X2Y Attenuators, LLC

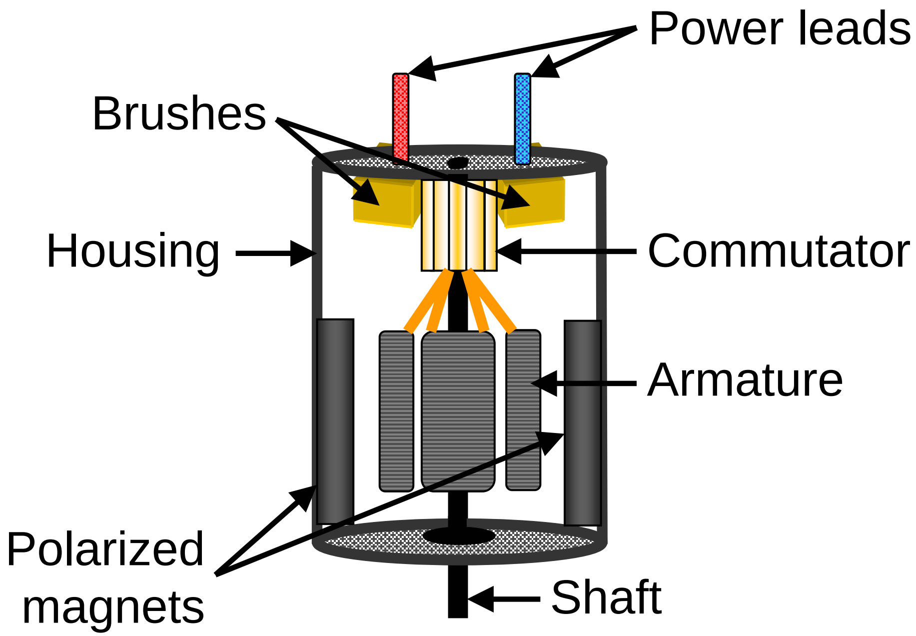
DC Motor EMI Suppression

Presented at Ford Motor Company July 27, 2004
By Jim Muccioli

1. **Why Do DC Motors Need EMI Suppression?**
   - System integration
   - Understanding EMI Noise Sources in DC Motors
   - Compliance with specs.
2. **Designing DC Motors for EMI**
   - Motor Housing Design
   - End Cap Design
   - Connector Design
3. **Applying EMI Suppression to DC Motors**
   - Filtering Elements
   - Building EMI suppression Filters
4. **Filtering Examples**
   - Radiated Emissions
   - Conducted Emissions
   - Transients
5. **Summary/Questions**

- **Integrating increased number of electronic devices and electrical systems in a single automobile fuels Electromagnetic Compatibility (EMC) issues such as:**
  - Reliability
  - Anomalies
  - Functionality
  - Safety
  - Cost
- **Guaranteed EMC requires the suppression of or immunity from electromagnetic noise sources within a system (automobile).**
- **This presentation examines DC motor suppression for EMC**

- **Electrical Current Loop (antenna)**
  - Power leads
  - Brushes
  - Commutator
  - Wire coil around armature stack
- **Brush/Commutator Contact Bounce (arc)**



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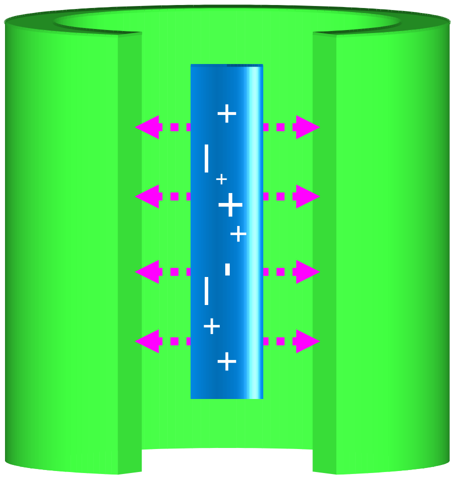

Ford Emissions Requirements (From ES-XW7T-1A278-AC)

Band #	Region	RF Service (User Band in MHz)	Frequency Range (MHz)	Limit A [2] Peak (dBuV/m)	Limit B Quasi Peak (dBuV/m)
M1	Global	--	30 - 75	52 - 25.13*Log(f /30)	62 - 25.13*Log(f /30)
M2	Global	--	75 – 400	42 + 15.13*Log(f /75)	52 + 15.13*Log(f /75)
M3	Global	--	400 - 1000	53	63
EU1	Europe	Long Wave	0.15 - 0.28	n/a	41
G1	Global	Medium Wave (AM)	0.53 - 1.7	n/a	30
NA1	North America	DOT 1 (45.68 - 47.34)	45.2 – 47.8 [1]	12	24
G2	Global	4 Meter (66 – 87.2)	65.2 – 88.1 [1]	12	24
JA1	Japan	FM 1 (76 – 90)	75.2 – 90.9 [1]	12	24
G3	Global	FM 2 (87.5 – 108)	86.6 – 109.1 [1]	12	24
G4	Global	2 Meter (142 – 175)	140.6 – 176.3 [1]	12	24
EU2	Europe	TV, DAB 1 (174.1 – 240)	172.4 – 242.4 [1]	12	24
G5	Global	RKE, TPMS 1	310 - 320	20	30
G6	Global	RKE , TPMS 2	429 -439	25	30
G7	Global	TV	470 - 890	24	32
G8	Global	GPS	1567 - 1574	50 - 20664*log(f /1567) [3,4]	n/a
			1574 - 1576	10 [3,4]	n/a
			1576 - 1583	10 + 20782*log(f /1576) [3,4]	n/a
NA2	North America	SDARS	2320 - 2345	25	n/a
G9	Global	Bluetooth	2400 - 2500	25	n/a

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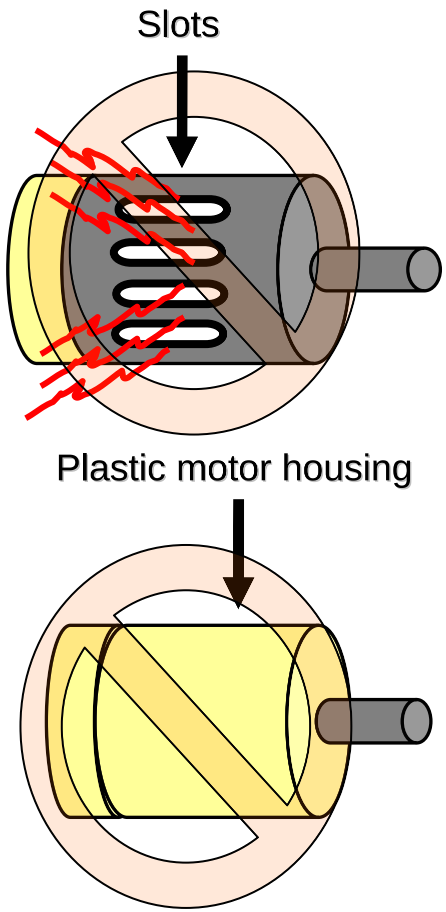
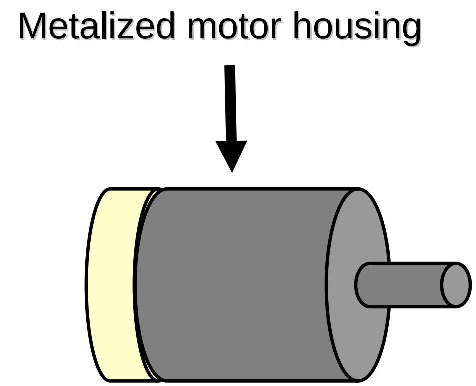
   - Compliance with specs.
2. **Designing DC Motors for EMI**
   - Motor Housing Design
   - End Cap Design
   - Connector Design
   - Metal Joint Design
3. **Applying EMI Suppression to DC Motors**
   - Filtering Elements
   - Building EMI suppression Filters
4. **Filtering Examples**
   - Radiated Emissions
   - Conducted Emissions
   - Transients
5. **Summary/Questions**

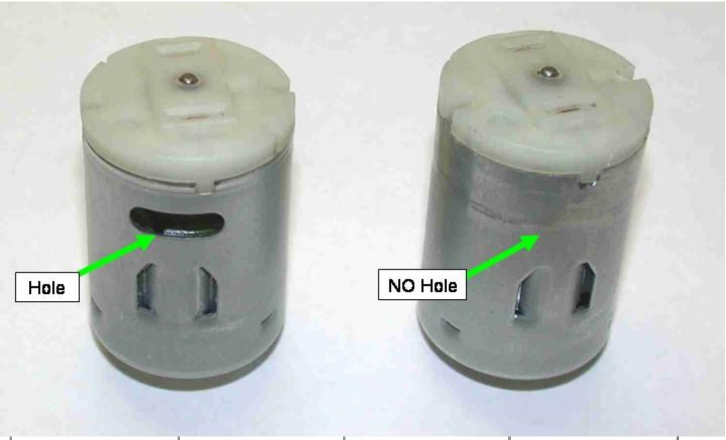
- **Housing should be metal or metalized to provide shielding.**
- **Slots should be eliminated or minimized to keep from making them “slot antenna”.**

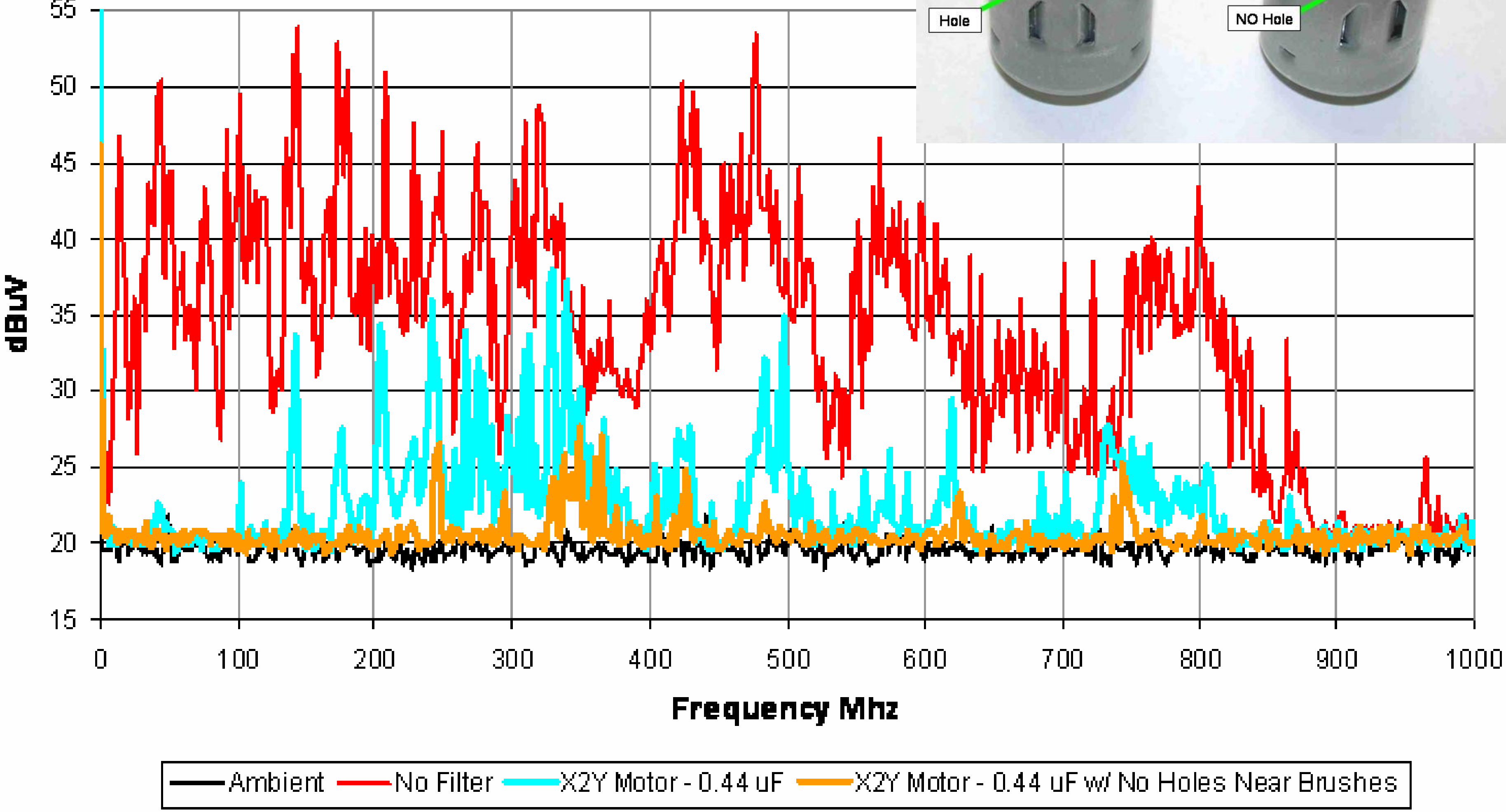




Improved

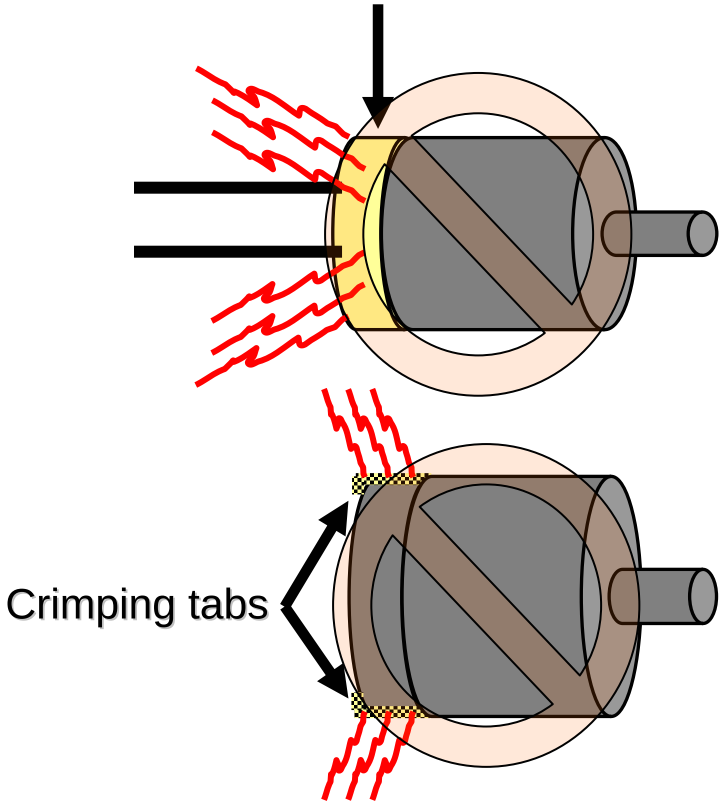
Motor Housing Design (Example)



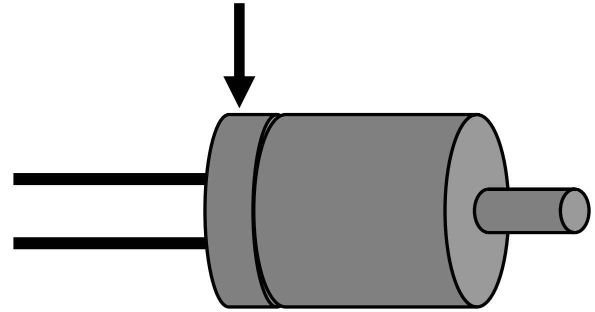


- **End caps should be metal or metalized to provide shielding.**
- **Crimping tabs should not electrically connect inside and outside surfaces.**

Noise can couple outside the motor case when using a plastic end cap.



