enclosure outer skin radiates.
- Complementary H field couples to victim antennae.
- Ability to radiate depends on:
  - Power in the noise source
  - Coupling efficiency between the effective antenna structure and the surrounding space
    - Leads and case form the antenna

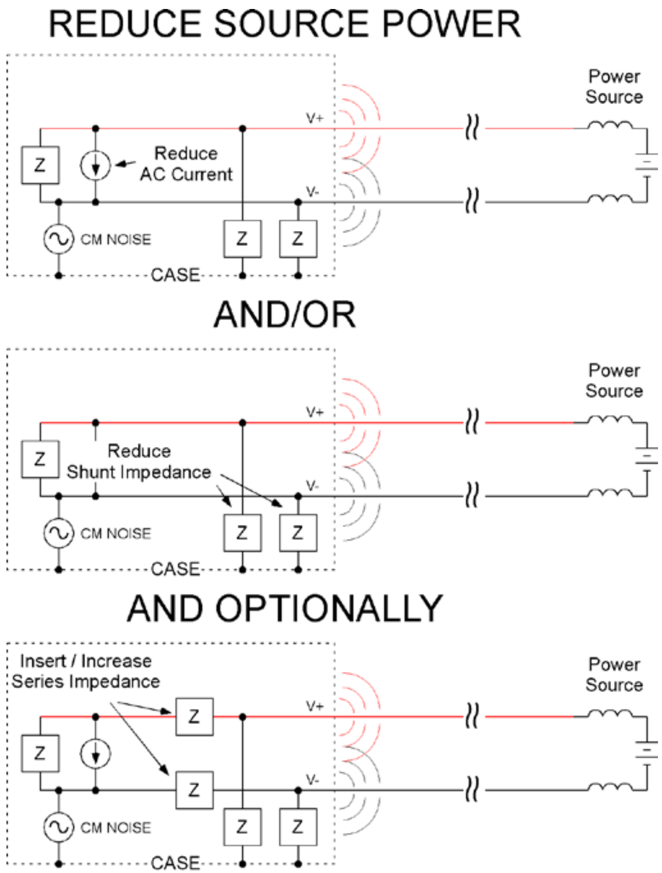
Common Mode Noise Model



- Reduce radiation by:
  - Reducing potential between the case and leads, AND/OR
  - Reducing coupling efficiency to surrounding space
    - Reduce antenna gain.
    - Mismatch source impedance to the antenna impedance.

Reduce CM Source Power

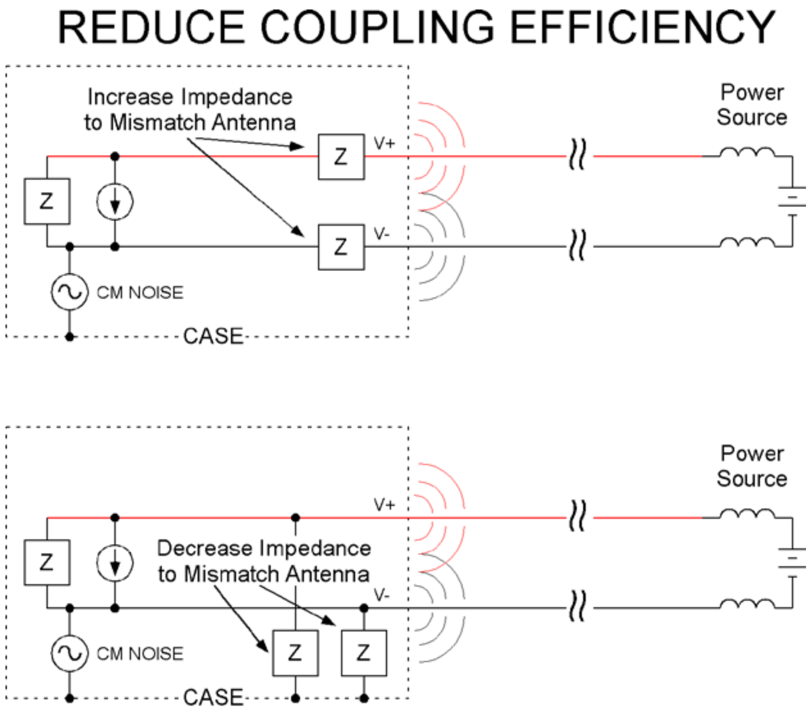
- Reduce HF current in product
  - Rarely an option
- Decrease shunt impedance to case
  - Optionally insert additional series impedance between source and shunt



Reduce Coupling

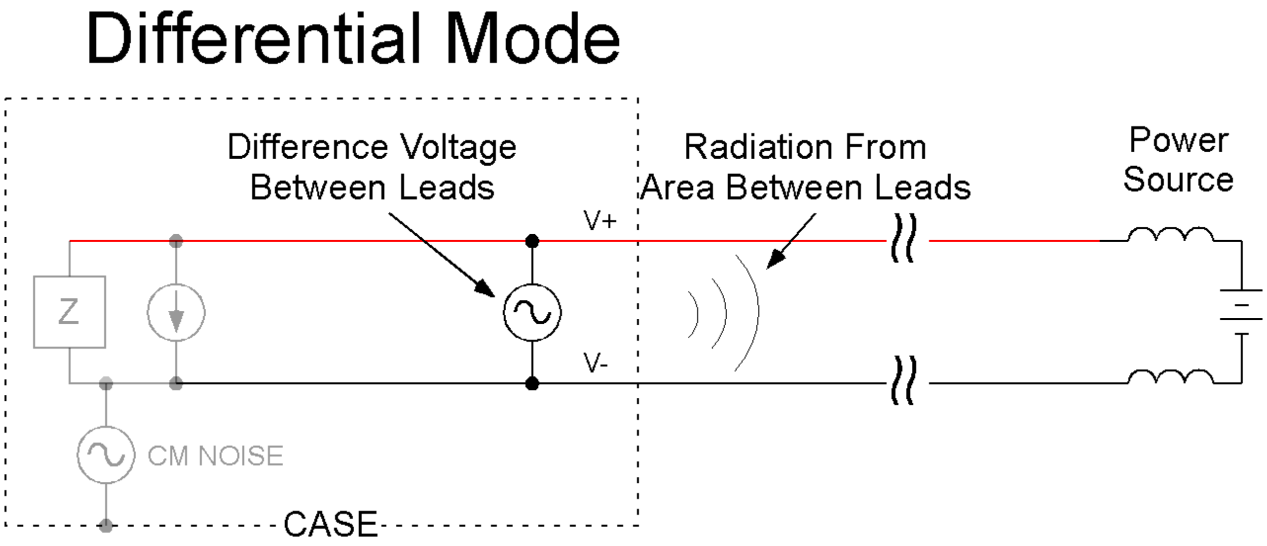
- Reduce antenna efficiency
  - Cable length
  - Cable routing / shielding
- Mismatch antenna impedance
  - Increase driving impedance >> 377 Ohms*
  - Decrease driving impedance << 377 Ohms*

*Antenna impedance may be anywhere from 10's to 100's of Ohms



Differential Noise

- Voltage(s) between multiple leads that form an antenna in the area between.

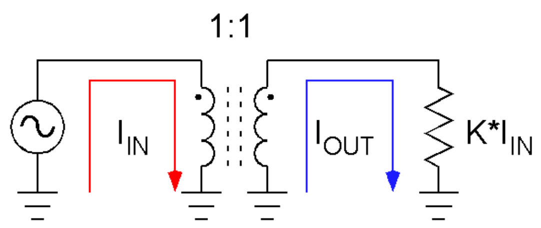


Mode Conversion

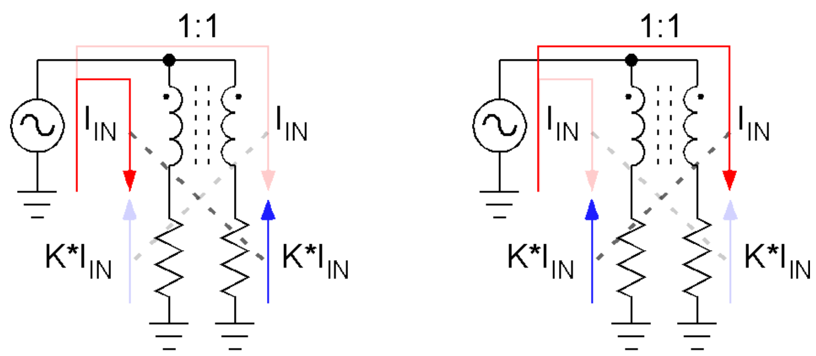
- Occurs when individual filters are not matched.
- Differential signal energy converts into common-mode energy.
- Common-mode energy converts into differential energy.
- Avoid by matching filters throughout stop-band.
- Not an emissions concern where signals do not exist in the noise stop band.
- A susceptibility concern at all frequencies.

