BROADBAND TESTING OF LOW COST FILTER SOLUTIONS FOR DC MOTORS

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I. Abstract

In an earlier paper [7], four small DC washer pump motors (FIG. 1**)** with EMI filters or EMI filter network configurations were tested for radiated emissions using a broadband KuTEM Cell (FIG. 2). Because of the unexpected results achieved with one specific filter (X2Y® (1)-unit filter), requests were made to the authors to provide further testing validation in the form of an even more scrutinized series of tests. The test series presented in this paper provides a correlation of three earlier test run series made by an actual end-user OEM at an EMI Proving Laboratory in Michigan and at two international EMI test sites, owned by a motor manufacturer, in Europe and in Asia.

For this paper, five DC washer pump motors used in the automotive industry were chosen, pulled from a production line, and tested. Motor #1 was initially tested unfiltered. After this baseline measurement was taken, the motor was tested with two different proposed configurations. The first was with the addition of tin-plated copper foil tape. The second was with the X2Y® (1)-unit filter, a multi-layered circuit architecture packaged in standard passive component, industry specified sizes [1] [2]. Motors #4 and #5 were also tested using the X2Y® (1)-unit filter, to insure that earlier test results for this filter were not anomalies. Motor #3 was tested using another proposed filter solution. All proposed solutions were designed to meet the EMI requirements set by the end-user OEM customer. Motor #2 was tested using the current production filtering configuration. Radiated emissions tests were performed inside the KuTEM Cell using a battery power supply attached to each motor to examine the RF emission level range from 150 KHz to 1,000 MHz.

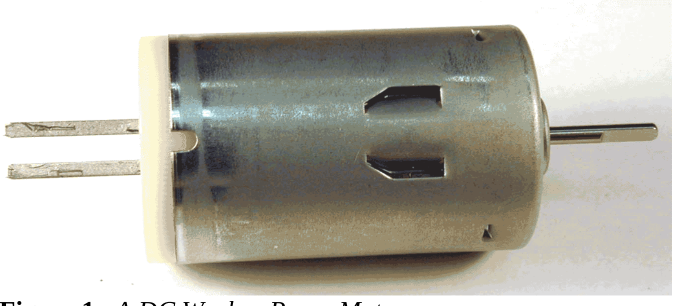

Figure 1. *A DC Washer Pump Motor*

II. Introduction

Use of DC motors of all types has increased dramatically in recent years. As many as 100 DC motors can now be found in a typical luxury automobile. Other high volume applications include printers, consumer electronics, power tools, industrial automation modules, etc. All have gained dramatically in terms of sales for major motor manufacturers and are not expected to diminish anytime soon.

A critical problem associated with the use of DC motors is the RF emissions created and their effect upon other electronic devices operating nearby in the same frequency range. Specifically, a DC motor is the type of RF source that can easily interfere with other electronic devices through common and differential mode noise on the power lines. Once common and differential mode noise rises above a certain frequency on power lines, these lines begin to take on antenna-like characteristics and radiate energy into free space. Substantial RF noise can easily be generated by the high speed switching within a typical DC motor which can occur at angular velocities as high as 23,000 to 24,000 rpm at 12 V DC.