A metal end cap works as a shield to contain the noise within the motor case.



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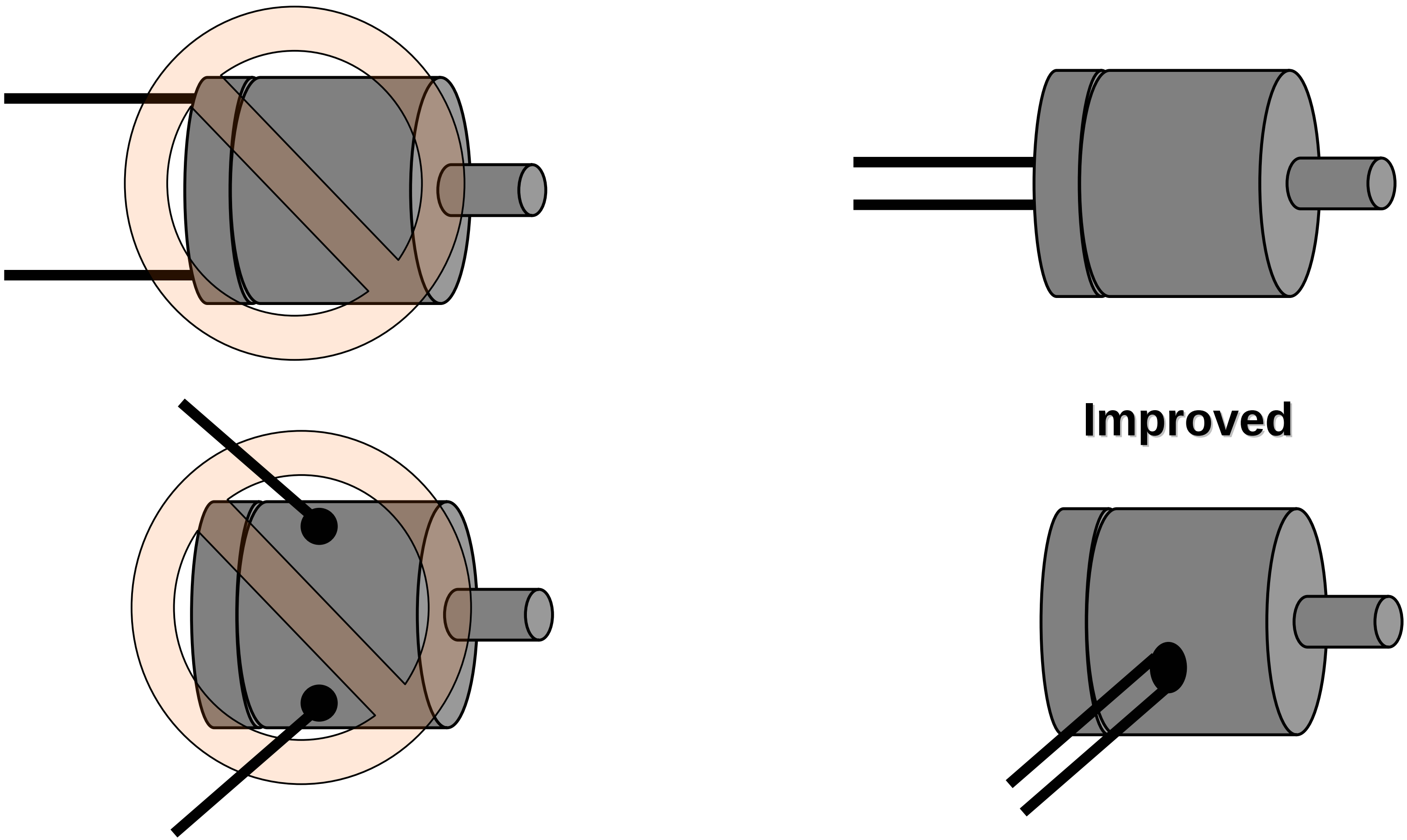
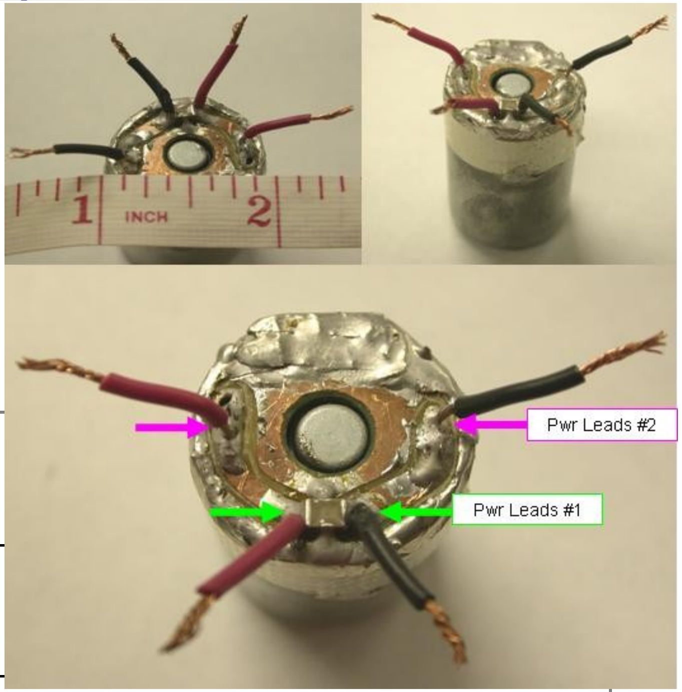
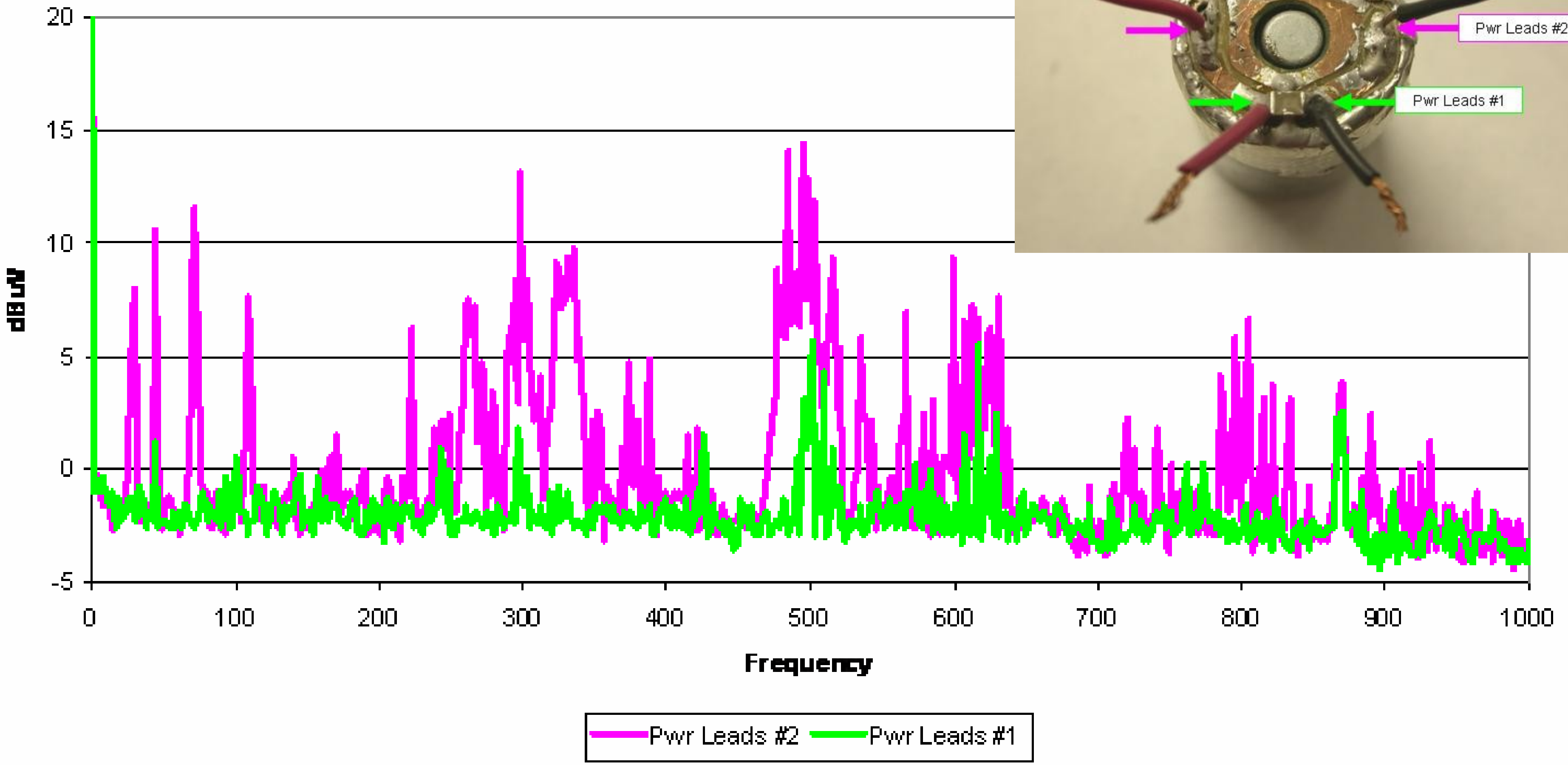
- **Leads/connector pins should exit the housing close together to reduce current loop.**

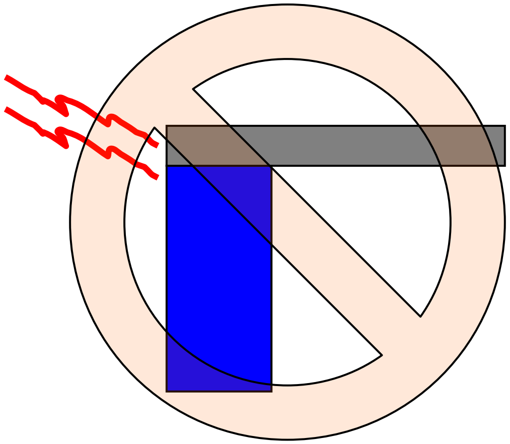


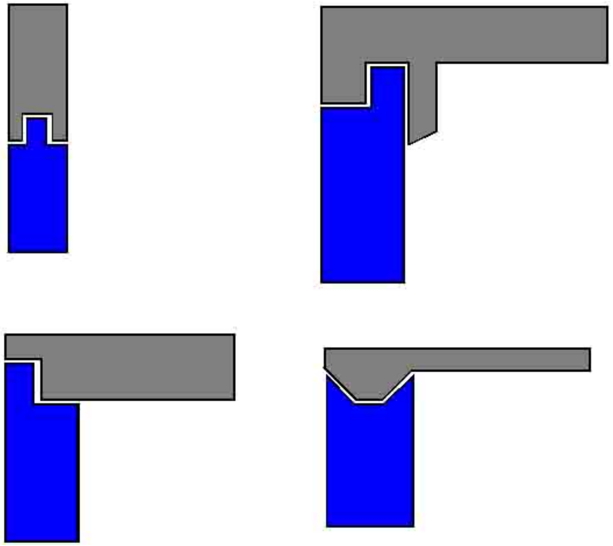
Exit points of Power Leads





- **Metal joints are typically only design with mechanical strength.**
- **Electrical conductivity and shielding should also be considered.**
  - Joints should overlap and be interlocking.
  - Oils and paint should be removed.
  - Oxidization and galvanic action should be prevented at the joints.