CM Chokes as EMI Filters

- Ideally, CM chokes work by increasing the noise source impedance, mismatching it to the antenna.
- A CM choke is a 1:1 transformer where the primary and secondary are both driven.
  - Both windings act as both primary and secondary.
  - Current through one winding induces an opposing current in the **other** winding.
  - For K close to 1.0, effective impedance is:
    - $Z \approx 2\pi F^{*} L_{MAG}$



1:1 Transformer, 0.95 <= K <= 0.99

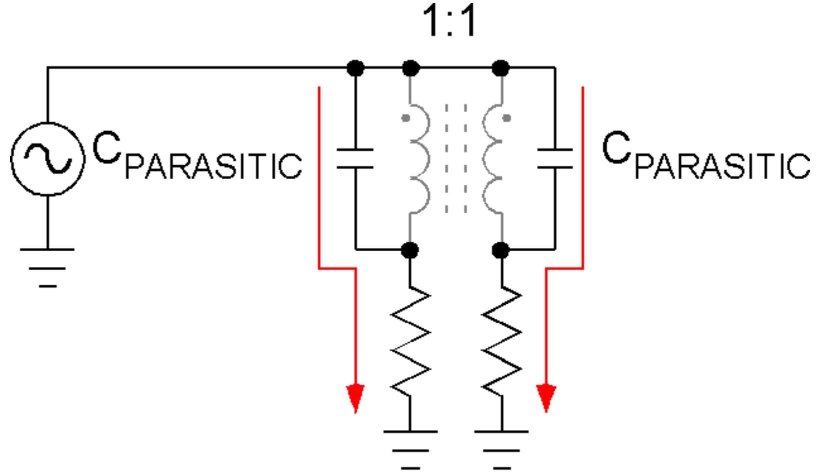


$I_{OUT} = 2^{*}(V_{IN}/Z^{*}(1+K))$

CM CHOKE, 0.98 <= K <= 0.99

CM Chokes as EMI Filters

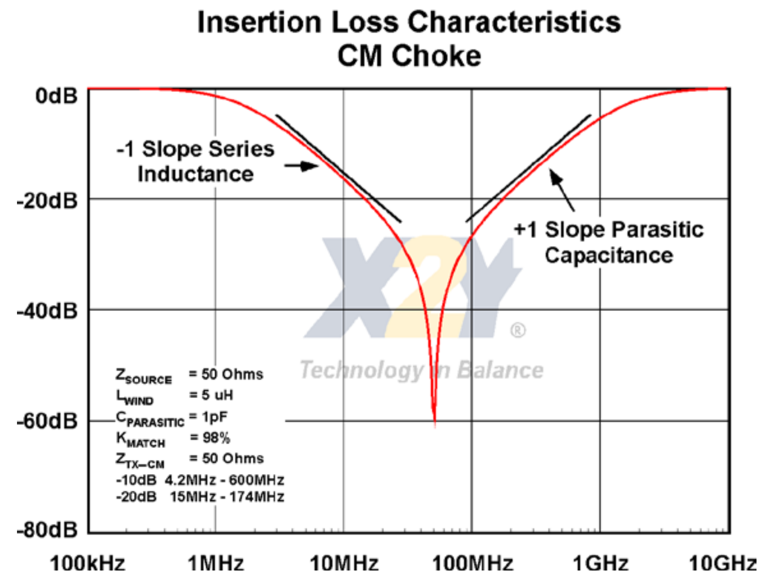
- Real CM chokes work over a limited frequency range due to parasitic capacitance.
- For a given core material, the higher the inductance used to obtain lower frequency filtering, the greater the number of turns required and consequent parasitic capacitance that defeats high frequency filtering.

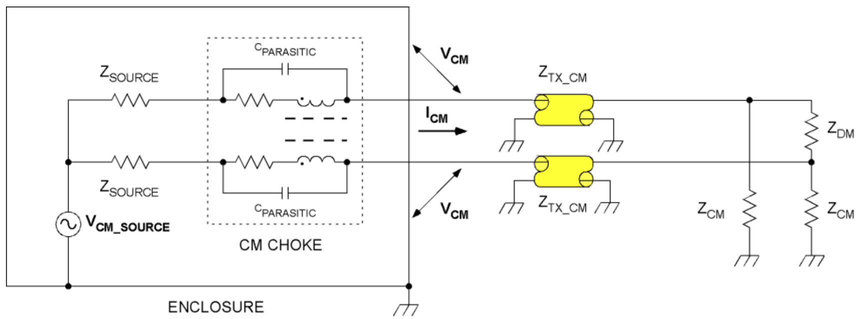


Capacitor current bypasses the transformer coupling. At frequencies > F_{RES} impedance is capacitive and low.

CM Choke Bandstop

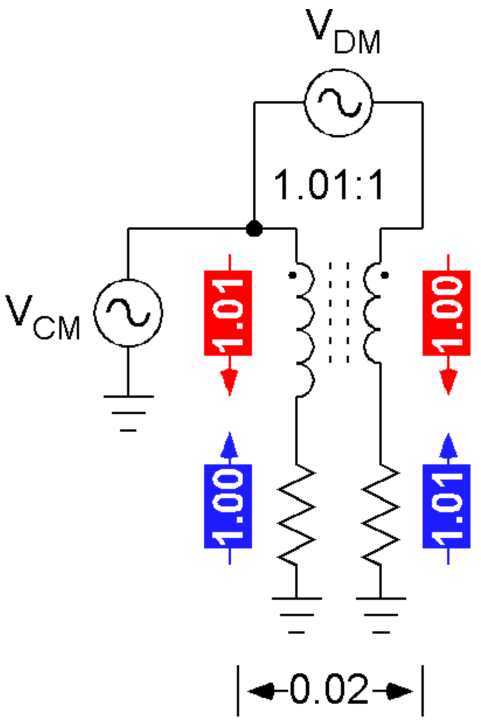
- Insertion loss builds up to F_{SRF} due to series inductance.
- Insertion loss declines past F_{SRF} due to parasitic shunt capacitance.
  - Parasitic capacitance, noise source impedance and lead antenna impedance define high impedance noise attenuation.
  - Parasitic capacitance is combined effects of the CM Choke and the CM Choke PCB mount.
  - Very small capacitances, < 1pF can have very big effects above 100MHz





CM Chokes Winding Mismatch

- Mismatch between windings from mechanical manufacturing tolerance causes mode conversion.
  - A percentage of signal energy converts to common mode, and vice-versa.
  - This gives rise to EMC issues as well as immunity issues.
- Mismatch reduces the effective inductance in each leg.
  - $L_{EFF} \approx L_{MAG} * (1+K_{MATCH})$
  - $0.9 < K_{MATCH} < 0.99$



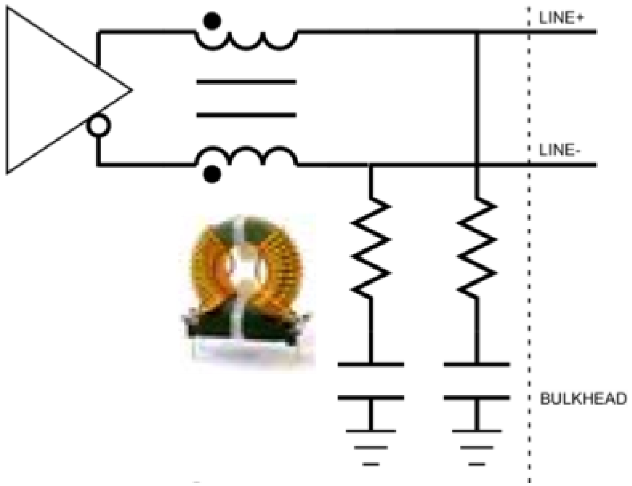
CM to DM /
DM to CM
Conversion

CMCs Stop Band Mode Conversion

- Parasitic capacitance and winding mismatch both defeat inductive cancellation in the stop band causing mode conversion.
- Not a major concern where signal energy is negligible in the stop band.
  - Conditions under which a shunt filter is a viable alternative.

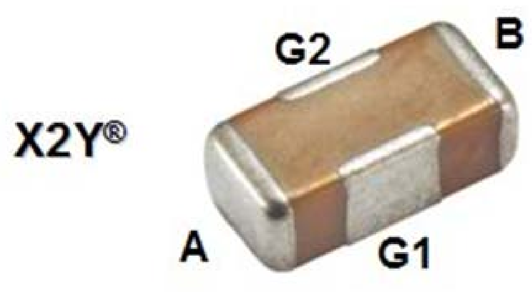
CM Chokes as EMI Filters

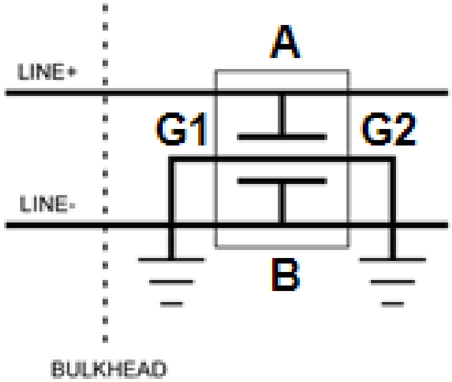
- CM chokes have one really good application:
  - Signals must be passed that operate in the same frequency range as CM noise that must be suppressed.
  - Mode conversion and winding mismatch is a major concern in these applications.
- Otherwise, CM chokes are: large, heavy, expensive, and subject to vibration induced failure.



X2Y® Capacitors, Nearly Ideal Shunts

- Two closely matched capacitors in one package.
  - Effects of temperature and voltage variation eliminated
  - Effect of ageing equal on both lines
- Very low inductance between terminals.

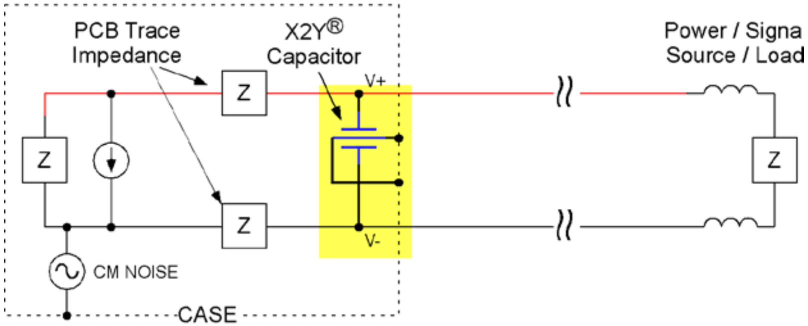




X2Y® Capacitors, Nearly Ideal Shunts

- When properly applied, X2Y® capacitors filter CM noise by ***both*** attenuating source energy, and mismatching antenna impedance.
- The key is very low, and matched inductance.
- Proper application must mind inductance in the common path: G1/G2 terminals.