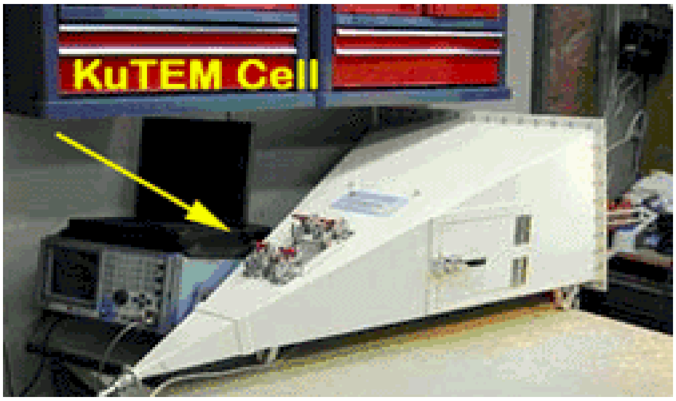

Figure 2. *A KuTEM Omni-Cell with Spectrum Analyzer***.**

The best way to prevent RF noise problems is to suppress RF emissions at the source. Economics, however, commonly place constraints or limitations on what can be done with a low cost DC motor when attempting to arrive at an acceptable RF emissions level. An ideal goal for suppressing unwanted noise in a low cost DC motor is to provide an effective and equally low cost EMI solution in the smallest package size possible. At the same time, any additional re-design and re-tooling changes on the motor itself can have serious economic impact upon any DC motor's application viability.

III. Test Methodology

A broadband KuTEM Cell was used for radiated emissions measurements because it can provide good correlation to Open Area Test Sites working up to 1 GHz [4] [5] [7]. The KuTEM Cell set-up provides an effective solution for making accurate and quantitative measurements of various DC filter configurations on small motors due to its characteristically low ambient noise floor. The spectrum analyzer used in this test is an IFR AN920 (9kHz - 2.9 GHz) and the frequency range is set from 150 kHz to 1000 MHz.

Test run resolutions for all tests were set to 9 kHz and the video bandwidth was turned off so that the spectrum analyzer would not filter signals being analyzed. Each DUT (device under test) was then run in a steady state condition to minimize variability in the test data. To insure that the spectrum analyzer captured a true peak hold mode or condition for all runs, each test-run duration was allowed to capture four complete sweeps in peak hold mode with the IFR AN920 Spectrum Analyzer.

IV. Test Configuration

The DUTs are five randomly chosen, small production washer pump motors. Motors #2 and #3 had a total runtime documented of over two hours each before their test series were actually run. Thus, brushes from Motors #2 and #3 had "seated," or worn in, to the point that the filter units configured inside actually had an EMI noise advantage over the remaining three motors, #1, #4, and #5. Motors #1, #4, and #5 had a total runtime documented at less than five minutes each before their test series were actually run.

The test fixture was made out of wood and had wooden dowels to hold the DUT motor and the three-meter cable in place, consistently for each test (FIG. 4). When DUTs were switched-out, the cable assembly, connections, and fixture itself were not moved. Only the DUT was changed for each test run. To begin the test procedure, an ambient measurement was required. An unfiltered Motor #1 was placed in the broadband KuTEM and attached to cabling but the +12V energy source was not connected. A power-off, ambient measurement was then recorded.

A baseline measurement was obtained by testing Motor #1 without filtering. To determine the effect of tin-plated copper foil tape on radiated emissions from the DUT, Motor #1 was tested further after the baseline measurement, using a "Taped" configuration. This was done to completely understand the tape's effectiveness for this motor test series and the previously run test series, as well. All other motors (#1 through #5) tested after this also used the tin-plated copper foil tape (FIG. 3).

Motors #1, #4, and #5 were configured with the X2Y (1)-unit filter (FIG. 8) placed external to the noise source, directly attached on top of the conductive tape already in place (FIG. 5). Solder connections were made to the tape as well as to the two power pins, to attempt to capture and suppress noise emissions at this specific location.

Motor #2 was tested using a (4)-unit EMI filter network, which is the current production configuration. Motor #3 was tested using a (7)-unit EMI filter network, a proposed solution. Both filter networks (FIGS. 6 and 7) were placed inside the respective motor units and sealed, with tape placed over the plastic end caps.

To power the motors for the tests, a 12V battery was connected to a three-meter cable having two conductors (+12V & Ground) (FIG. 4).