1. **Why Do DC Motors Need EMI Suppression?**
   - System integration
   - Understanding EMI Noise Sources in DC Motors
   - Compliance with specs.
2. **Designing DC Motors for EMI**
   - Motor Housing Design
   - End Cap Design
   - Connector Design
3. **Applying EMI Suppression to DC Motors**
   - Filtering Elements
   - Building EMI suppression Filters
   - Other Considerations for EMI Filtering Elements
   - Filtering Examples for Electronics Inside Motors
4. **Filtering Examples**
   - Radiated Emissions
   - Conducted Emissions
   - Transients
5. **Summary/Questions**

Element	Advantage	Disadvantage
Capacitor	Low cost, some transient suppression	Narrow filtering band, Limited to under 800MHz
Feed Thru Capacitor	Broad filtering band	Cost, Failure mode is a short
Ferrite Beads	Easy Implementation, Filter more than 1 line, CM & DM configurations	Heat can cause saturation, Cost, Moderate filtering performance
Inductor	Effective below 300-500MHz	Heat can cause saturation, Quality material and tolerance add cost
Common Mode Choke	Filter 2 lines at once	Heat can cause saturation, Quality material and tolerance add cost
MOV	Transient suppression	Cost, no filtering
X2Y	Broadband filtering (DC – 6GHz), low cost, Filter 2 lines, Good Tolerances, transient suppression	Surface mount only, Location in the circuit is critical

- **Typical Electrical Testing provided by manufactures**
  - Capacitance distribution.
  - Capacitance balancing.
  - DC Voltage Breakdown testing.
  - Impulse/surge testing.
  - ESD testing.
  - Reliability testing.
  - Stress Test.
- **Test Standards**
  - ISO 9001:2000
  - ISO 14001
  - OHSAS-18001
  - AEC-Q200

- **ESD Test Summary**
  - Up to 6KV on Contact Discharge Test.
  - Up to 8KV on Air Discharge Test.
- **Reliability Test Summary**
  - Upper Category Temperature +125°C
  - Voltage 1.5 x Rated Line to Ground voltage
  - Number of Components
  - Test hours
  - Number of Failures

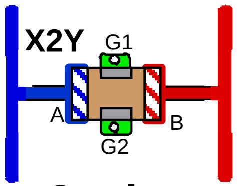
Note: These test summaries are courtesy of Syfer Technology Ltd.

For broadband filtering consider:

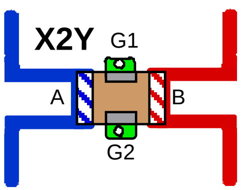
- Component's parasitics
- Trace/lead length parasitics – widen path, avoid sharp 90° turns

Placement of a filter into a motor consider:

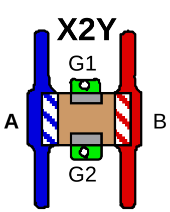
- Location, Location, Location – prevent noise from coupling around filter.
- Failure mode (open/short)
- Performance over temperature
- "Brush Dust" – filter may need a non-conductive coating to protect from shorting.
- Some filter technologies require housing to be "grounded".