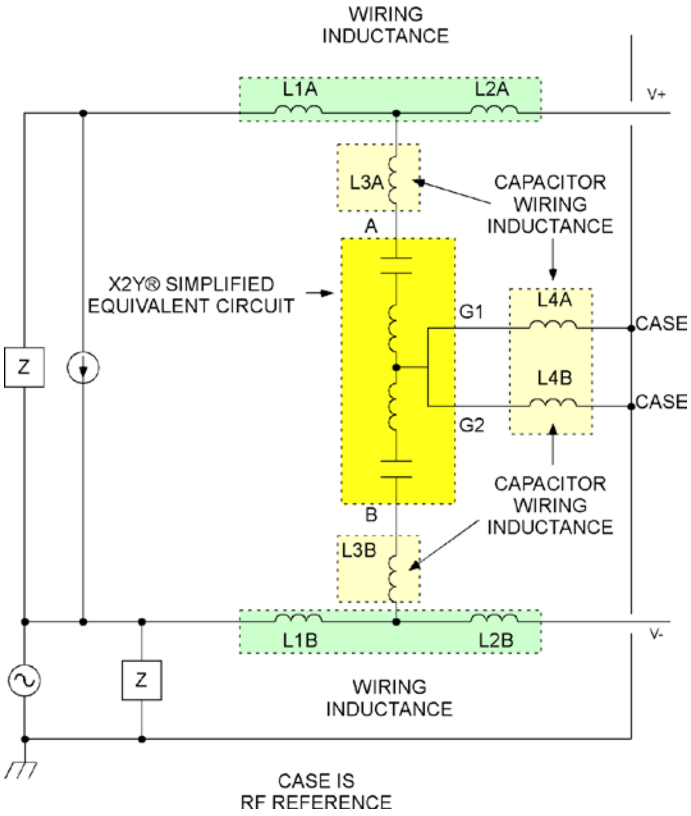
X2Y® Circuit 1 CM Filter



X2Y® Capacitors, Nearly Ideal Shunts

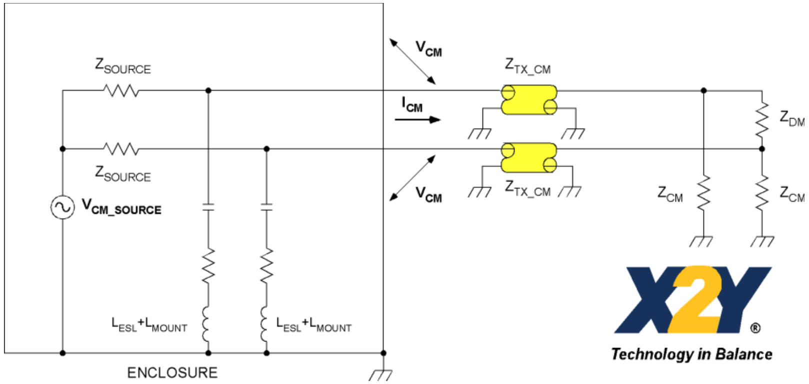
- X2Y® capacitor shunts between A, B, and G1/G2 attachments.
  - Component inductance is very low:
    - ≈110pH from each A or B to G1/G2.
- Low impedance shunt serves two purposes:
  - Divides noise voltage
  - Mismatches external antenna impedance
    - Reflects inside noise back inside
    - Reflects external noise: EFT/ESD back towards outside.
- Performance is typically limited by external capacitor wiring inductance:
  - L3A/L3B, L4A, L4B
  - Minimize w/ best practices
    - See Slides 39-41 for Technique

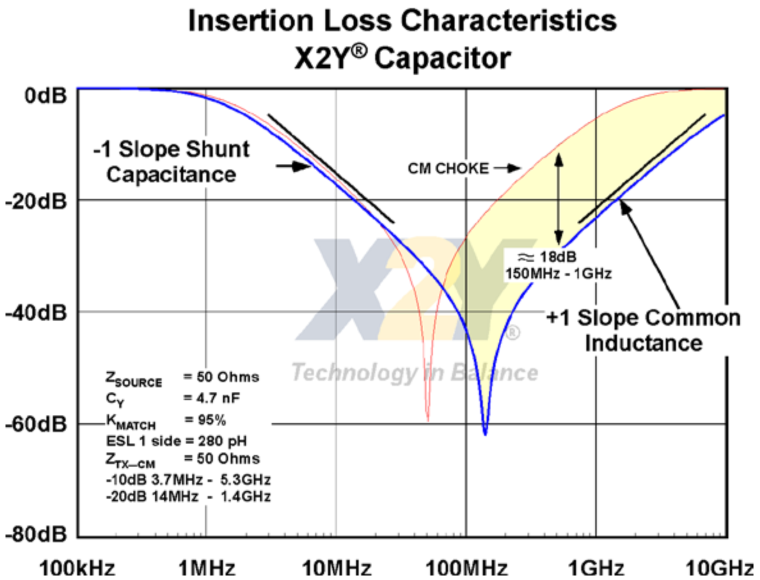
X2Y® Circuit 1 CM Filter



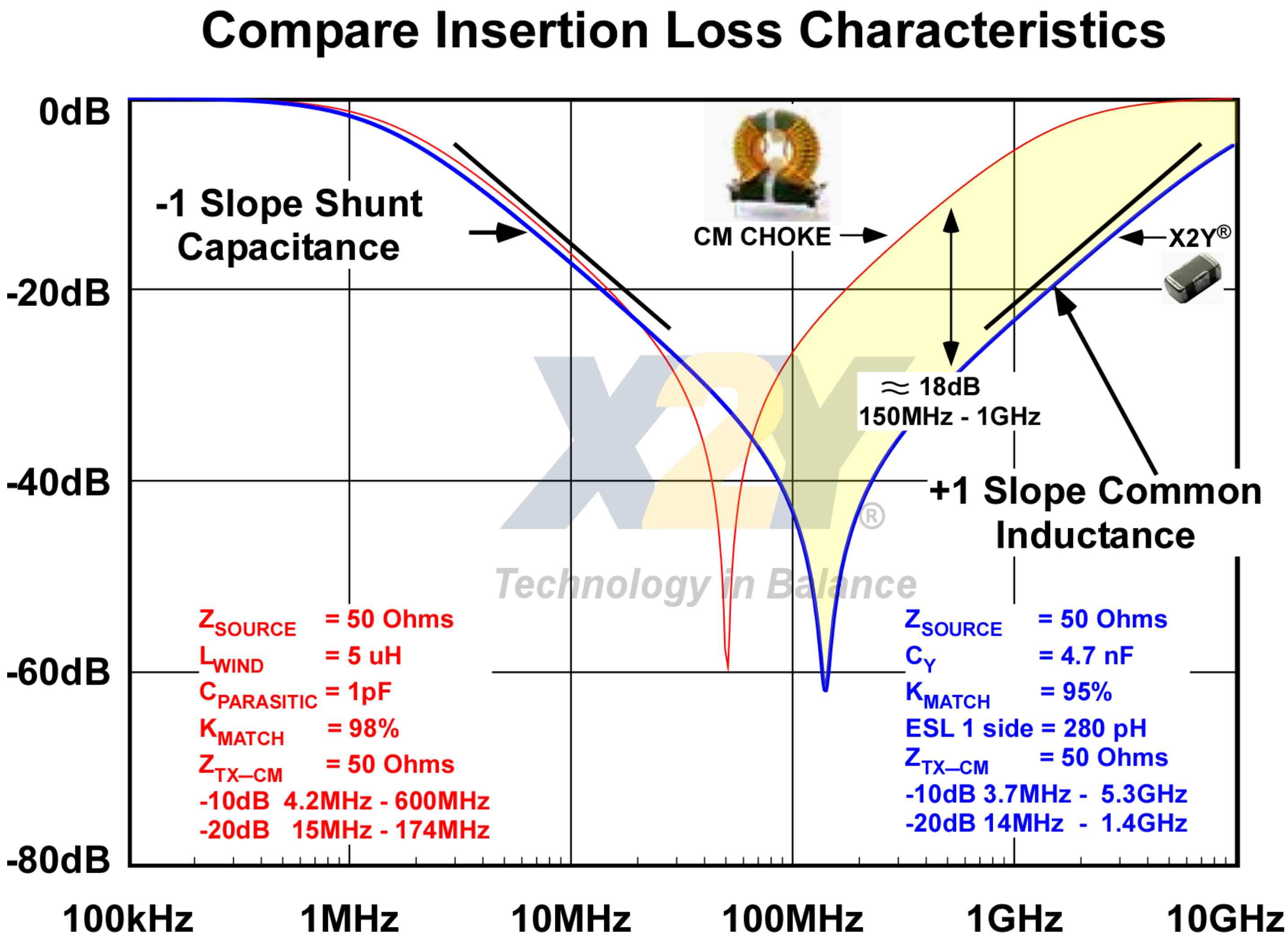
X2Y® Bandstop

- Insertion loss builds up to F_{SRF} due to parallel capacitance.
- Insertion loss declines past F_{SRF} due to parasitic common inductance.
- Y capacitor mismatch reduces insertion loss below $F_{SRF.}$
  - Increases low frequency cut-off by ≈ $2/(1 + K_{MATCH})$
  - $0.9 < K_{MATCH} < 0.99$
  - Generally no concern



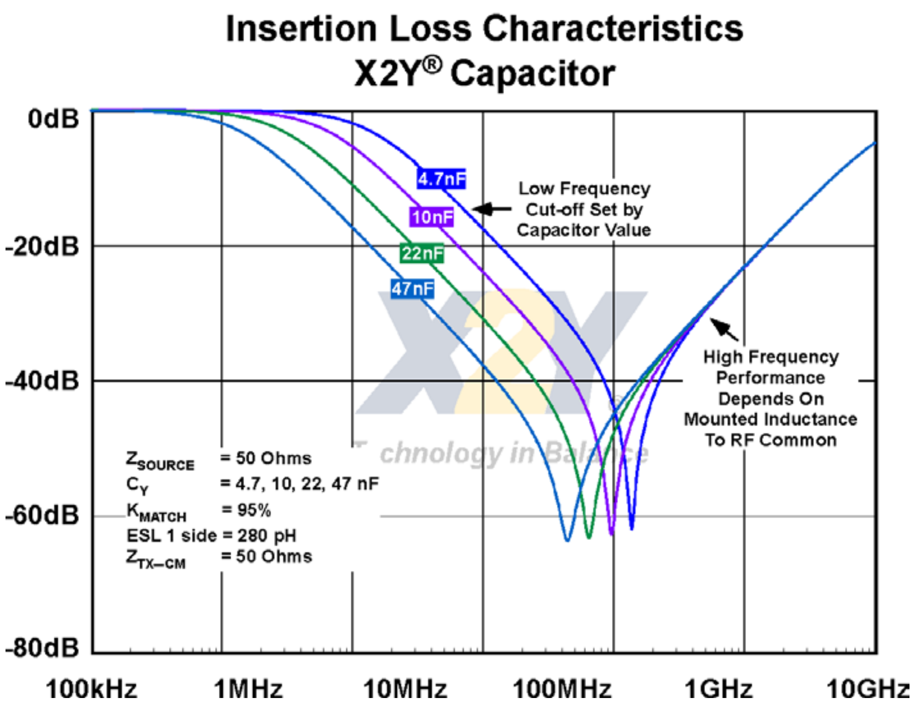


X2Y® vs. CM Choke Bandstop



X2Y® Bandstop

- Low frequency performance determined by source and antenna impedances and X2Y® capacitance.
  - Increase capacitance as required to set filter lower cut-off frequency.
- High frequency attenuation determined by: noise source Z, antenna Z, and mounted capacitor common inductance.
- Unique X2Y® advantage is larger capacitors do not substantially increase common inductance.
  - Larger values simply set wider stop bands.