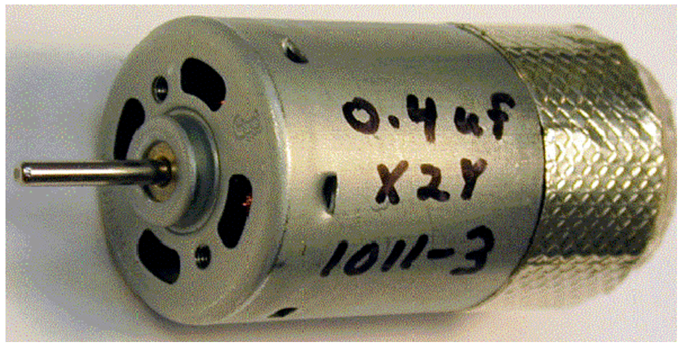

Figure 3. *DUT shown with Tin-plated Copper Foil Tape Applied*

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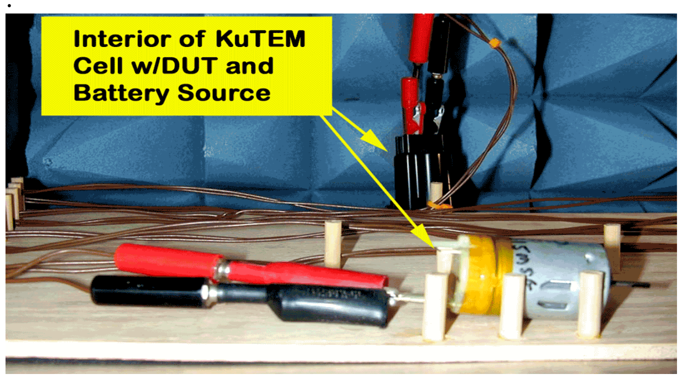

Figure 4. *Baseline DUT shown inside KuTEM Omni-Cell*

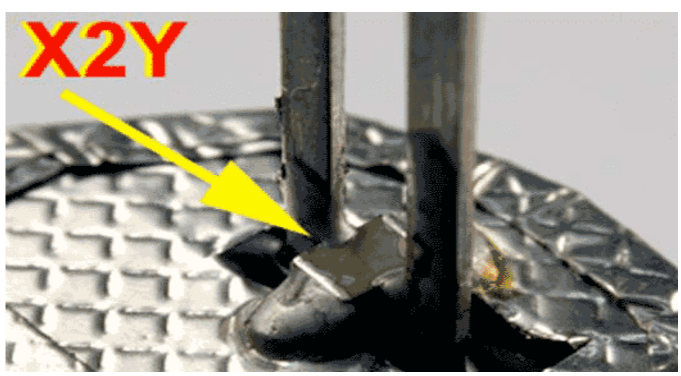

Figure 5. *Attachment External to DUT*

V. The Filter Configurations

The filter used on Motor #3 (FIG. 6) was a (7)-unit component design placed internally. It included (2) 7.5 uH inductors to limit the amount of noise that passed through. It also used (2) X-capacitors, 0.47 uF and 1000 pF, to bypass the noise to ground and to the metal motor case. The filter network also used (2) ferrite beads that provided high impedance at the frequencies of the unwanted noise. The beads' ferromagnetic material absorbed the noise and dissipated it as heat, due to a time varying magnetic field. The final component in the network was a relatively expensive 0.47 uF MOV Cap-Varistor placed across the power leads to clamp the noise to 14 Volts and bypass any remaining noise to ground. This type of filter network in a small motor cap leaves no remaining space.

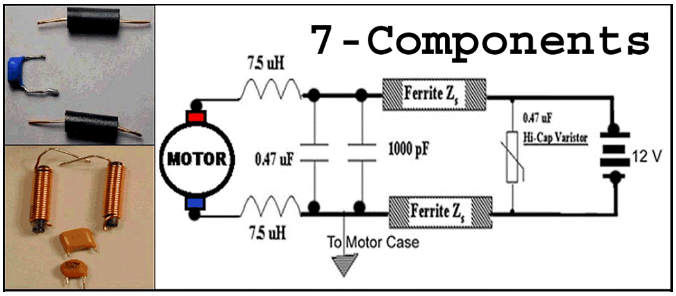

Figure 6. *(7) Component Motor Filter Network.*

The filter used internally on Motor #2 (FIG. 7) was a (4)-unit component network that used (2) ferrite beads to provide high impedance at the frequencies of the unwanted noise. A 0.47 uF MOV Cap-Varistor was also utilized to clamp the noise to 14 volts. (2) 0.47 uF Y-capacitors were also connected from the power leads to the motor case ground to bypass the remaining noise to the internal motor shell.