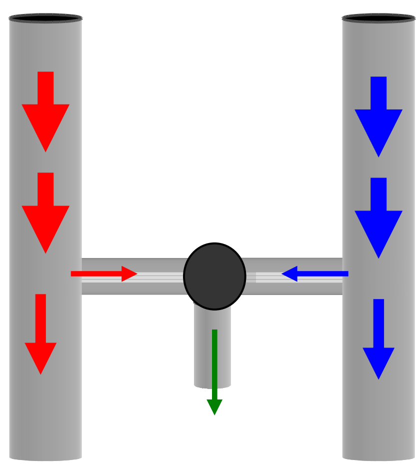
Option

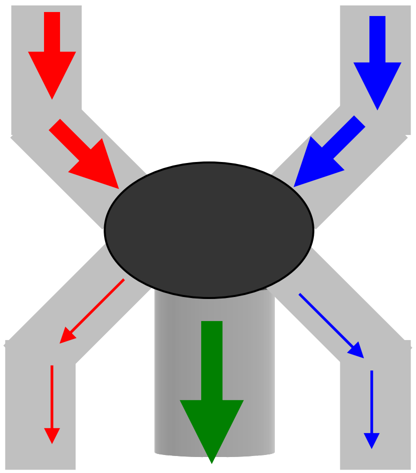


Improved

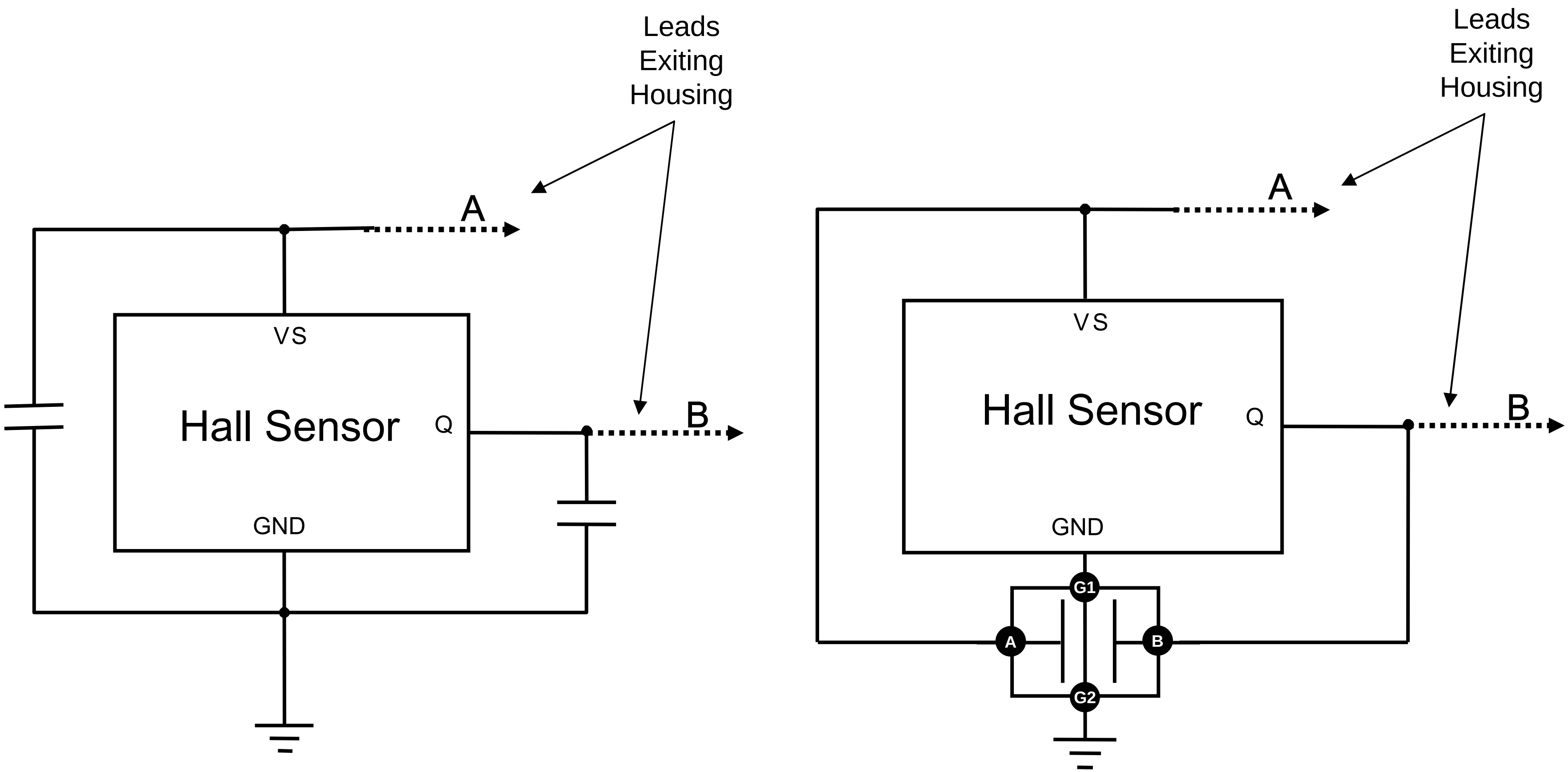


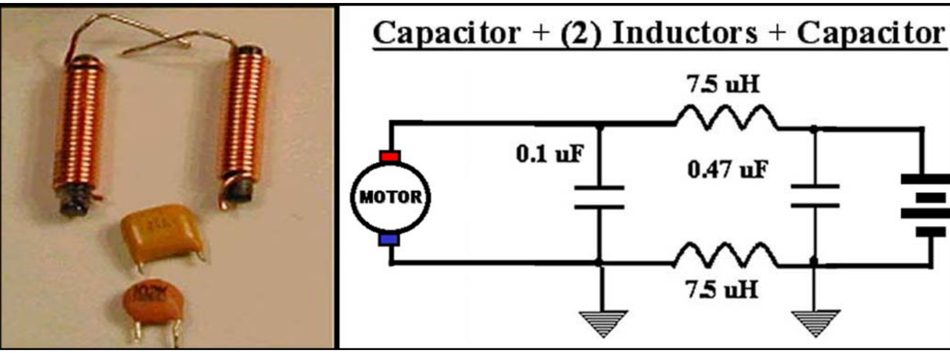
Best



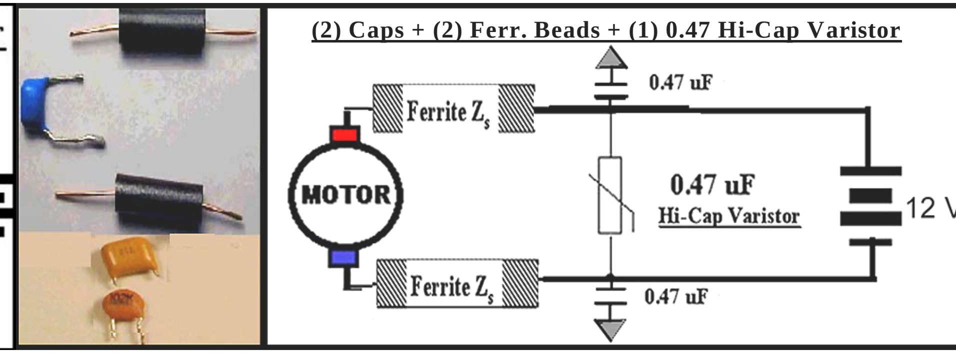


- Hall Effect Sensor

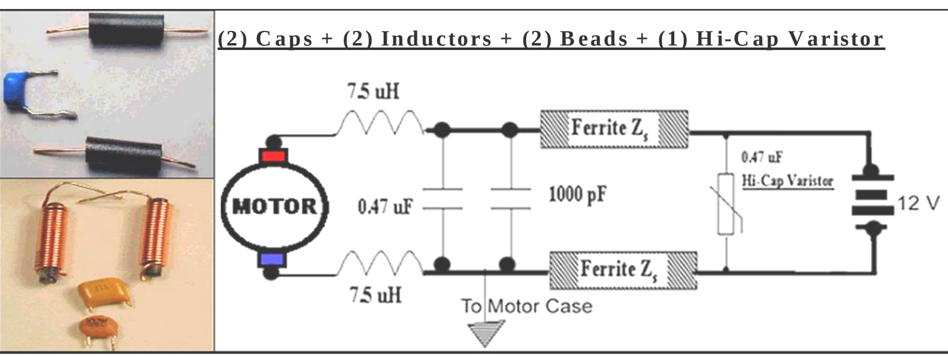




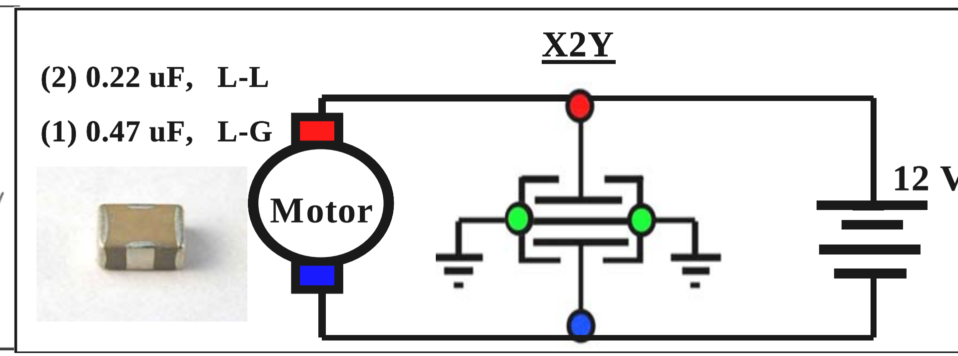
(4) element Filter



(5) element Filter

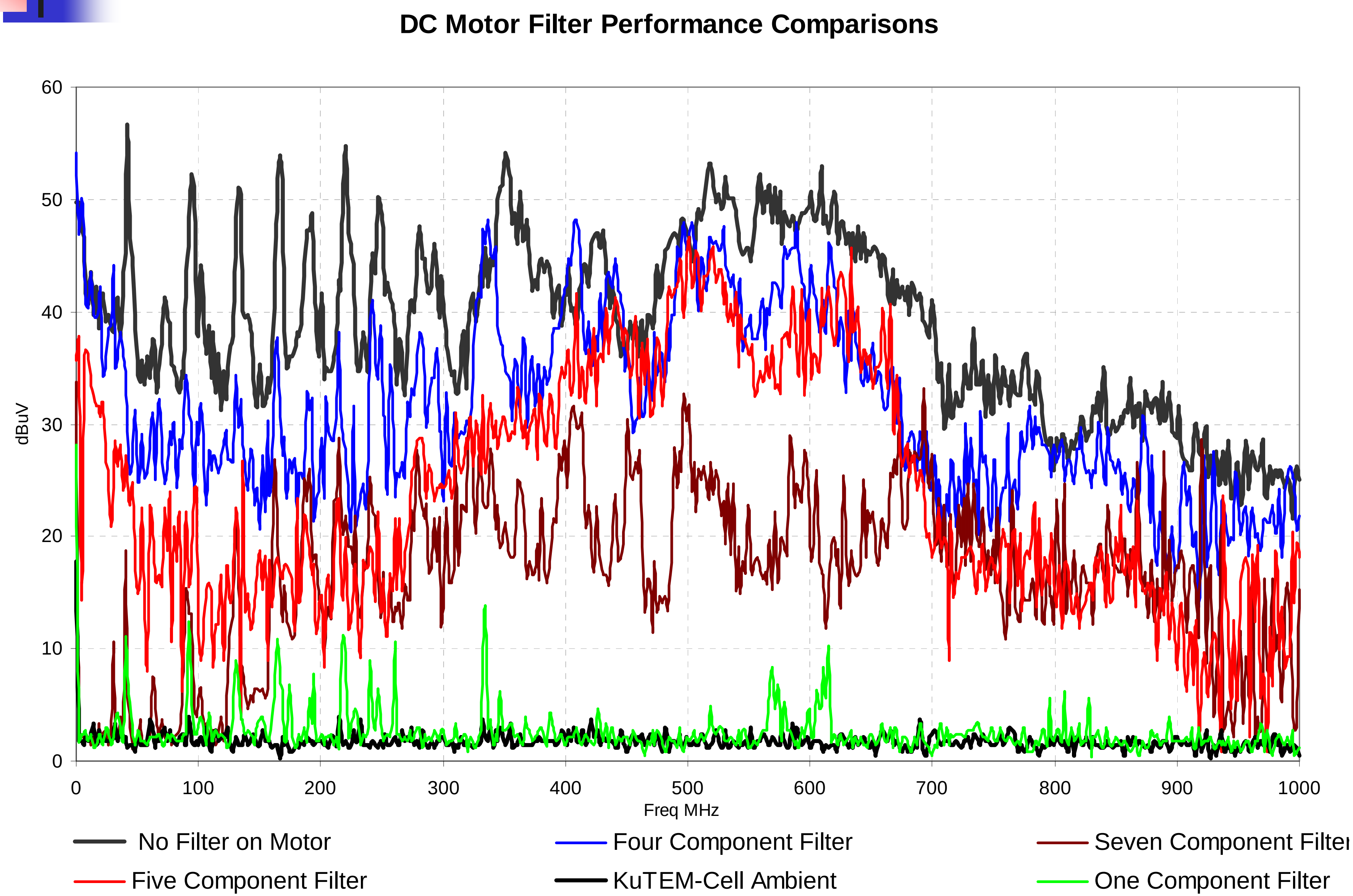


(7) element Filter



(1) element Filter

Radiated Emission Filtering Performance



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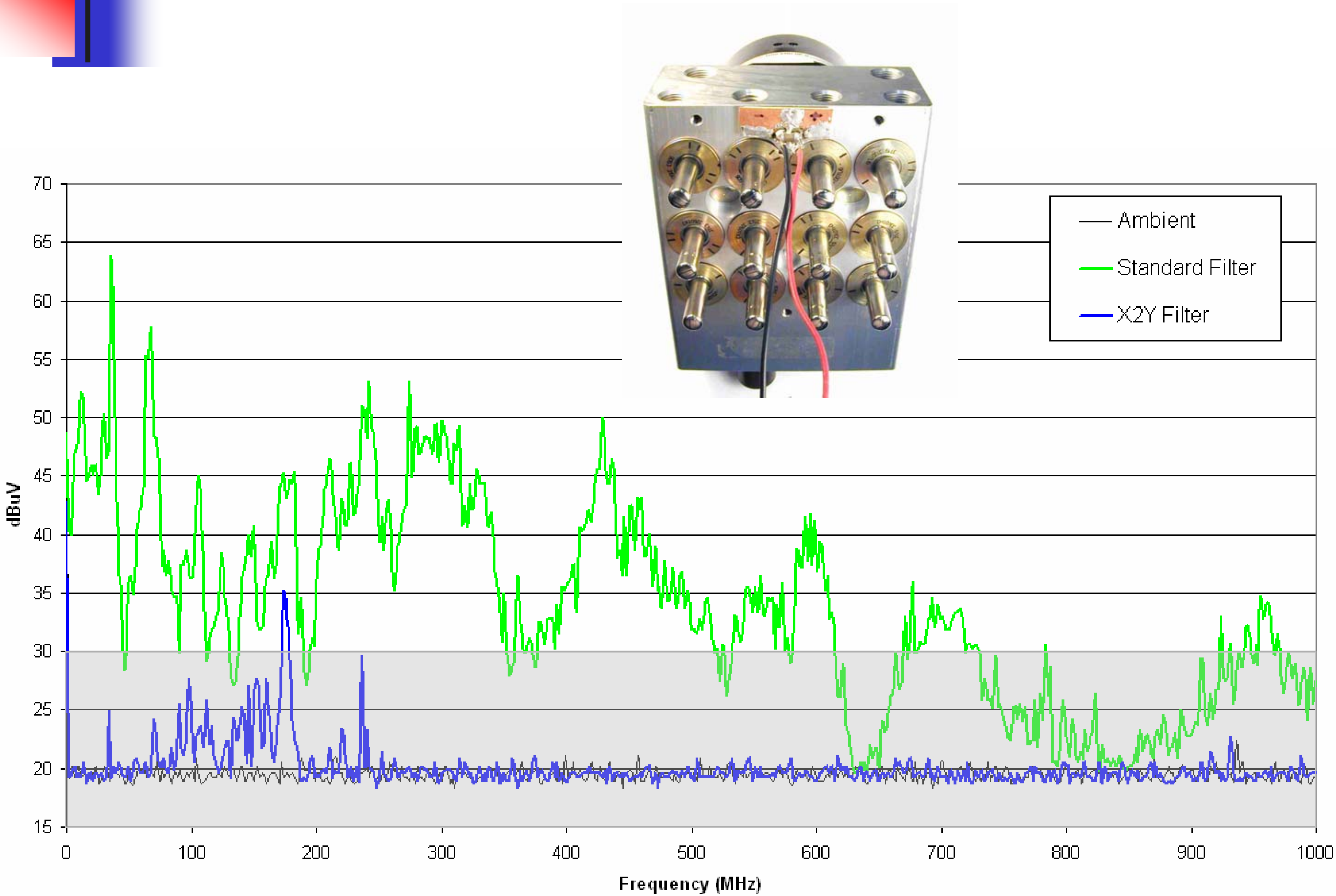
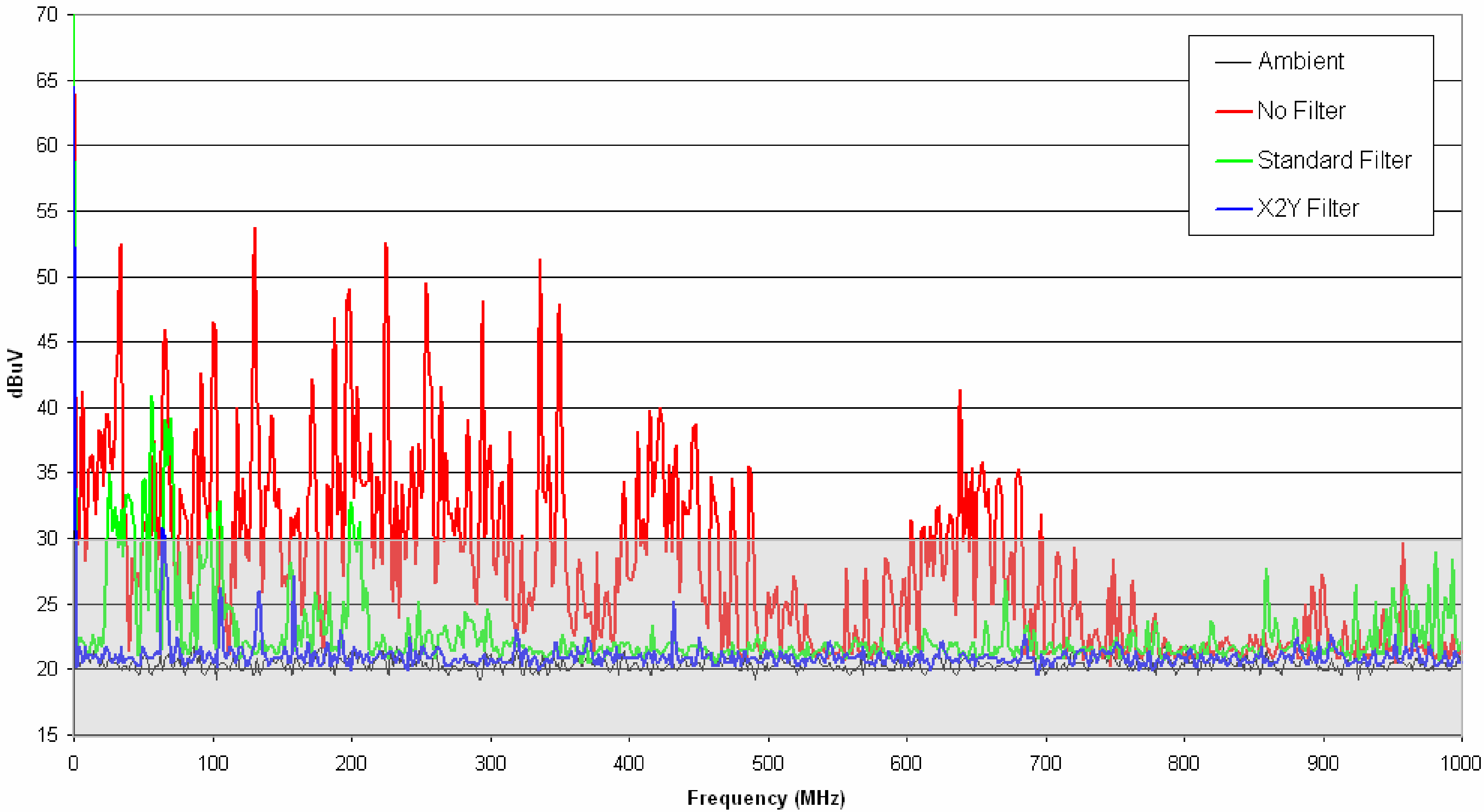
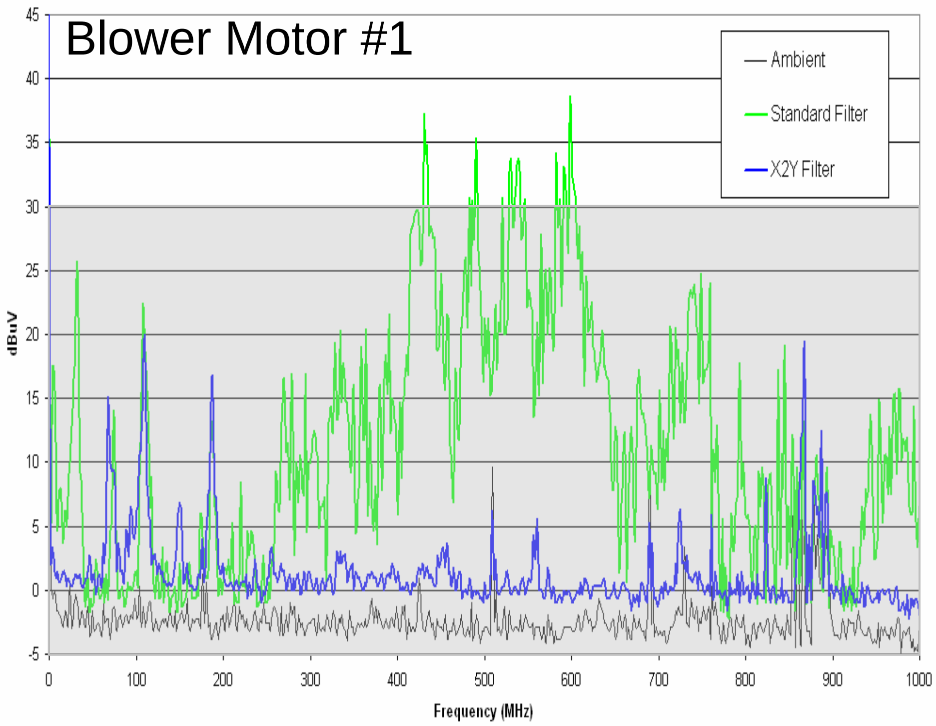
Radiated Emissions - ABS Motor

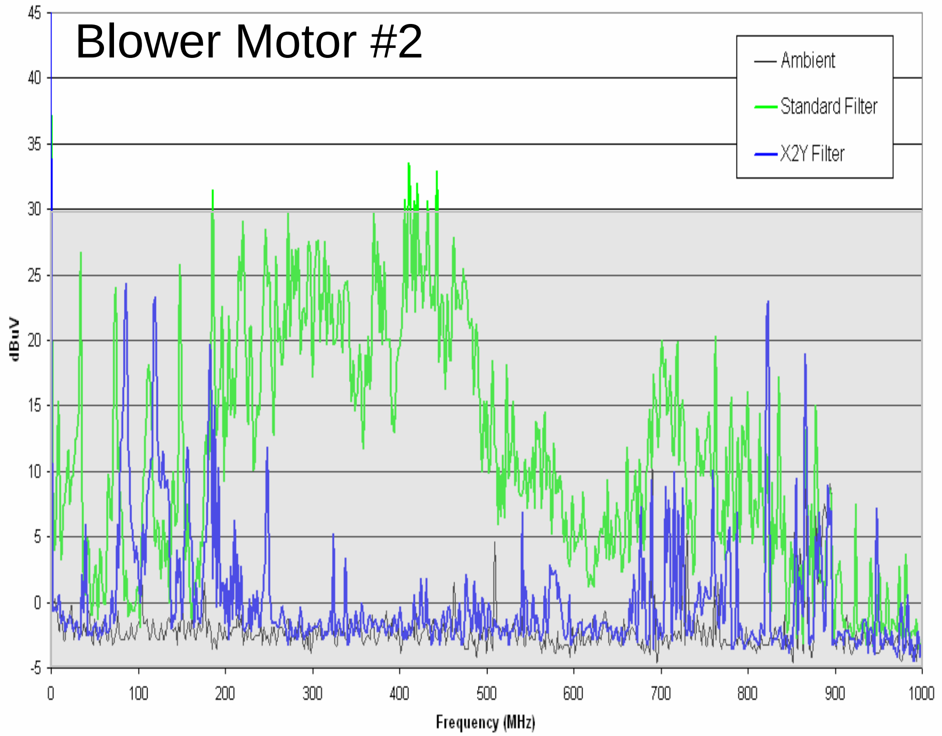


Radiated Emissions - Air Compressor Motor



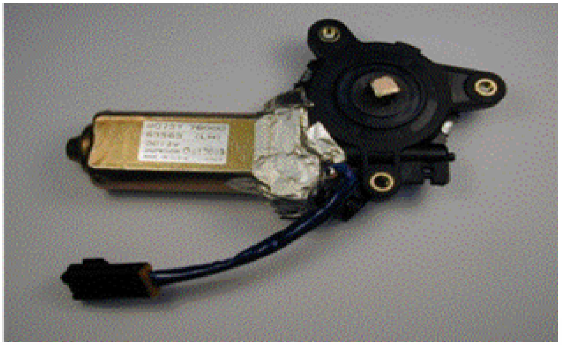
- 30dB pre-amp was used.