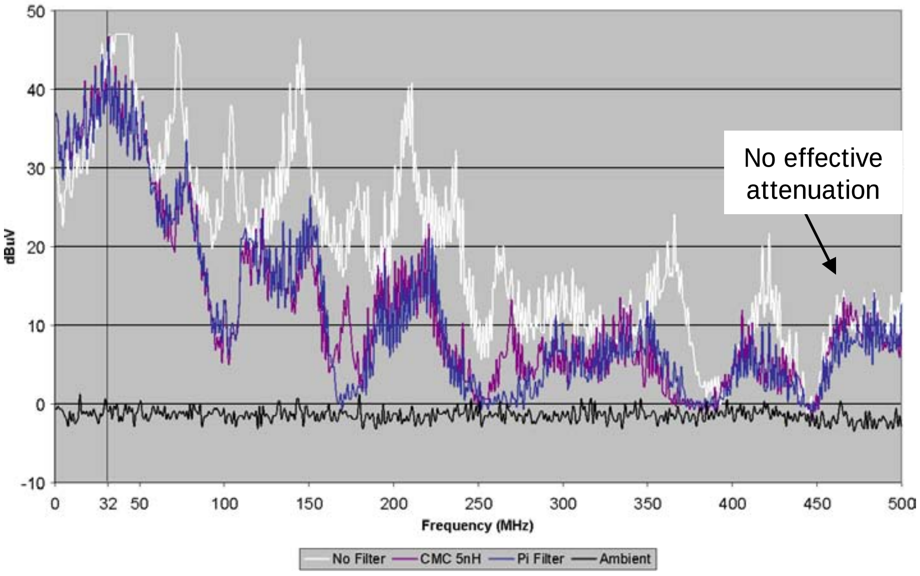
Comparative Performance

- Example, Single Board Computer Power Feed:
  - 68HC11 processor
- 5uH CM choke tested
- PI filter w/ 5uH CM choke tested
  - 0.1uF cap_5uH CM choke_220nF cap
- Seven values of X2Y® capacitors tested
  - 47pF, 100pF, 220pF, 330pF, 470pF, 560pF, 1000pF

Comparative Performance

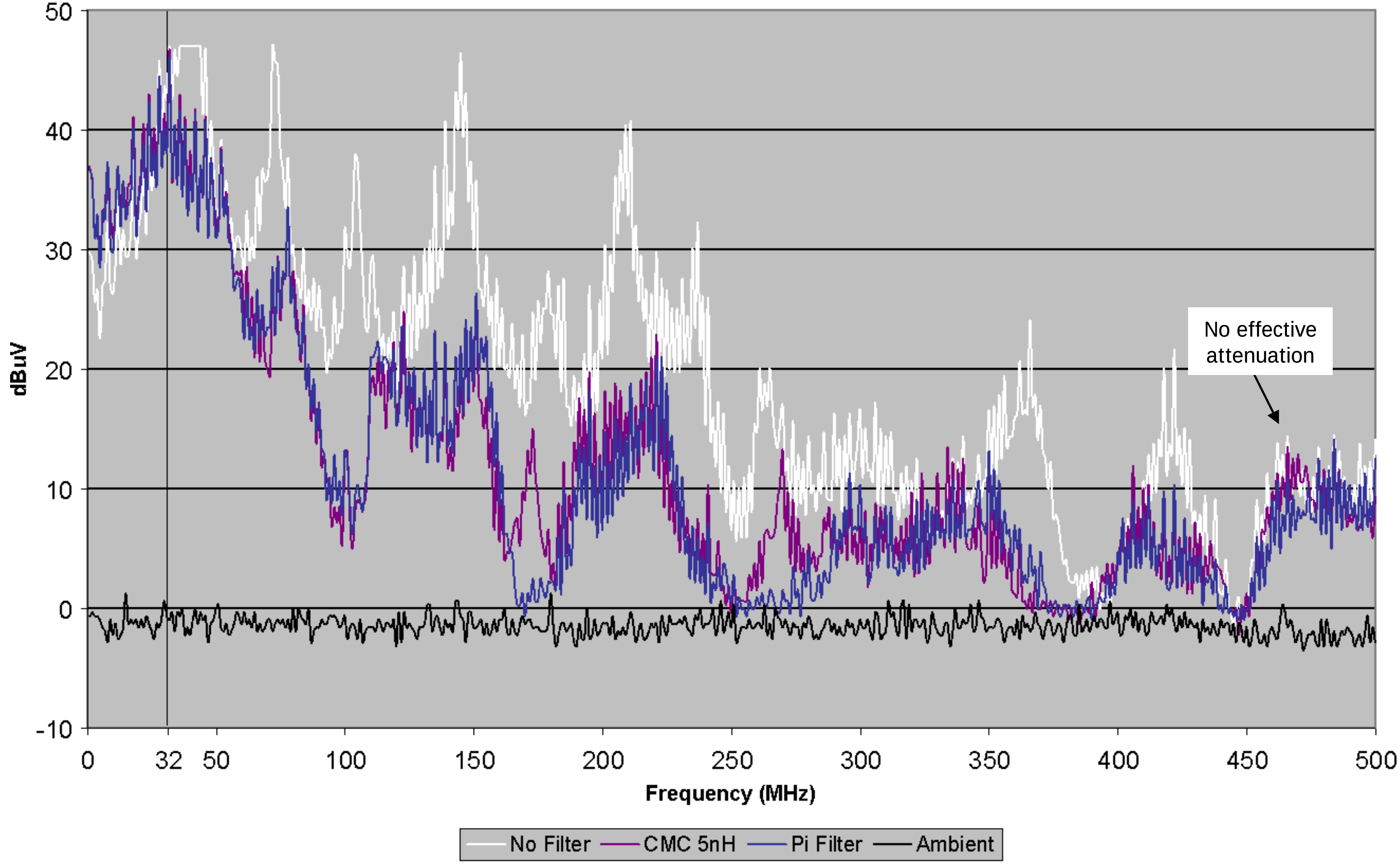
- CM Choke and PI filters both exhibit similar performance
  - Filter cut-off ≈ 32MHz
  - Attenuation effective to about 450MHz
- Parasitic capacitance completely defeats CM choke and PI filter above 450MHz

HC11 (1MHz – 500MHz, CMC and PI)



Comparative Performance

HC11 (1MHz – 500MHz, CMC and PI)