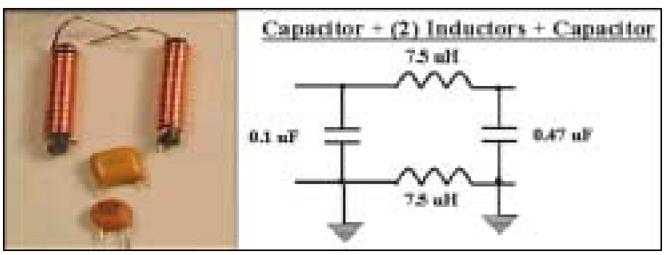

Figure 7. *(4) Component Motor Filter Network.*

The filter placed in Motors #1, #4, and #5 (FIG. 8) was a 1410 sized X2Y (1)-unit chip. X2Y layered architecture combines a unique electrode layering method with an internal image plane between capacitor plates to minimize internal inductance and resistance. Alternating electrode layering allows opposing internal skin currents that are essentially 180 degrees out of phase to cancel. The mutual inductance can be positive, negative, or zero. This device was designed to have its' internal mutual inductance fields cancel (FIG. 9).

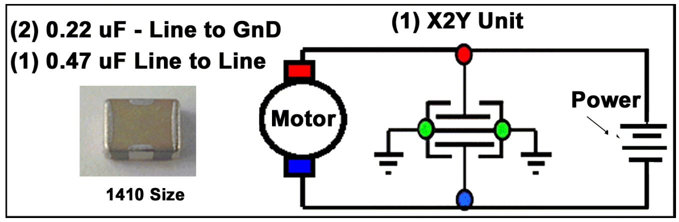

Figure 8. *(1) Component Motor Filter Unit.*

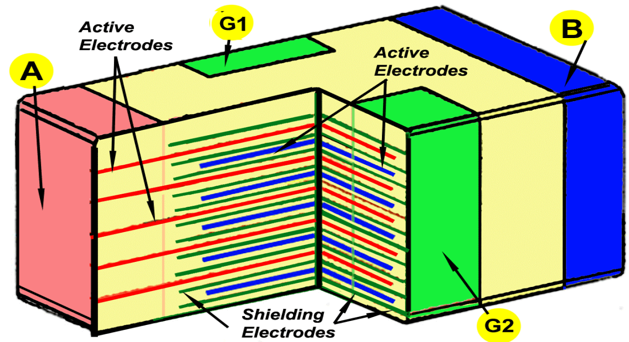

Figure 9. *X2Y® Shielding Electrode Architecture*

VI. Test Results

In Figure 10, the fine dotted color or gray lines represent the raw data to 1000 MHz. To clarify the reading of the data, a 5-point polynomial moving average was used and displayed with a thick line. A comparison of the different filters shows that the X2Y (1)-unit filter (FIG. 8), used on Motors #1, #4, and #5, gave the best performance. This filter provides between 25 to 50 dB of attenuation from 150 kHz to 1000 MHz. The 4-component filter, used in Motor #2 (FIG. 7), provides between 20 to 35 dB of attenuation from 40 MhZ to 250 MHz, but then the filter starts to lose performance.

Figures 11 and 12 show the test data over the frequency ranges from 150 kHz to 500 MHz and from 500 MHz to 1000 MHz, respectively. FIG. 11 shows that Motor #3, configured with the (7)-component filter network, does the best of the two network filter solutions. However, due to the costs of the passive components alone (particularly the varistor unit), this solution is economically unviable today. Of the three separate motor units configured for this test using the X2Y (1)-unit filter (placed externally on Motors #1, #4 and #5), it is noted that all three emissions level results were closely grouped together.