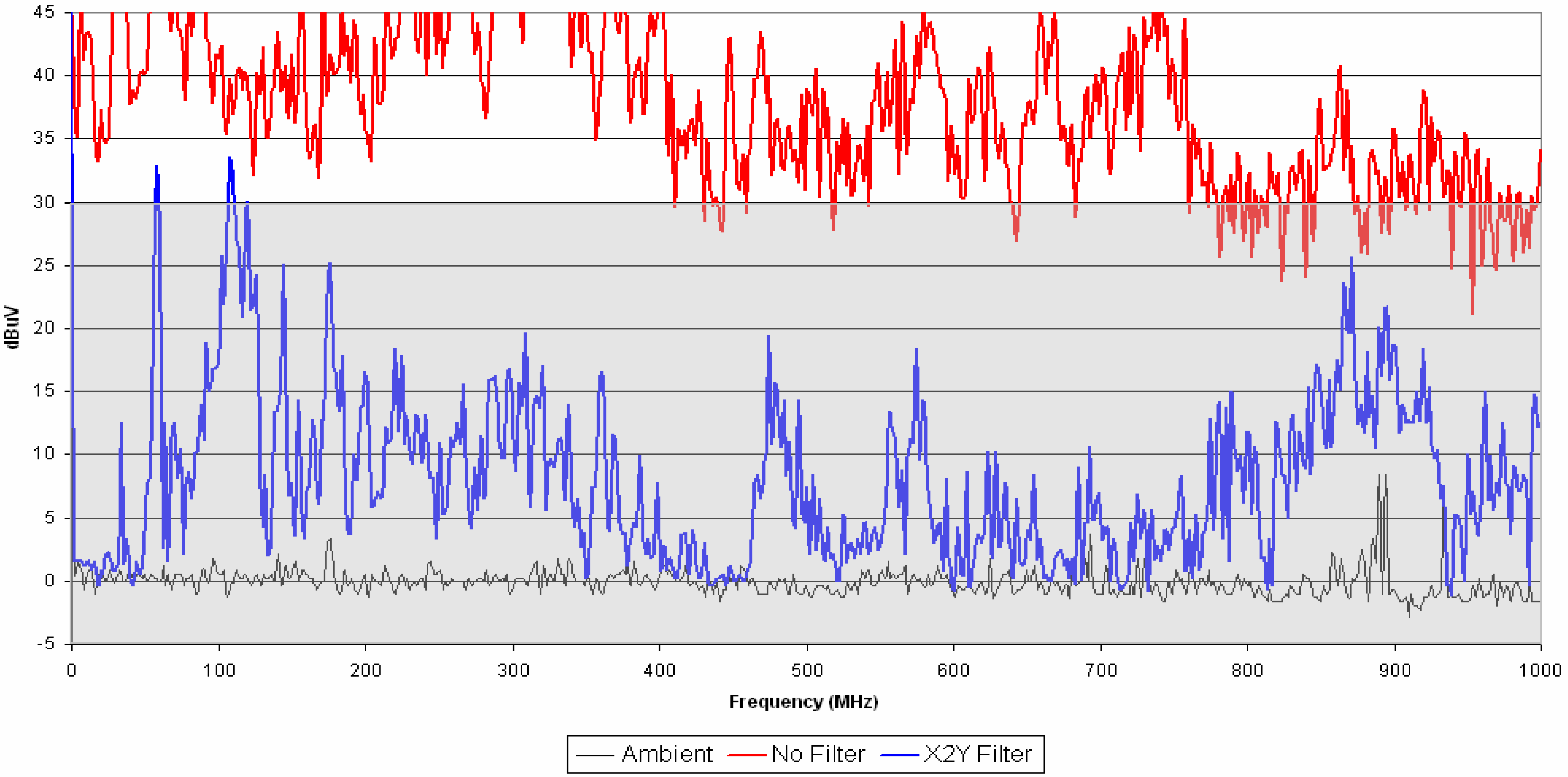




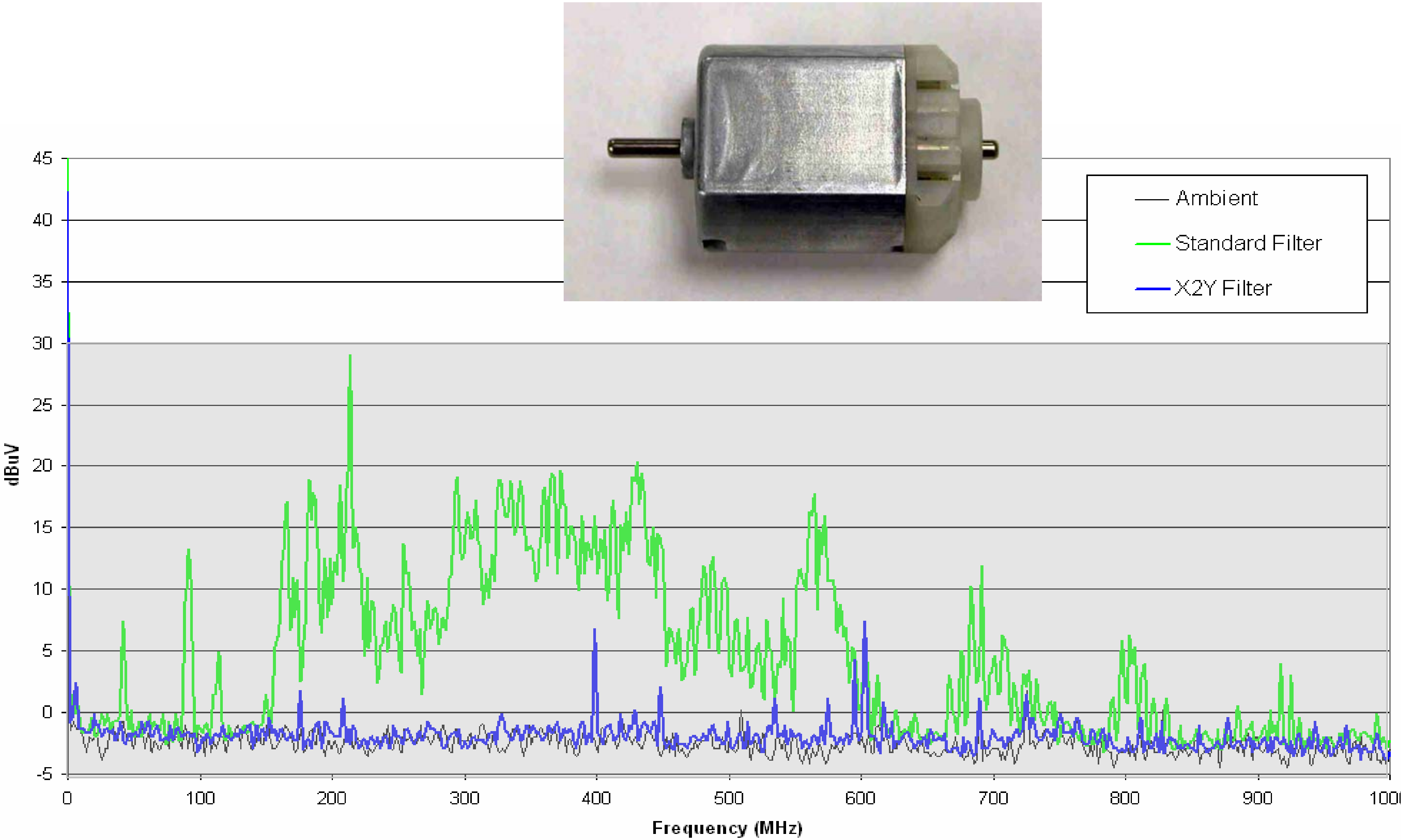
Radiated Emissions - Lift Gate Motor

- 30dB pre-amp was used.

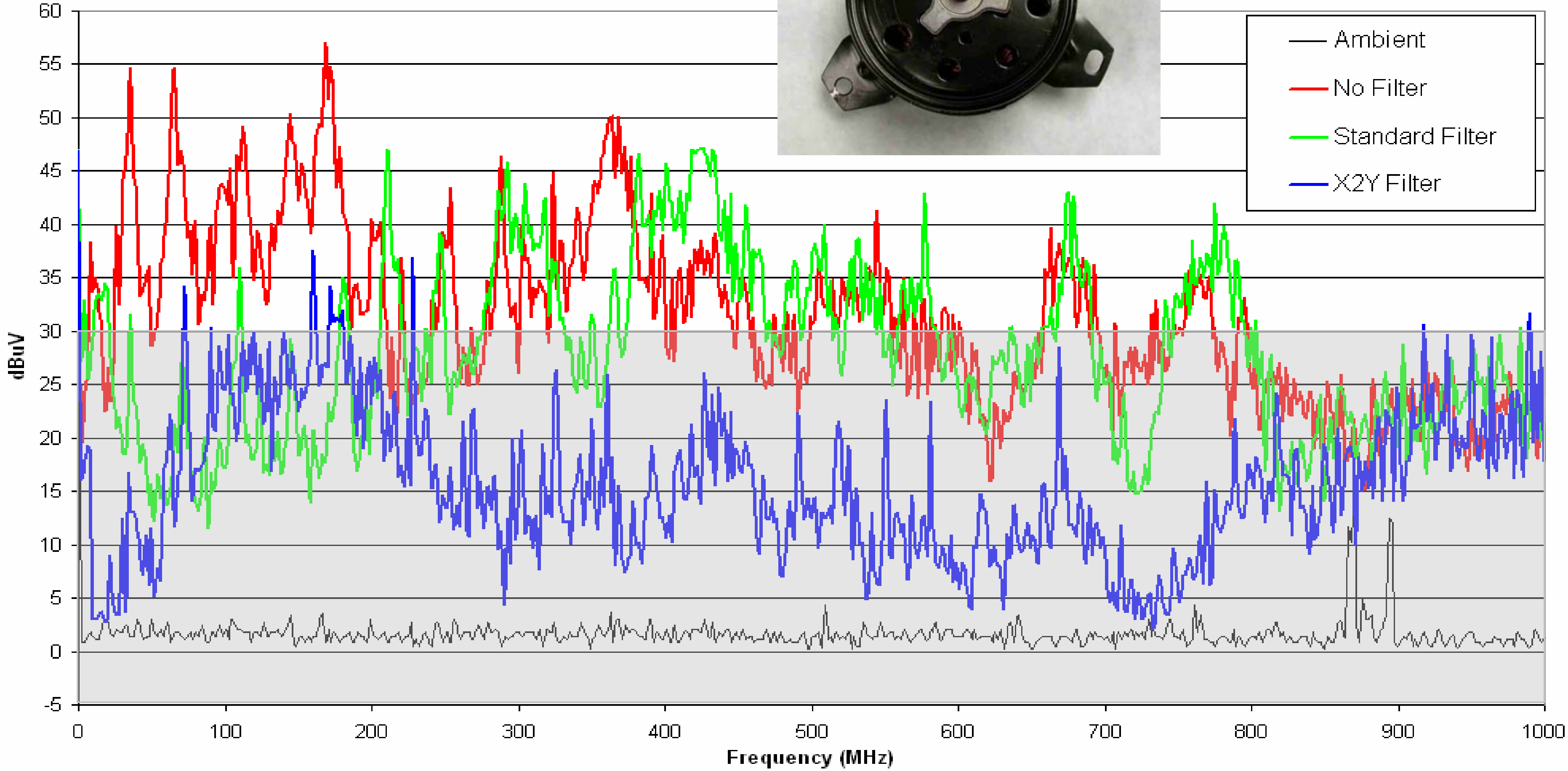




- 30dB pre-amp was used.

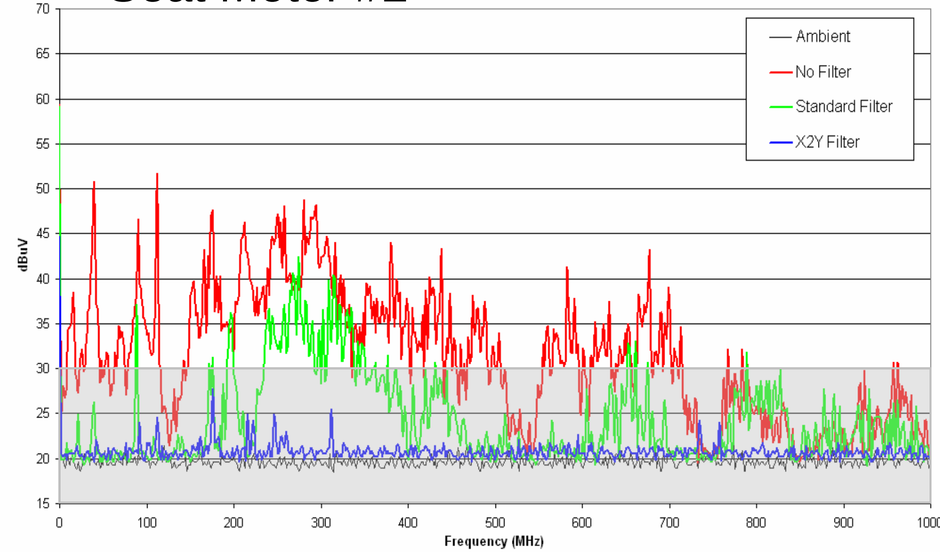


- 30dB pre-amp was used.