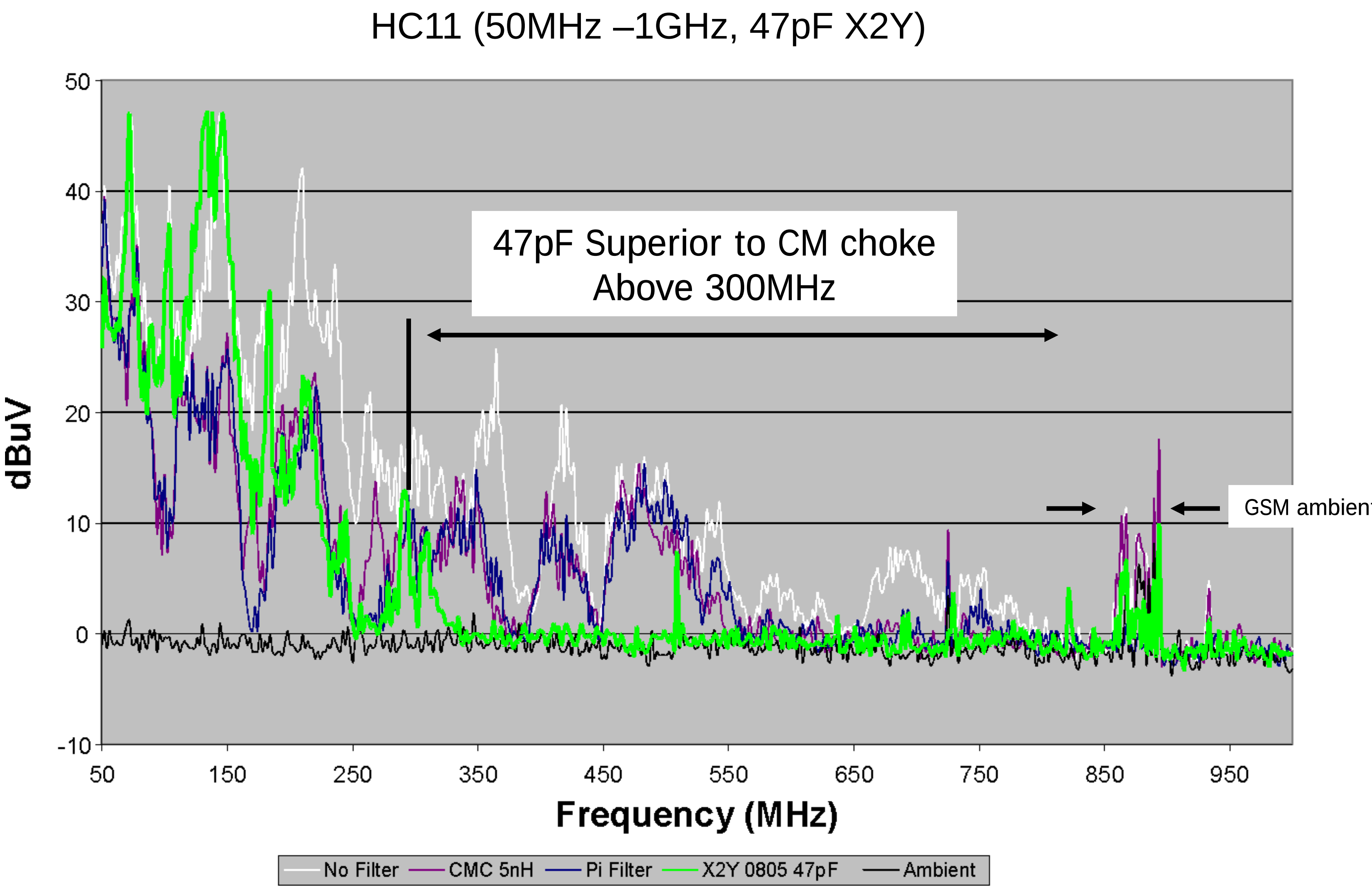


Comparative Performance

Slides 26-34, 50MHz –1GHz:

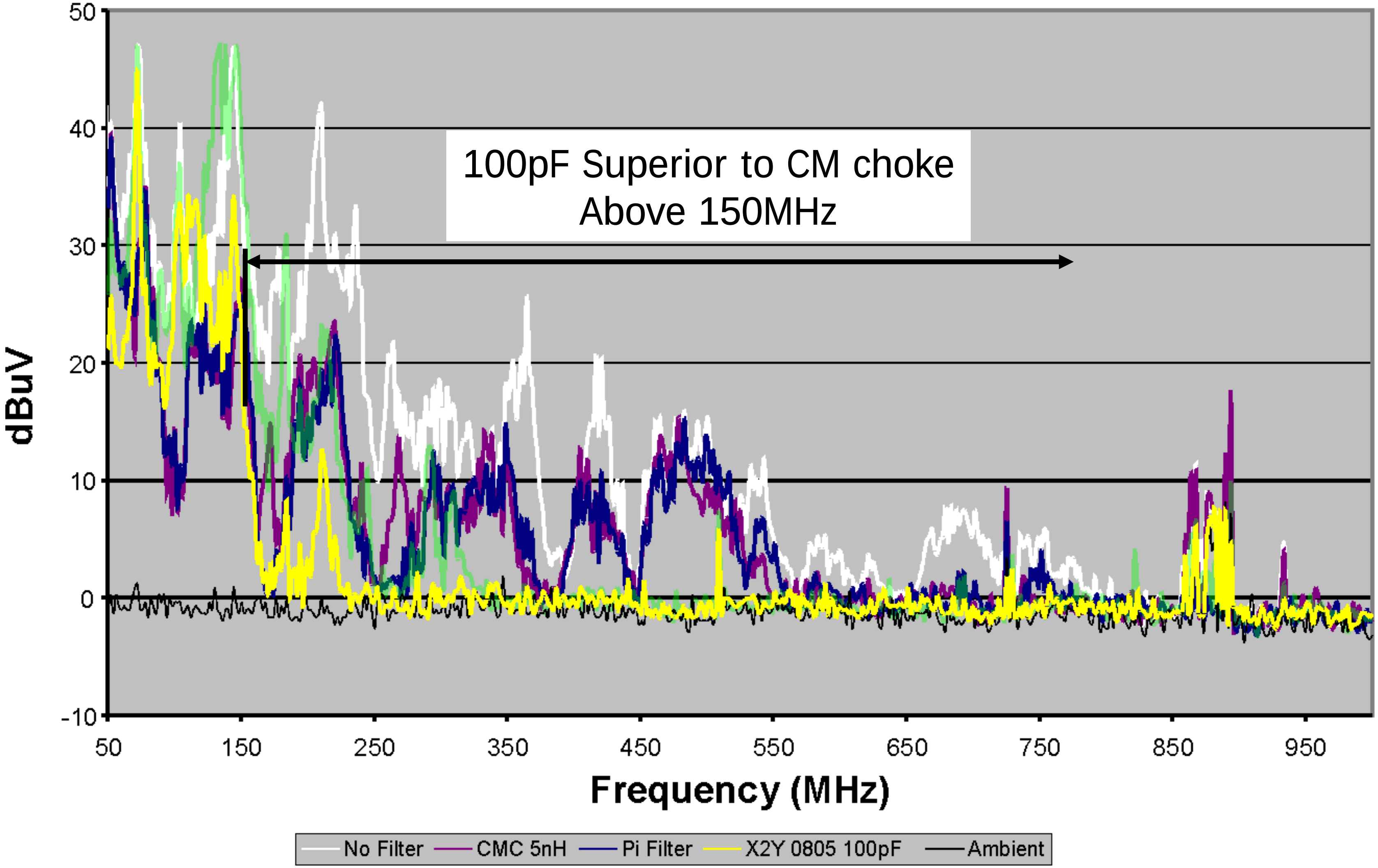
- X2Y® capacitors effective to 1GHz and beyond.
- Capacitance value determines low frequency rejection.
- Very small X2Y® caps (47pF) superior solution vs. CM chokes or PI filters down to 300MHz.
- 470pF and larger X2Y® caps superior over all frequencies.

Comparative Performance



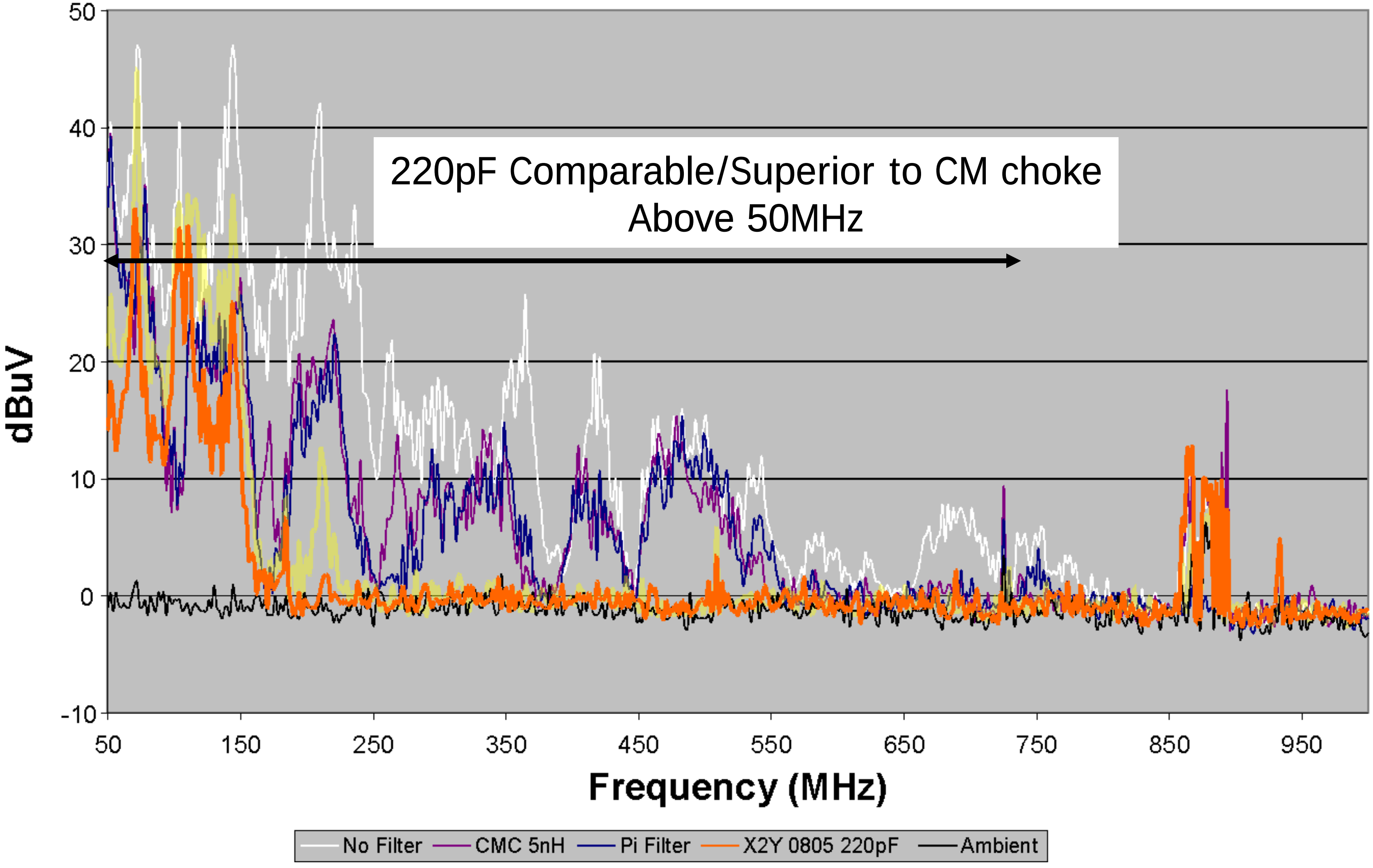
Comparative Performance

HC11 (50MHz –1GHz, 100pF X2Y)