Any differences seen in the radiated emissions data between each of the three single filter motors can be attributed to variations in motor contact resistance occurring at the load bearing points of the graphite brushes on the surface of the copper commentator segments, rather than to the filter. Of course, any practical, cost effective improvements to the quality of the motor commutation will reduce the amount of "brush arcs" radiating a portion of the unwanted energy prior to the filter circuit. It should also be pointed out that the results

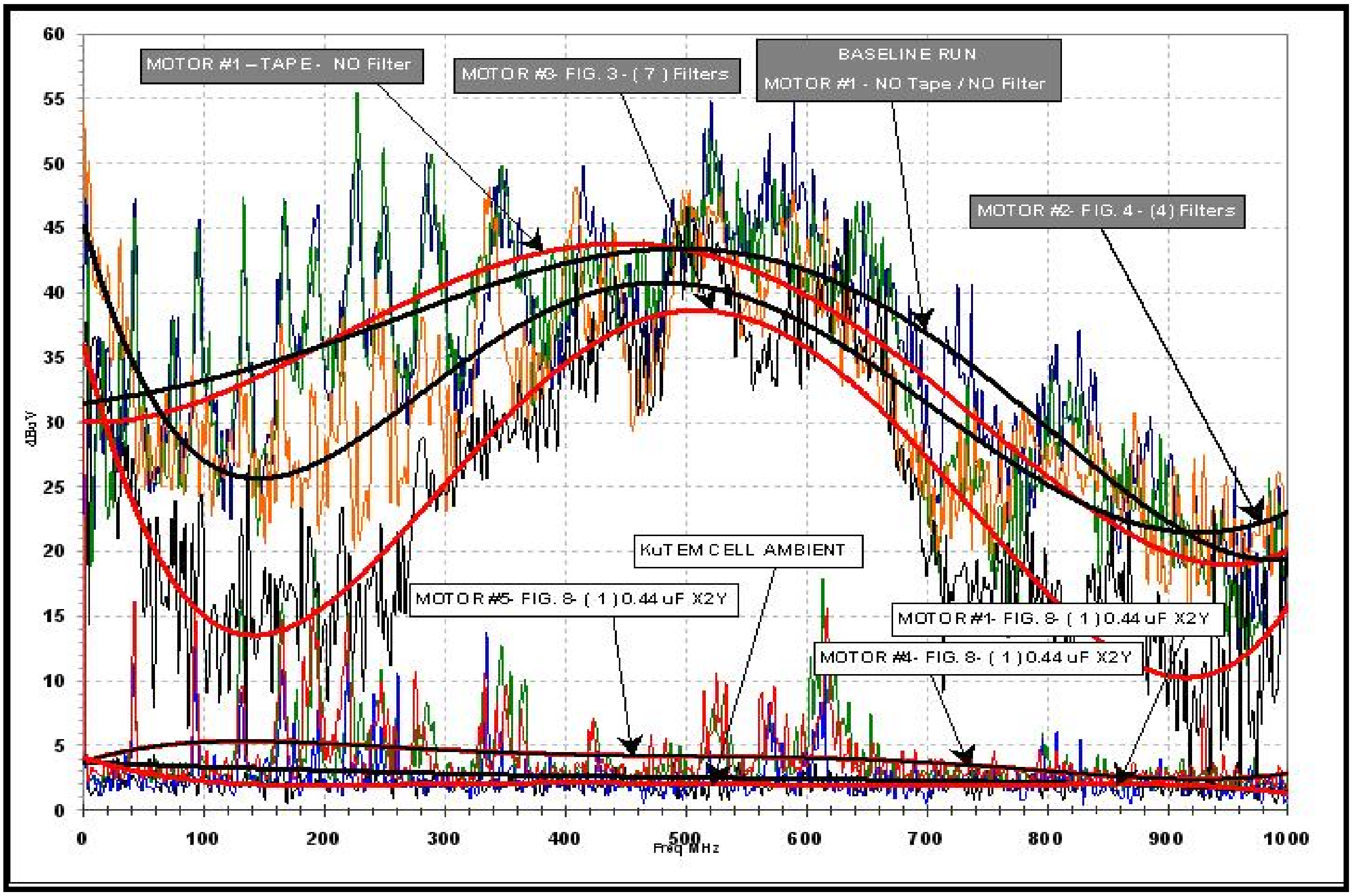

Figure 10. *Radiated Emission from 150 kHz to 1000 MHz.*

show that use of the tin-plated copper foil tape had minimal effect on the RF noise suppression of the motors and has been disregarded by the authors as a significant factor in achieving the results obtained.

VII. Filtering Techniques

Filtering results similar to those shown in Figures 10 through 12 can and are currently being obtained in other motor applications with placement of the X2Y (1)-unit filter internally within the motor itself. If one or both connections of G1 and G2 are not made, the filtering will not be optimized.

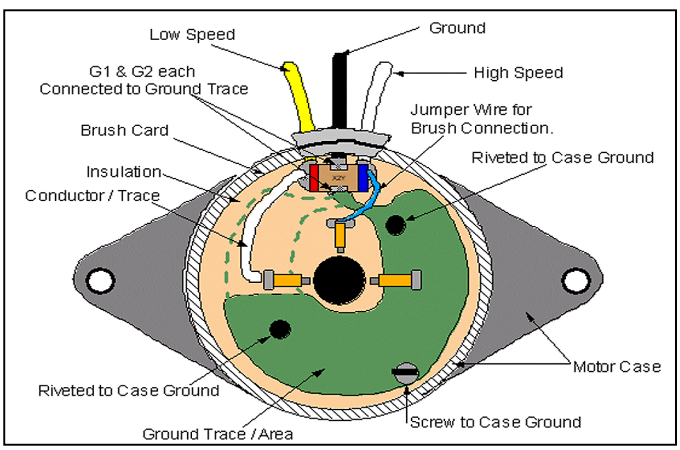

Figure 13. *Typical X2Y placement inside a DC Motor*

When placing the unit on the brush card holder (large motors) or end cap (small motors), differential power leads should be placed as tight as possible to the unit. (Placement is exaggerated in Figure 13, below). The G1 & G2 attachments are very essential to any filter solution and both terminals must be attached to the same voltage-potentialed GnD area, usually on the brush card or the internal motor case.

VIII. Conclusion

When all of the different variations are taken into account, the X2Y architecture performs better than the other motor filters in the attenuation of the unwanted conducted energies. From the test results shown in this paper and previous papers [7], the one-component filter did not need additional components to enhance filtering performance. The attenuation results attributed to the X2Y architecture do not emulate a normal filter and reach almost 40 dB per decade. A combination of functions, such as cancellation of mutual inductance, physical and electrostatic shielding, and the bypassing of common and differential mode noise to a third pathway, are all utilized by this new architecture filter and contribute to the best performance results for this test series. Along with a lower cost factor, this new technology should have the least significant impact on the additional space required to house a suppression circuit.