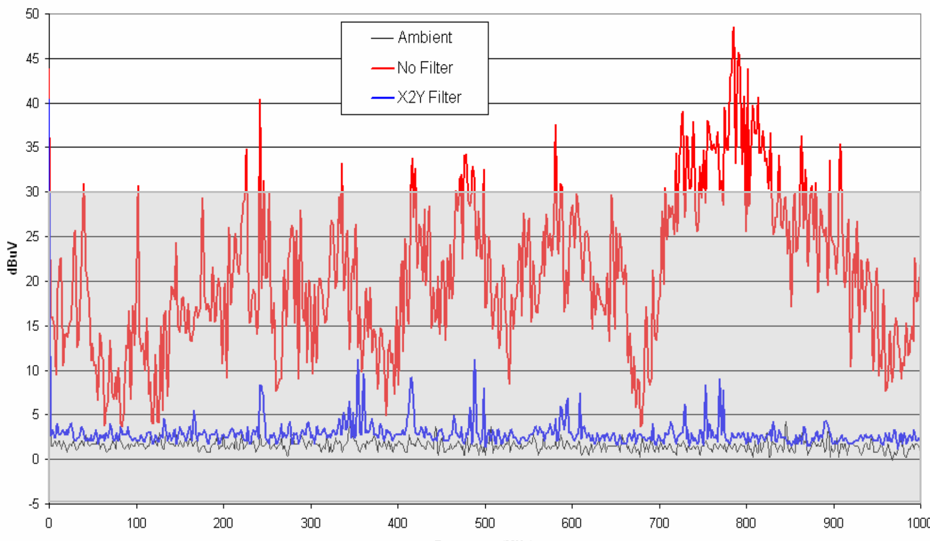


Radiated Emissions - Seat Motors

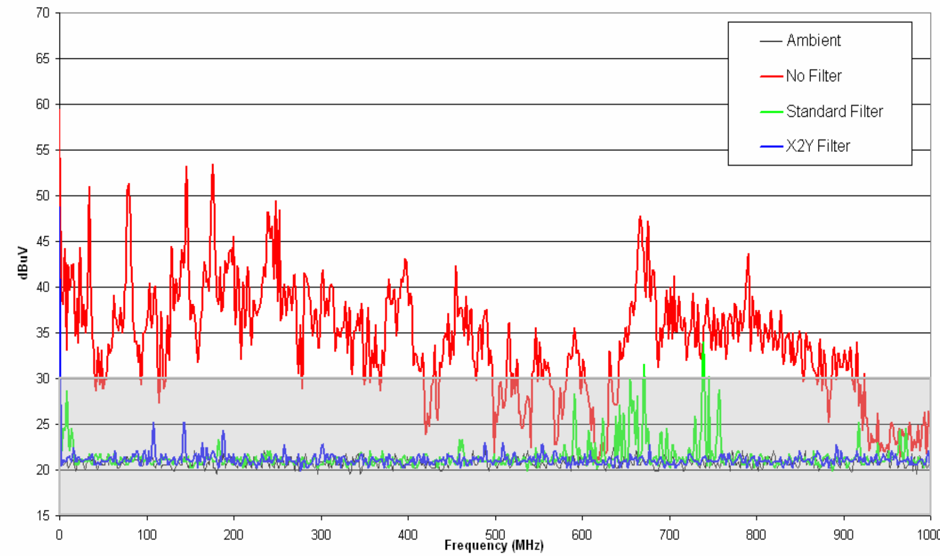
Seat Motor #2



Seat Motor #1

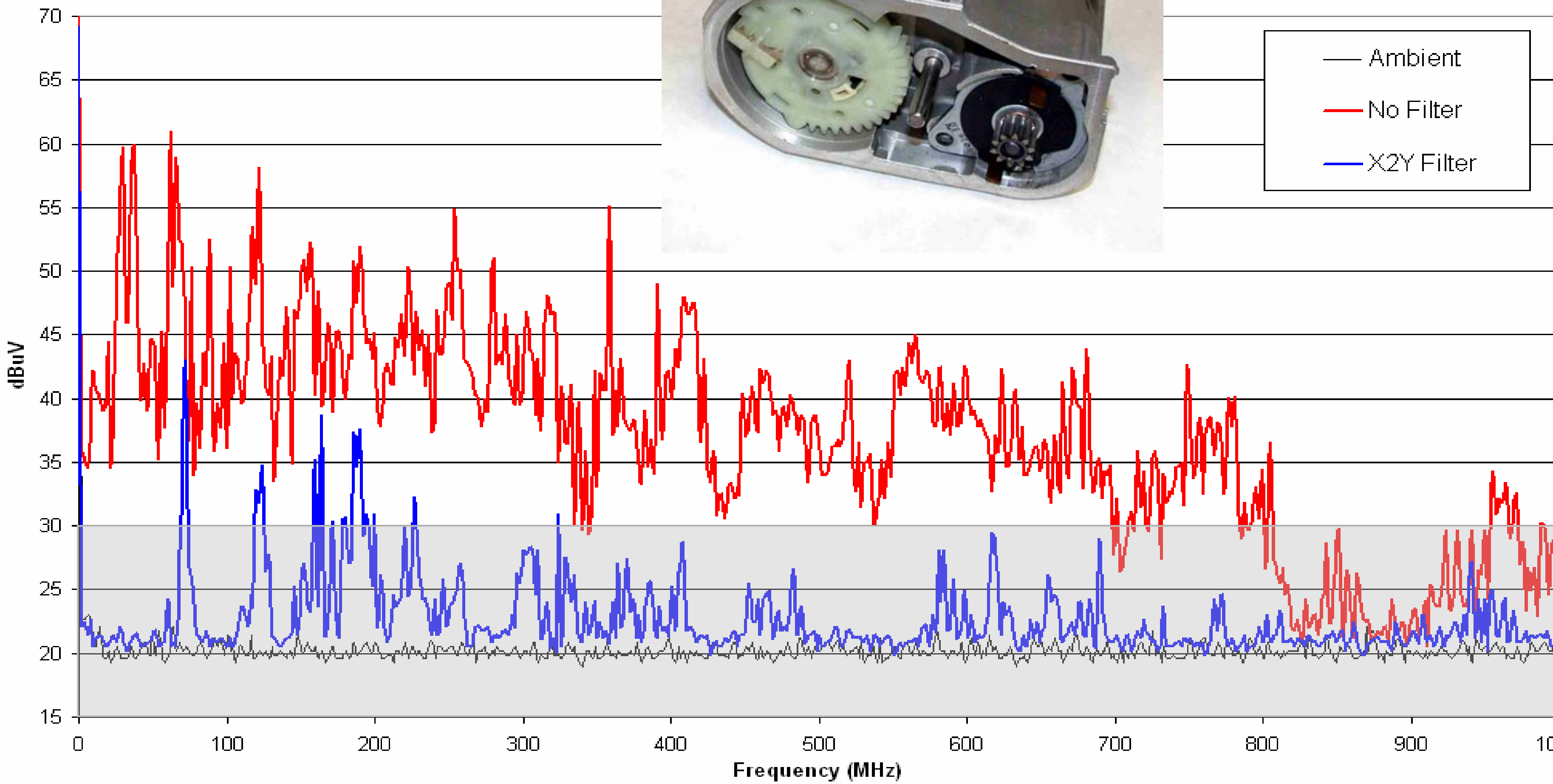


Seat Motor #3

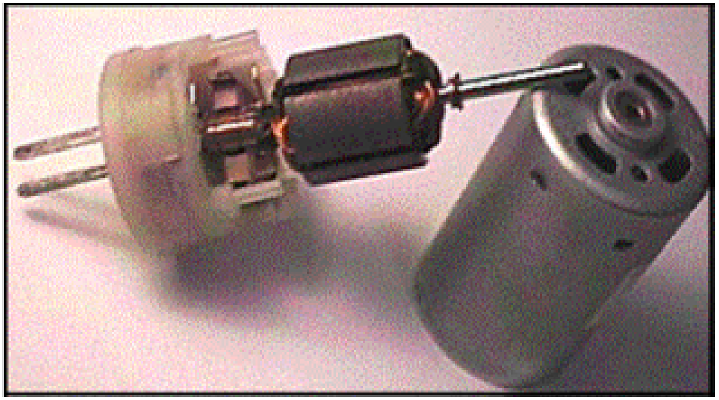


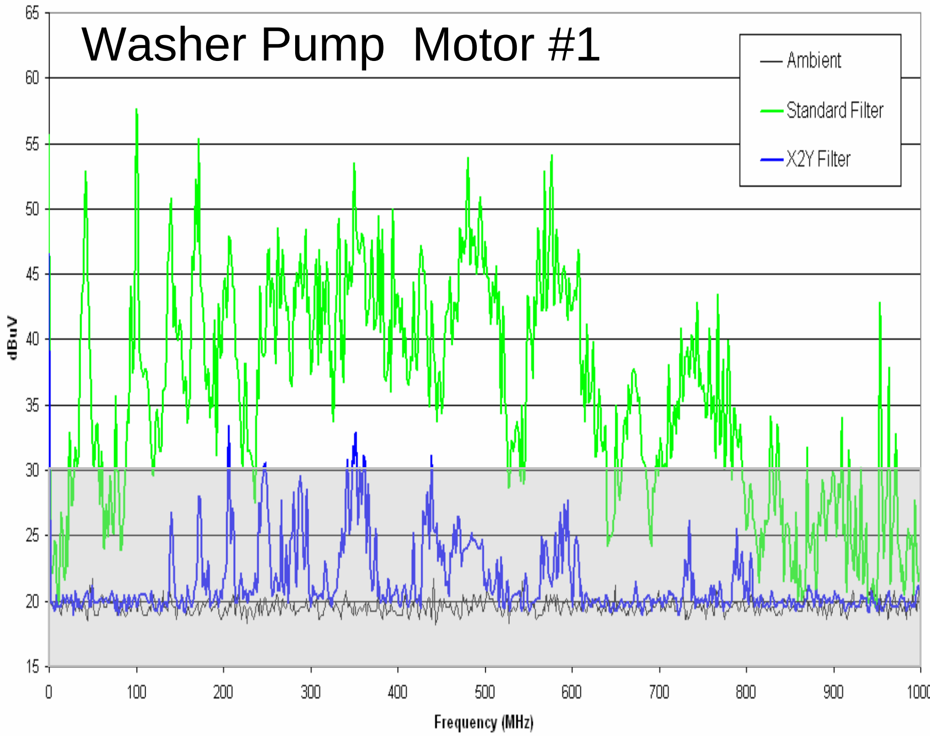
Note: 30dB pre-amp was used on Motor #1

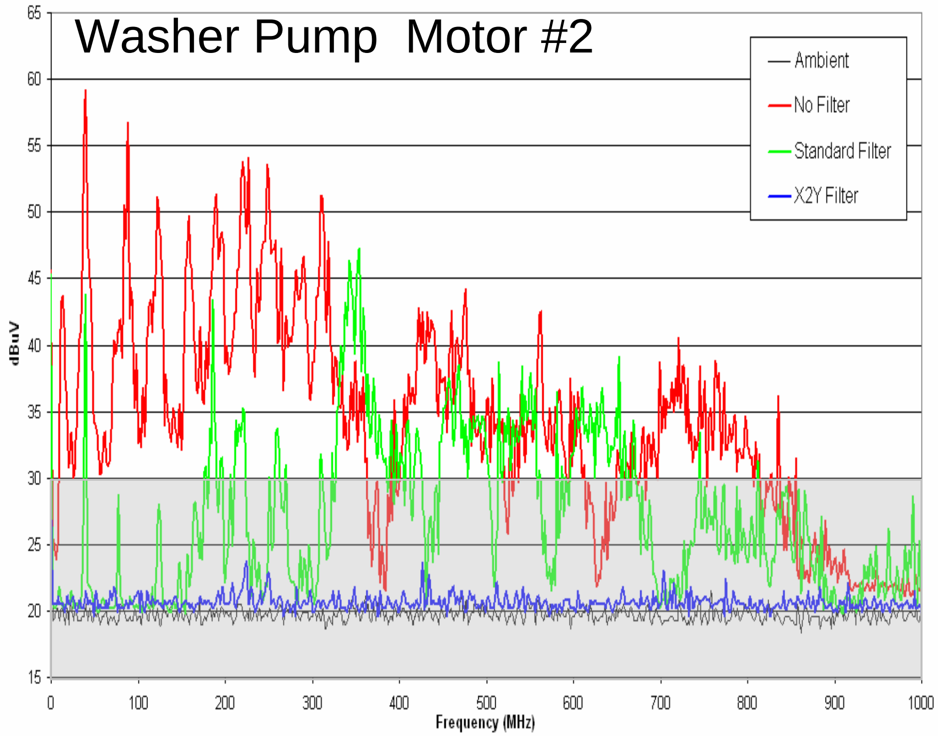
Radiated Emissions - Throttle Body Motor