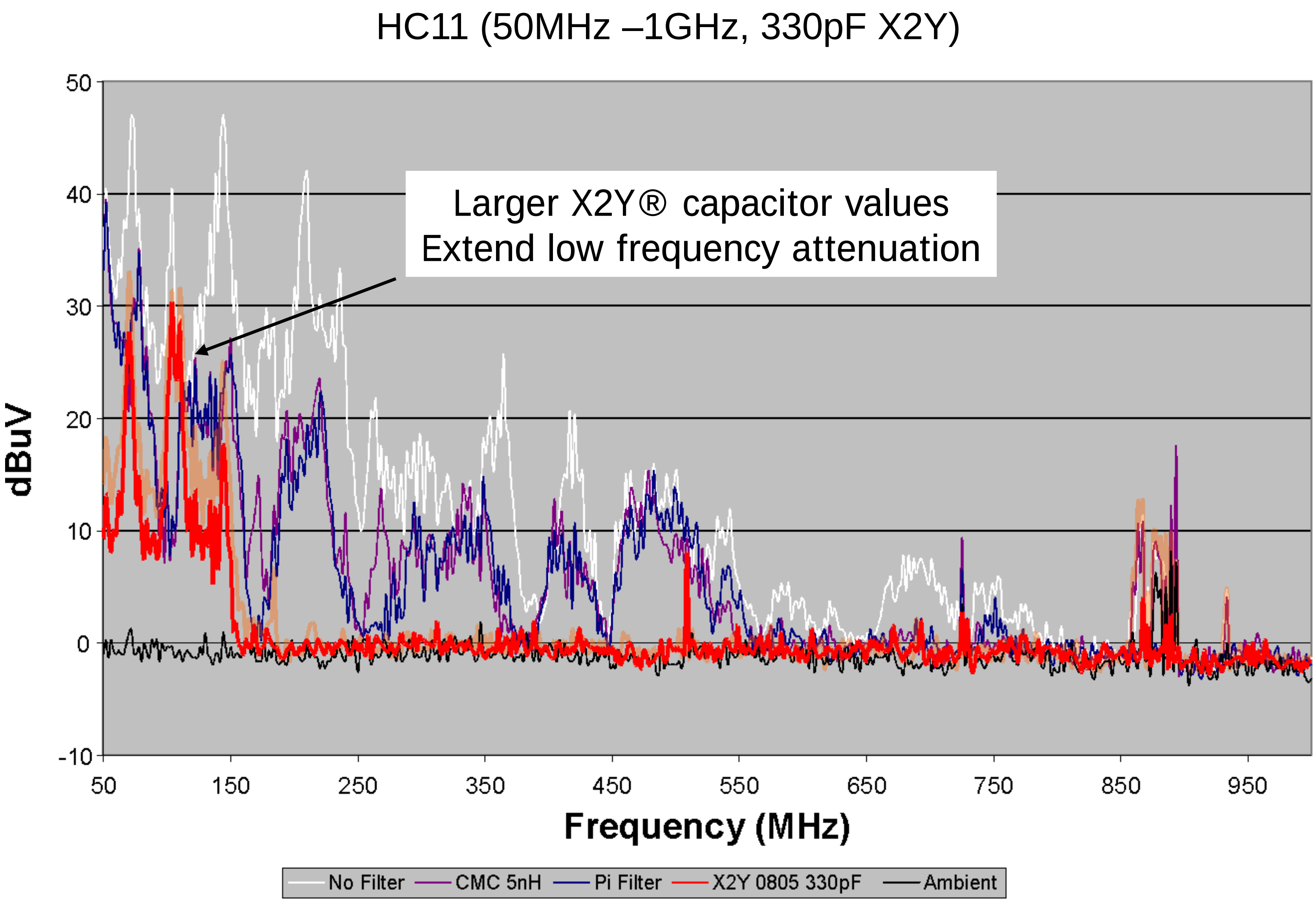


Comparative Performance

HC11 (50MHz –1GHz, 220pF X2Y)

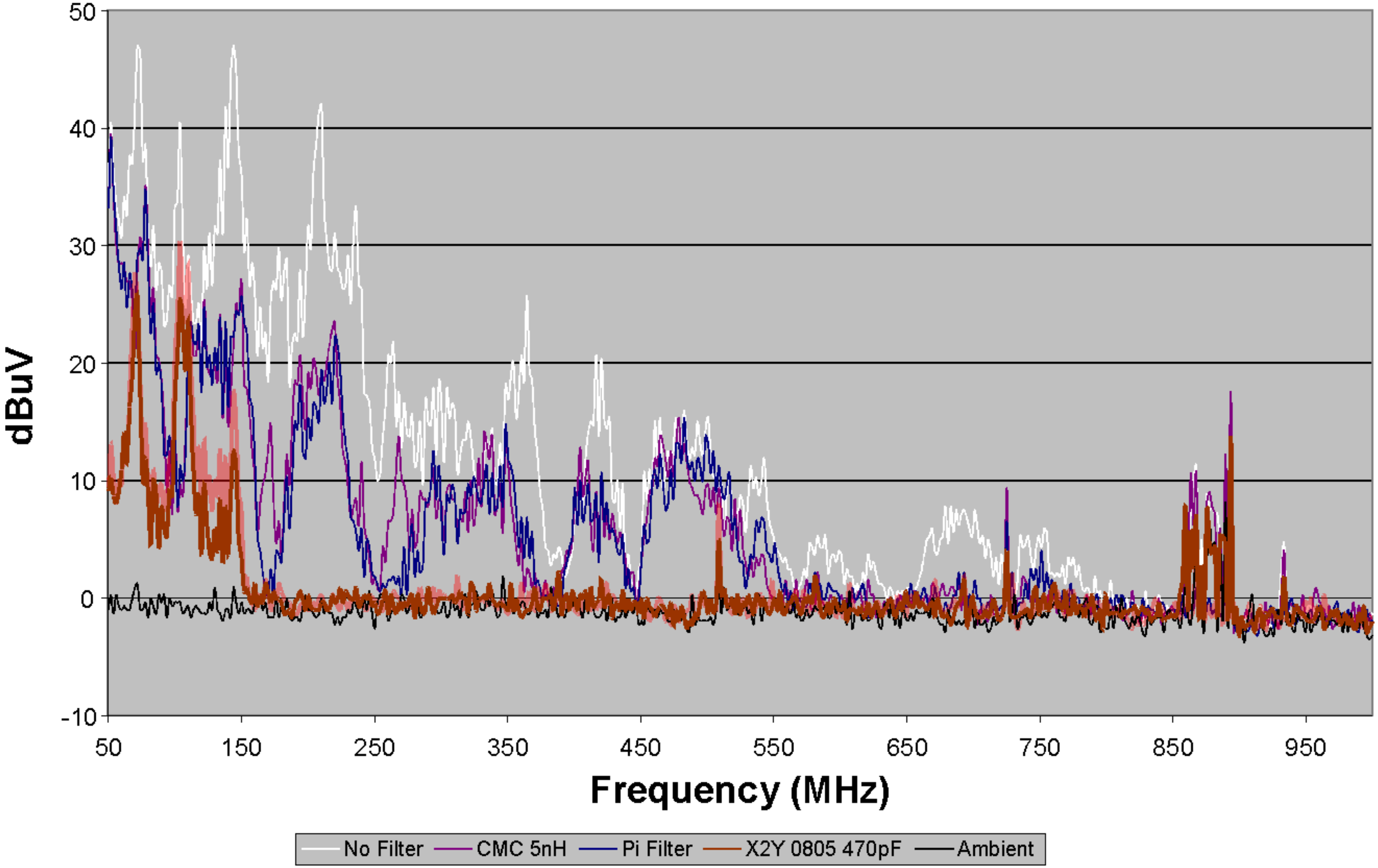


Comparative Performance



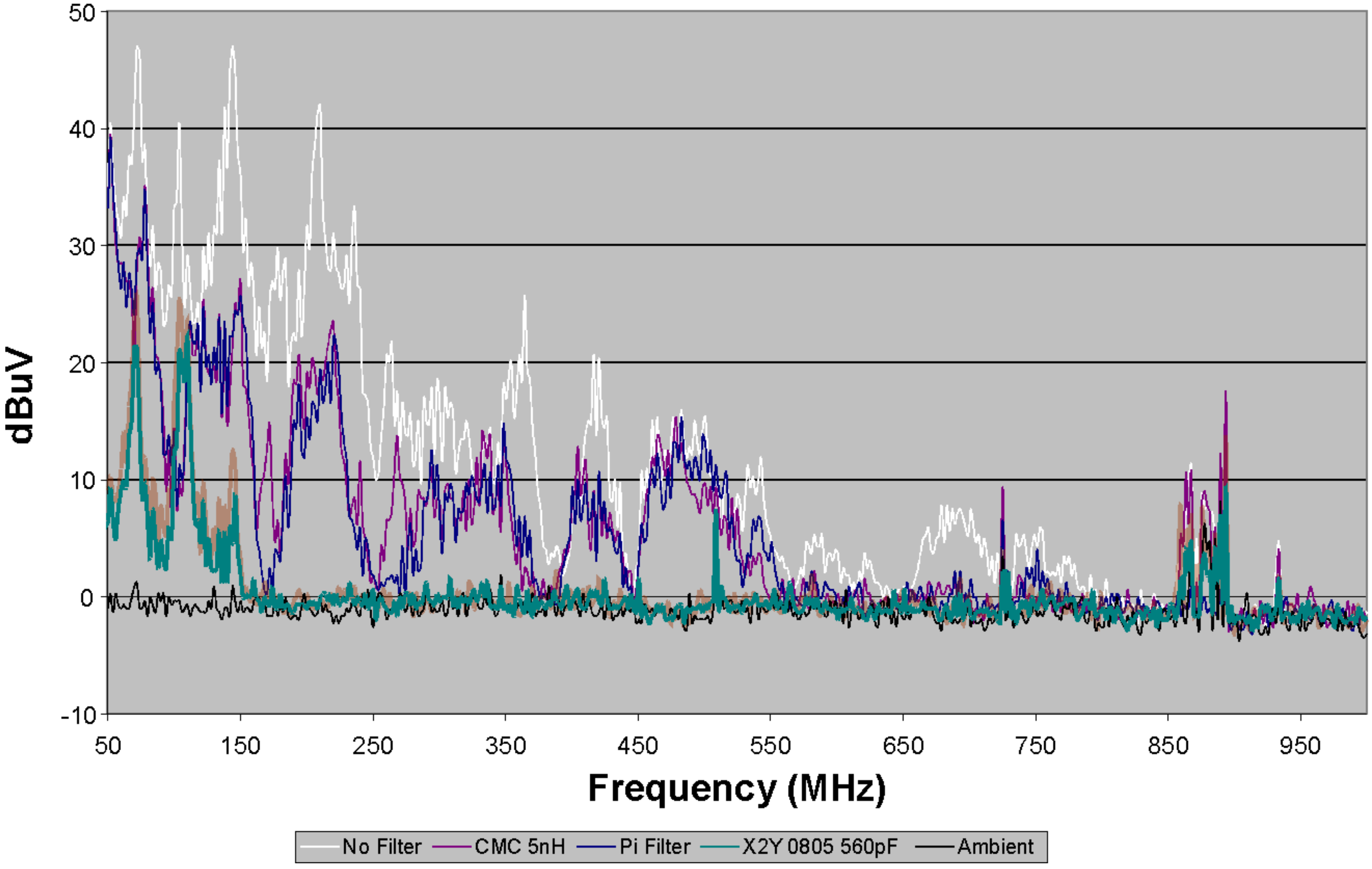
Comparative Performance

HC11 (50MHz –1GHz, 470pF X2Y)