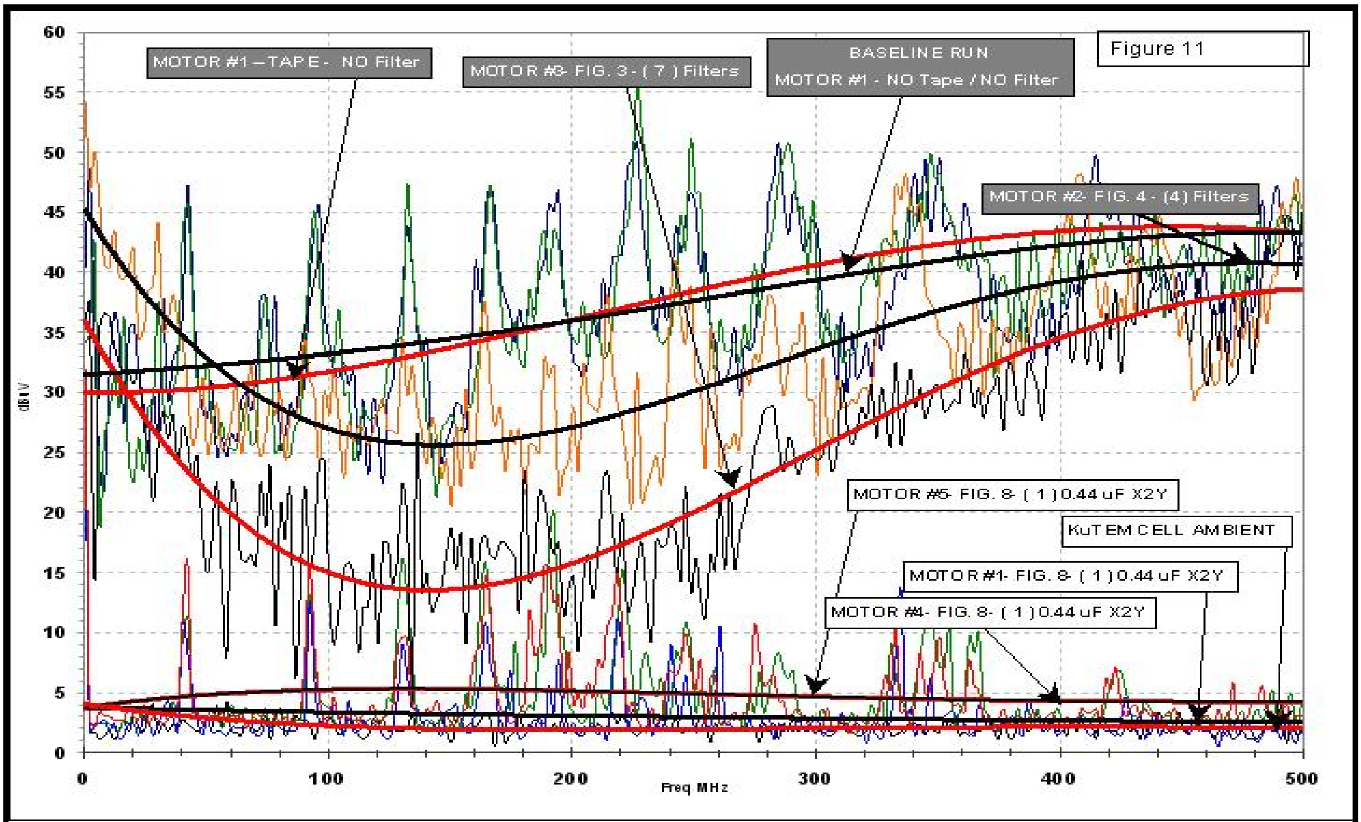
Figure 11
MOTOR #1 – TAPE - NO Filter
MOTOR #3- FIG. 3 - (7) Filters
BASELINE RUN
MOTOR #1 - NO Tape / NO Filter
MOTOR #2- FIG. 4 - (4) Filters
MOTOR #5- FIG. 8- (1) 0.44 uF X2Y
KuTEM CELL AMBIENT
MOTOR #1- FIG. 8- (1) 0.44 uF X2Y
MOTOR #4- FIG. 8- (1) 0.44 uF X2Y
dBuV
Freq MHz
0
100
200
300
400
500
5
10
15
20
25
30
35
40
45
50
55
60