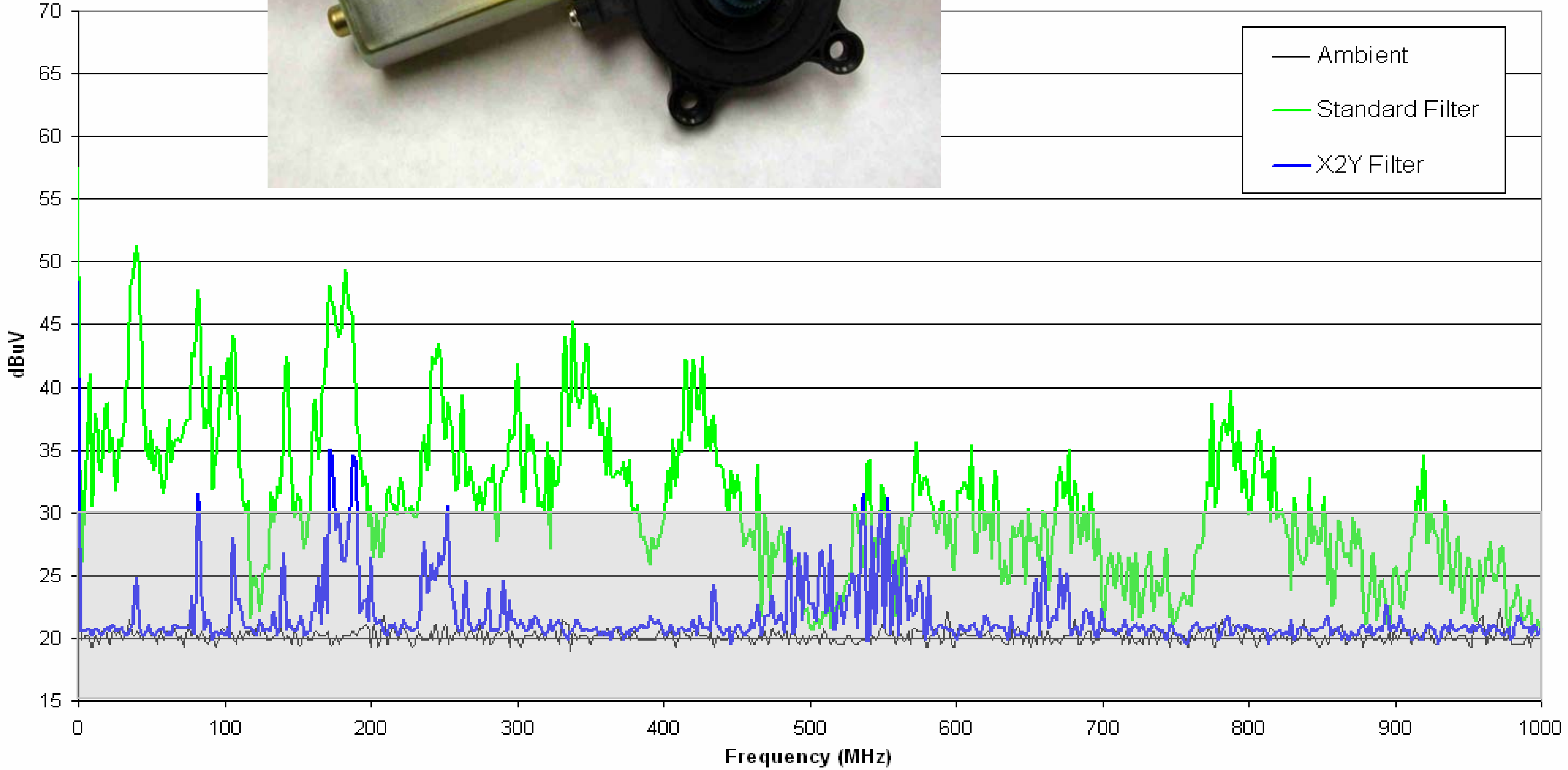
Radiated Emissions - Washer Pump Motors



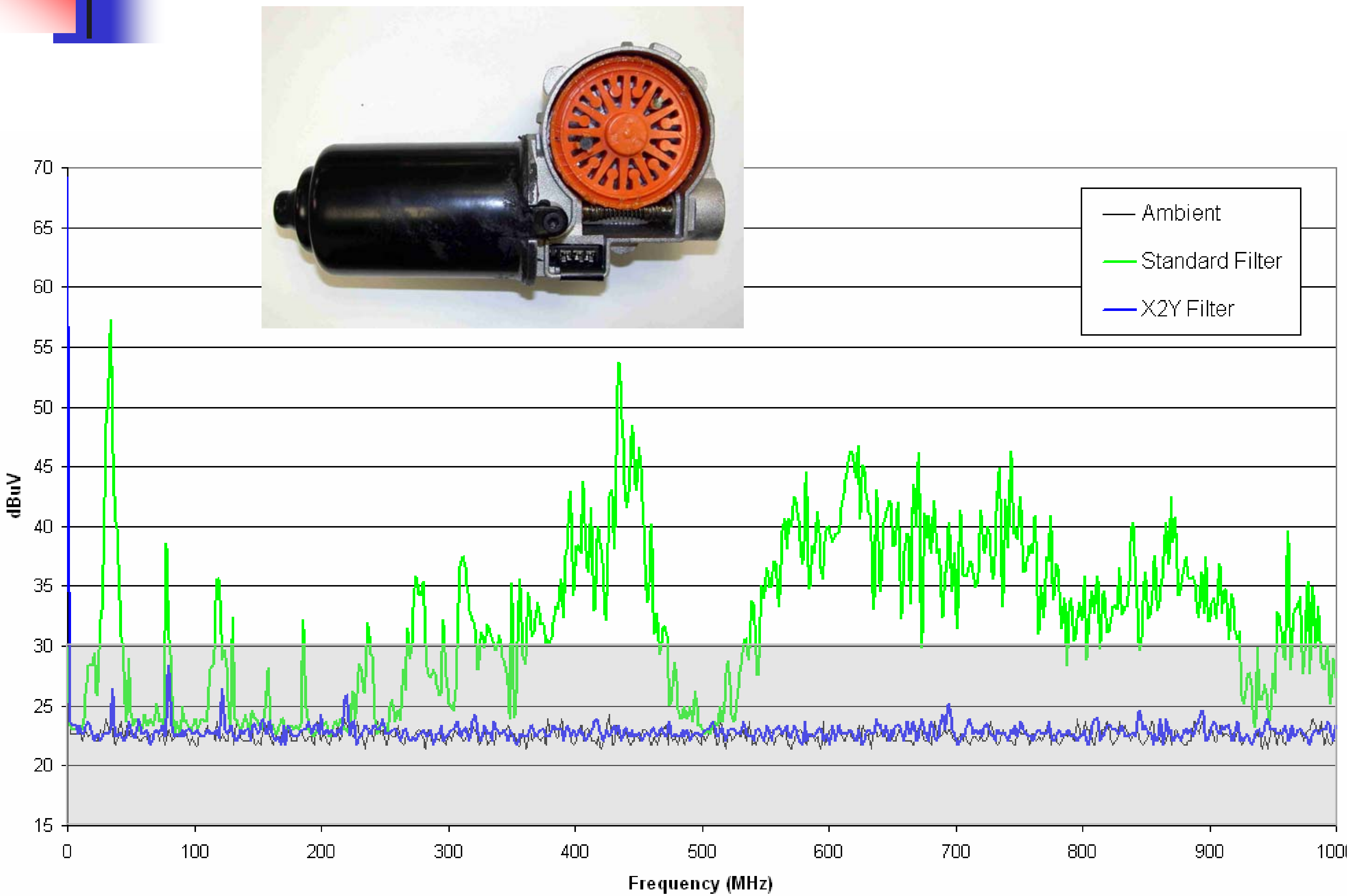




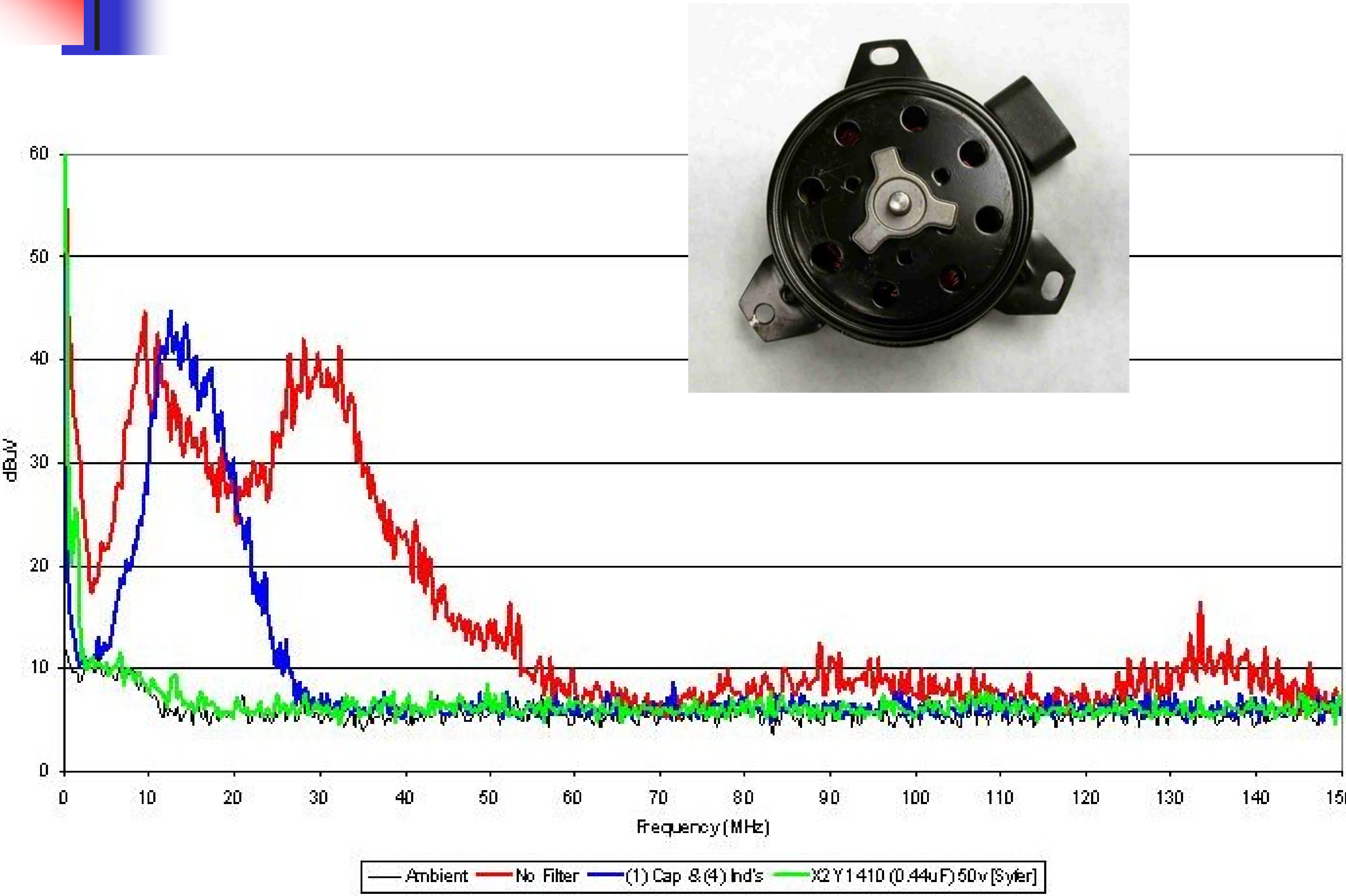
Radiated Emissions - Window Lift Motor

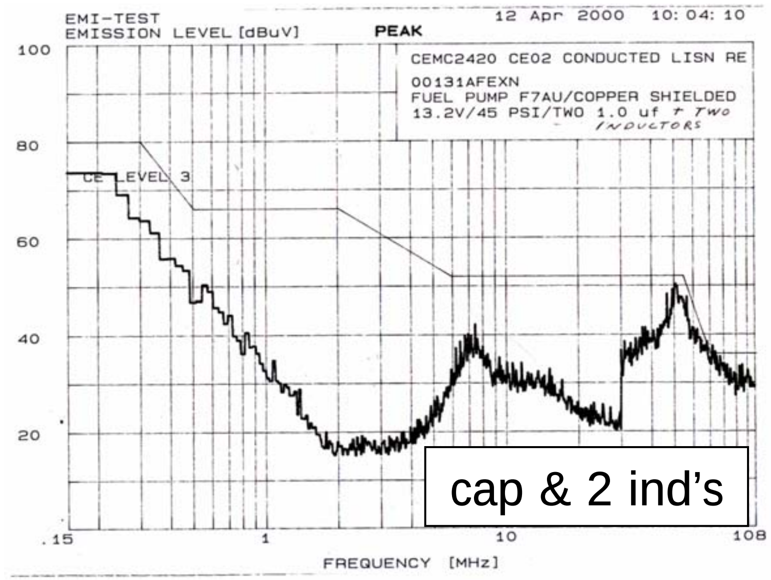


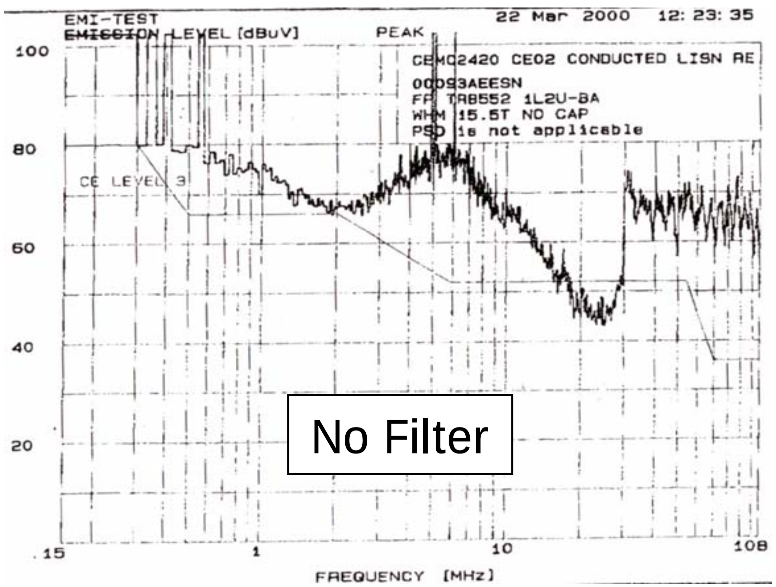
Radiated Emissions - Wiper Motor (3-brush, 2-speed)