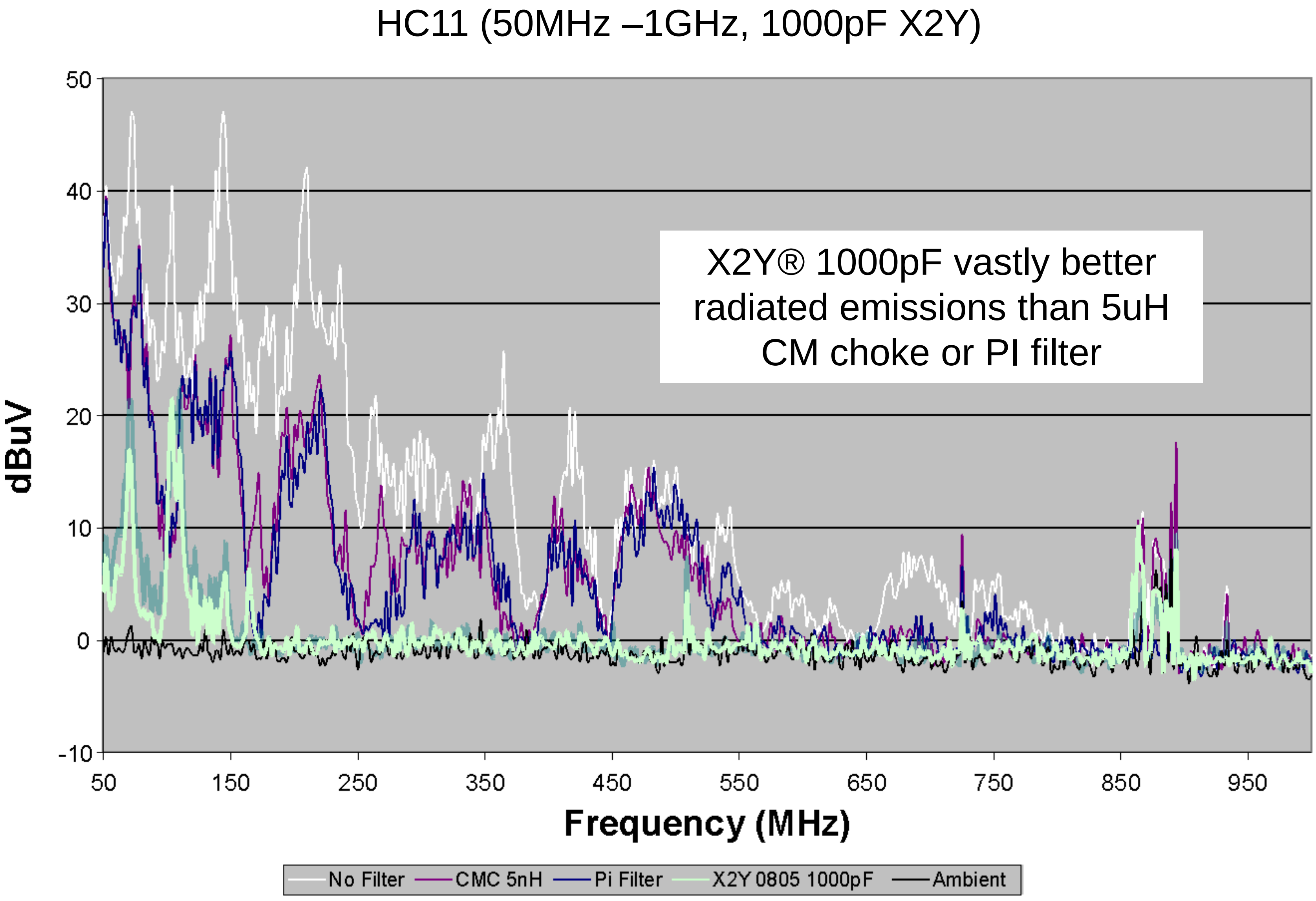


Comparative Performance

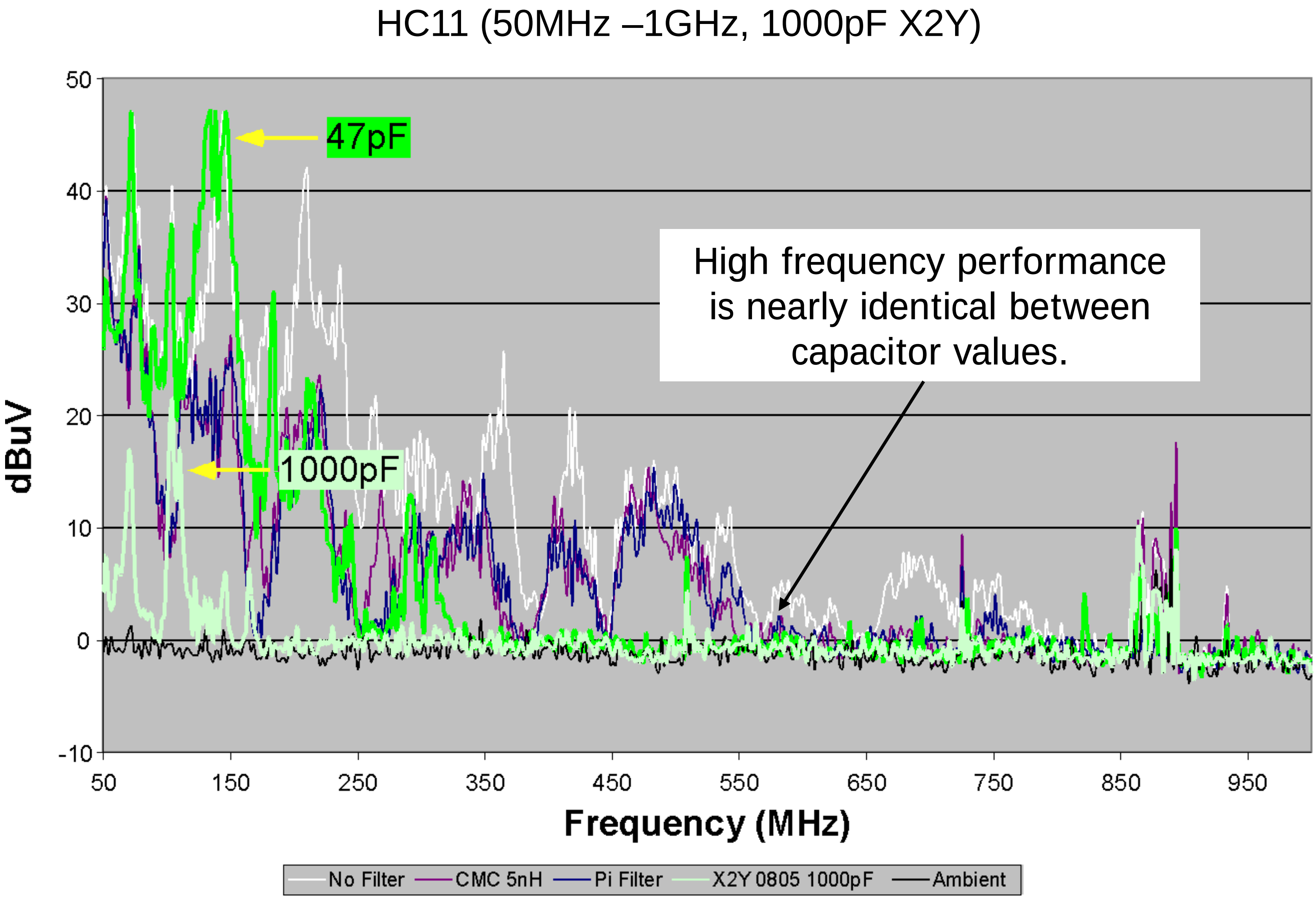
HC11 (50MHz –1GHz, 560pF X2Y)



Comparative Performance



Comparative Performance



X2Y® Capacitor Selection

- X2Y® capacitors operate as shunts.
  - Attenuate all energy above cut-off frequency
  - Select to pass required signal energy / block offensive HF noise.
  - Use capacitance value that is large enough to attenuate effectively to lowest noise frequency, but no larger than necessary.

X2Y® Capacitor Selection Method 1.

- Use Acceptable Signal Rise and Fall Times
- Establish T_{RISE} / T_{FALL}
  - $C <= T_{RISE\_10\%\_90\%\ \_MIN}/(2.2*Z_{SOURCE})$
- Example: CAN BUS 1Mbps, 120 Ohm
  - $T_{RISE\_10\%\_90\%} <= 50ns$
  - Z_{SOURCE} = 120 Ohms / 2 = 60 Ohms
  - C_{MAX} <= 50ns/(2.2*60 Ohms)
  - C_{MAX} <= 380pF
  - Recommended value = 330pF
  - $T_{RISE\_10\%\_90\%} <= 44ns$

X2Y® Capacitor Selection Method 2.