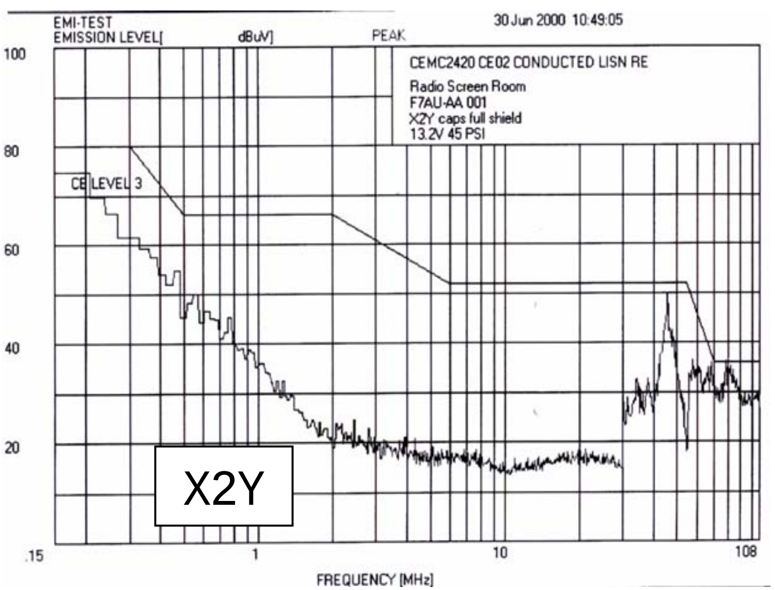


Conducted Emissions – Radiator Fan Motor

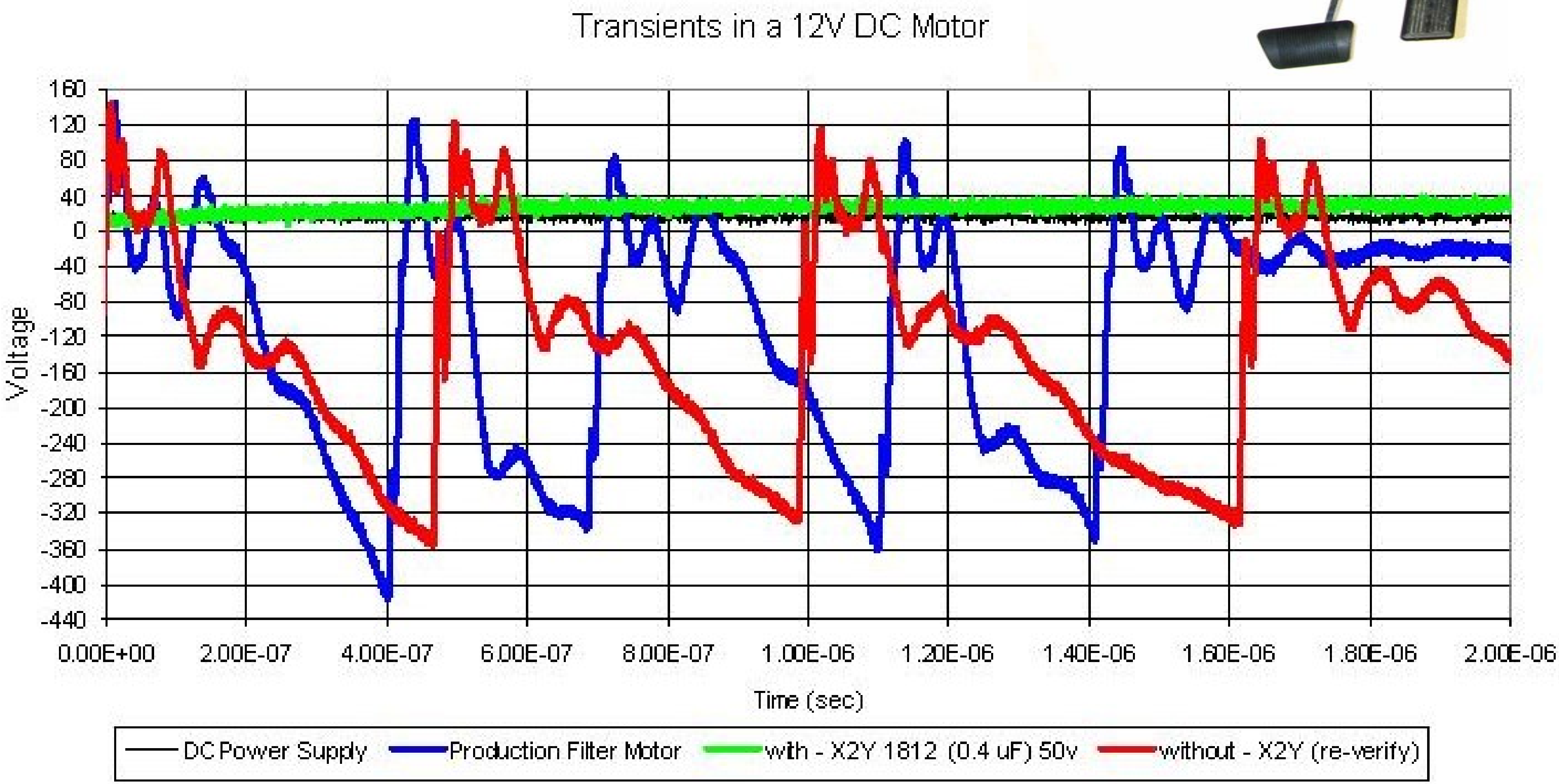


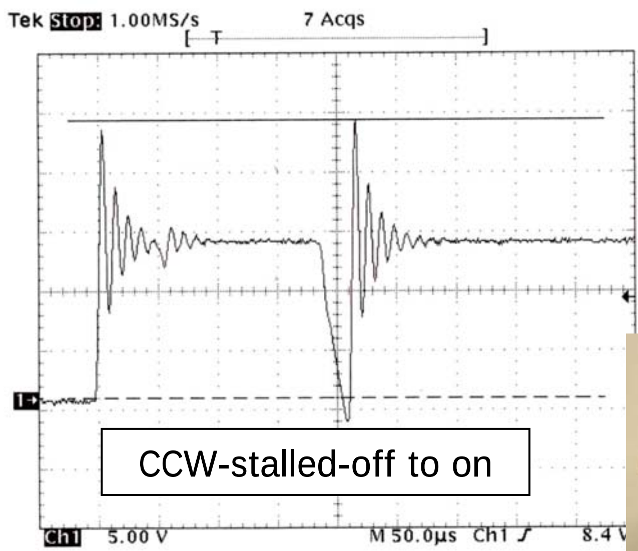

EMI-TEST
EMISSION LEVEL [dBuV]
PEAK
12 Apr 2000 10: 04: 10
CEMC2420 CE02 CONDUCTED LISN RE
00131AFEXN
FUEL PUMP F7AU/COPPER SHIELDED
13.2V/45 PSI/TWO 1.0 uf + Two INDUCTORS
CE LEVEL 3
FREQUENCY [MHz]
cap & 2 ind's

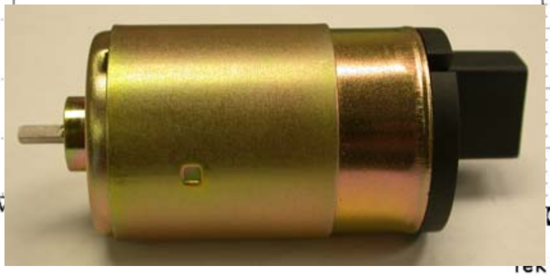

EMI-TEST
EMISSION LEVEL [dBuV]
PEAK
22 Mar 2000 12: 23: 35
CEMC2420 CE02 CONDUCTED LISN RE
00093AEESN
FP TRB552 1L2U-BA
WHM 15.5T NO CAP
PSD is not applicable
CE LEVEL 3
FREQUENCY [MHz]
No Filter

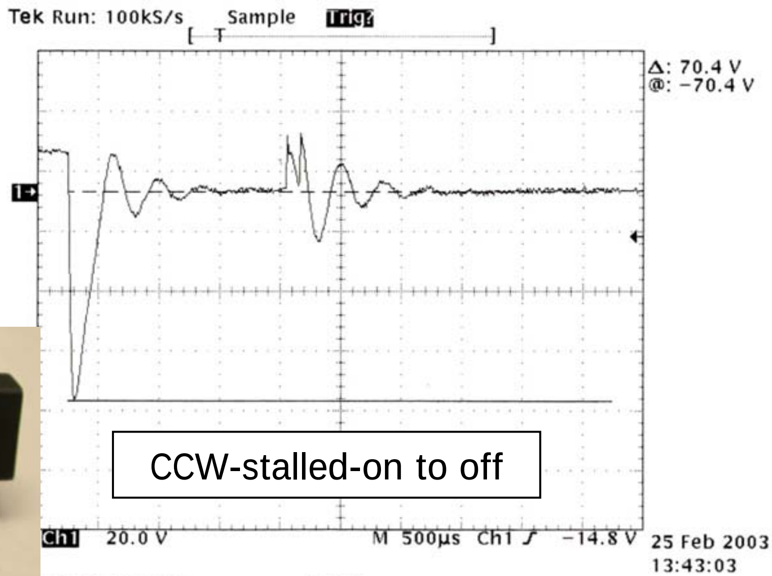

EMI-TEST
EMISSION LEVEL[dBuV]
PEAK
30 Jun 2000 10:49:05
CEMC2420 CE02 CONDUCTED LISN RE
Radio Screen Room
F7AU-AA 001
X2Y caps full shield
13.2V 45 PSI
CE LEVEL 3
FREQUENCY [MHz]
X2Y

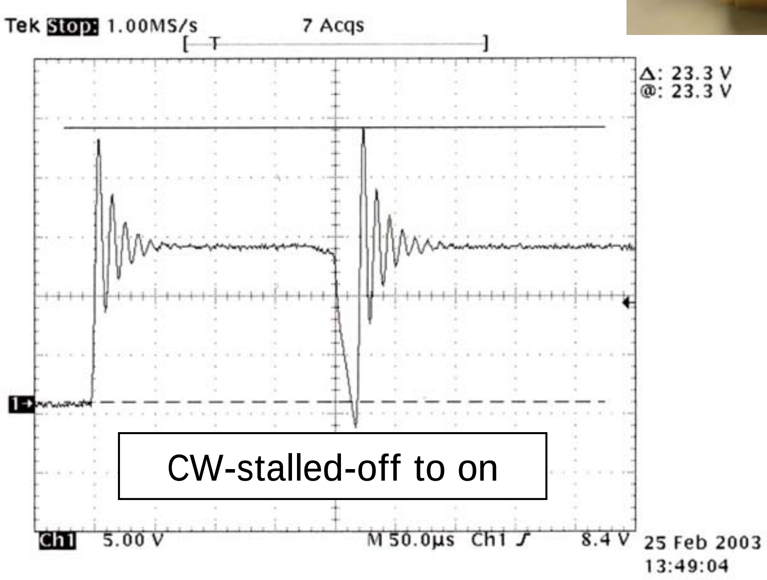
Transient Testing – 12v Brake Pedal Motor

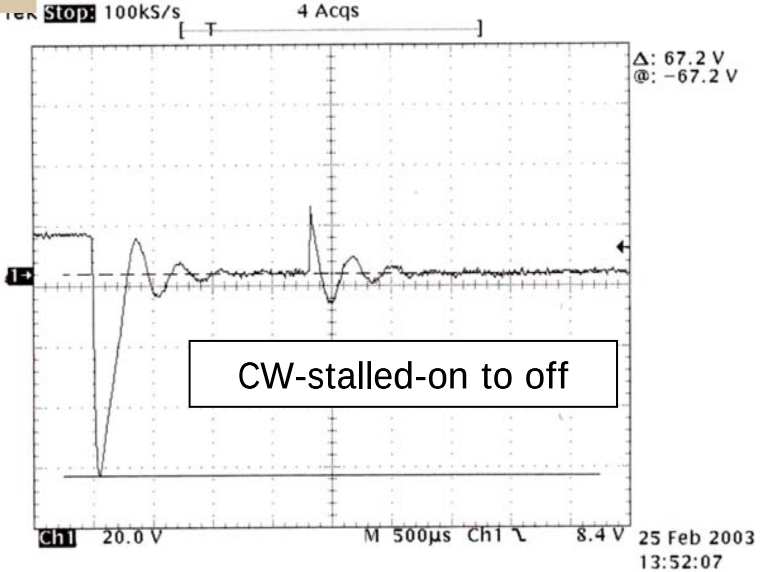



Tek Stop: 1.00MS/s
7 Acqs
Δ: 23.5 V
@: 23.5 V
CCW-stalled-off to on
Ch1 5.00 V
M 50.0µs Ch1 ∫ 8.4 V




Tek Run: 100kS/s
Sample
Trig?
Δ: 70.4 V
@: −70.4 V
CCW-stalled-on to off
Ch1 20.0 V
M 500µs Ch1 ∫ −14.8 V
25 Feb 2003
13:43:03


Tek Stop: 1.00MS/s
7 Acqs
Δ: 23.3 V
@: 23.3 V
CW-stalled-off to on
Ch1 5.00 V
M 50.0µs Ch1 ∫ 8.4 V
25 Feb 2003
13:49:04


Stop: 100kS/s
4 Acqs
Δ: 67.2 V
@: −67.2 V
CW-stalled-on to off
Ch1 20.0 V
M 500µs Ch1 8.4 V
25 Feb 2003
13:52:07

Questions?

Please Contact:
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37554 Hills Tech Dr.
Farmington Hills, MI 48331
248-489-0007
x2y@x2y.com

- **For more information on EMI filtering of DC motors go to www.x2y.com and refer to Application Notes:**
  - 4001 - DC Motor Design with X2Y® Technology
  - 4002 - DC Motor Design with X2Y® Example A
  - 4003 - DC Motor Design with X2Y® Example B
  - 4004 - DC Motor Design with X2Y® Example C
- **"*Suppression Techniques Using X2Y as a Broadband Filter*", Symposium Record – Workshops and Tutorials, 2003 IEEE Symposium on Electromagnetic Compatibility.**
- **"*Using Image Planes on DC Motors to Filter High Frequency Noise*." 2004 IEEE EMC Symposium, Santa Clara, CA. Aug 9-13, 2004.**
- **www.jastech-emc.com**