- Pass Signal Rise and Fall Times Based on Signal Bit Rate and % Allowable T_R / T_F

- $T_{RISE\_10\%\_90\%}$ / $T_{FALL\_90\%\_10\%}$ < 5-10% of bit period is usually OK
  - 5%
    - $C <= 1/(44*Bit\_Frequency*Z_{SOURCE})$
    - CAN BUS
      - C <= 1/(44*1MHz*60Ohms) <= 380pF
  - 10%
    - $C <= 1/(22*Freq*Z_{SOURCE})$

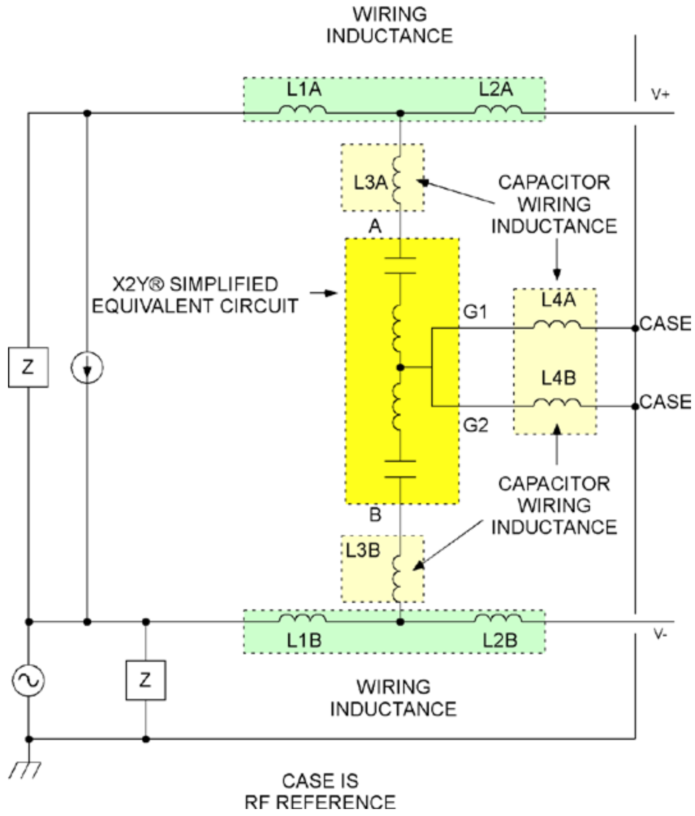
X2Y® Capacitor Selection Method 3.

- Cut Noise Down to a Specific Low Frequency
- Noise cut-off frequency F_{CO} is known, source impedance Z_{SOURCE}.
  - $C \Rightarrow 1/(2\pi * F_{CO} * Z_{SOURCE})$
- Example: Switching power supply harmonic suppression
  - F_{CO} = 2MHz
  - Z_{SOURCE} = transmission line impedance 1 Ohm
  - C_{MIN} >= 1/(2π*2MHz*1 Ohm) = 1/1.26E7 = 80nF
  - Recommended minimum value = 100nF
- Use larger capacitances for lower frequencies and/or lower impedances.

X2Y® Capacitors, Best Mounting Practices

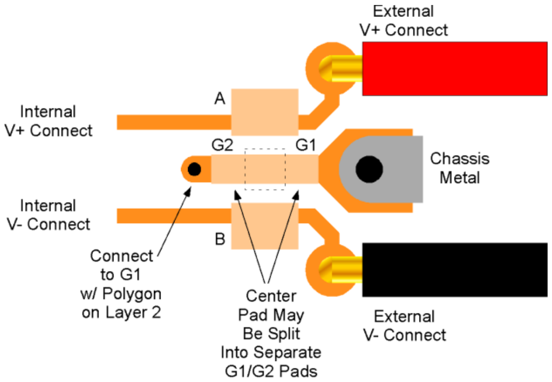
- Performance is typically limited by external capacitor wiring inductance:
  - L3A/L3B, L4A, L4B
- Maximize performance by minimizing L3x, and L4x inductances.
  - Follow X2Y® mounting guidelines.
- L1x, and L2x inductance is OK and even beneficial when balanced.
  - Limitation on L2 is to keep connection close to egress.

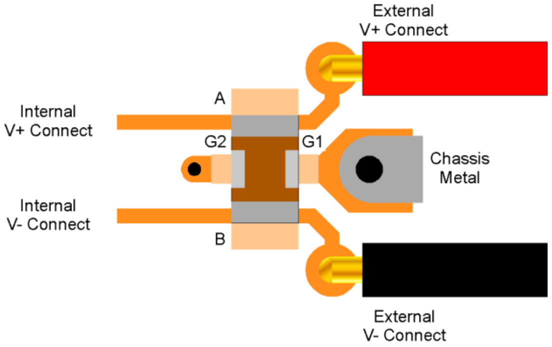
X2Y® Circuit 1 CM Filter



X2Y® Capacitors, Best Practices

- Example, Circuit 1 Mount:
- Minimize, L3A, L3B
  - Connect internal A, B pad connections near base of pads
  - Connect external A, B pad connections near base of pads
- Minimize L4A, L4B:
  - Connect through minimum length, maximum width connections to chassis edge.
  - G1 immediate connection to Chassis metal
  - G2 via to wide polygon on PCB layer 2



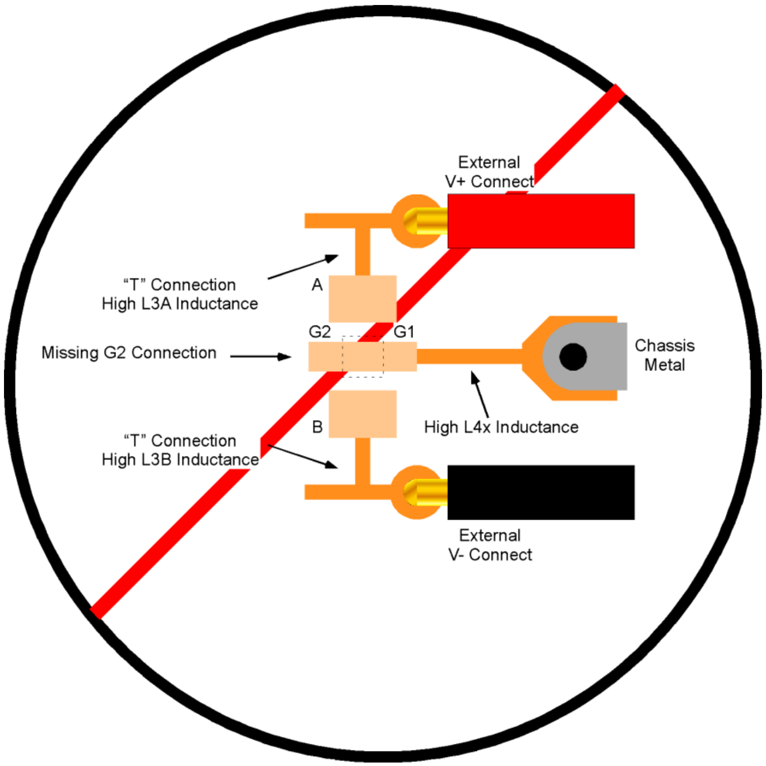


Example X2Y® Layout
Low L3x, L4x

X2Y® Capacitors, Mounting Errors

Example, Circuit 1 Mount:

- AVOID THESE BAD PRACTICES:
  - "T" to A, or B pad connections
  - Leaving G2 unconnected
  - Stringer trace from any pad.
- Any of the above practices insert substantial inductance which impairs performance at high frequency.



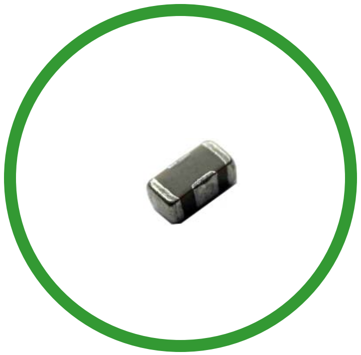
Example X2Y® Layout
Mistakes to Avoid
High L3x, L4x

Summary

- Most EMI problems are Common Mode
- Reduce common mode by attenuating driving voltage and/or mismatching antenna impedance
  - Properly mounted X2Y® caps do both
- Select X2Y® capacitor values based on known source impedance and either:
  - required signal pass-band (sets max value), or
  - required noise stop-band (sets min value)

Summary

- **X2Y®**
  - ✓ Small, Light
    - ✓ In bypass
  - ✓ Lower Cost
  - ✓ Higher Reliability
  - ✓ Lowest assembly cost
  - ✓ Superior HF performance



- **CM Choke**
  - – Large, Heavy
    - ➢ Current runs through
  - – Expensive
  - – Subject to vibration induced failure
  - – Poor HF performance

Thank You

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Company Overview
X2Y Attenuators, LLC is an Intellectual Property Company that develops advanced passive component solutions for the electronics industry. Founded in June 1996, the company is headquartered in Nevada and has engineering offices in Farmington Hills, Michigan and Erie, Pennsylvania.
X2Y Attenuators, LLC is dedicated to helping companies identify applications where X2Y components can improve circuit performance and save money.
Contact Us »
X2Y® Technology
Circuit designers today are challenged with maintaining Signal and Power Integrity amid increasing Electromagnetic Compatibility (EMC) requirements. Patented X2Y® Technology is an enabler to this end; ultra-low inductance X2Y components provide broadband performance for EMI suppression and power bypassing/decoupling applications. In either application use, X2Y improves circuit performance and reduces system cost through passive component reduction.
Technology Summary »
Manufacturing and Distribution
X2Y® capacitor technology is licensed to passive component manufacturers. End-users can then purchase X2Y components just as they would any other passive component, either direct from the manufacturer, or through a wide variety of sales distribution channels. Currently, there are six licensed manufacturers who make and sell X2Y components.
X2Y Manufactures and Distributors »
Technology in Balance
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