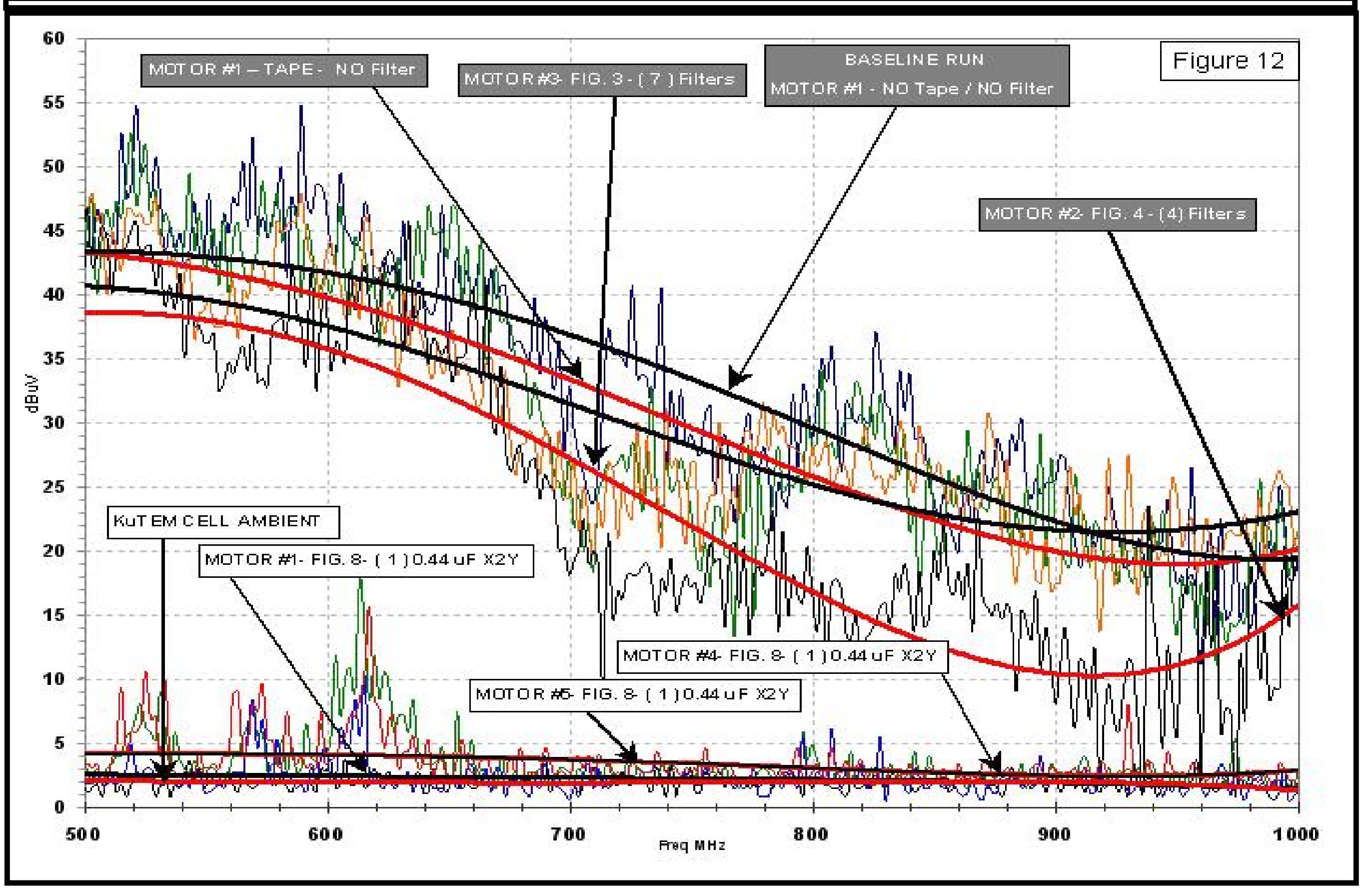
Figure 12
MOTOR #1 – TAPE - NO Filter
MOTOR #3- FIG. 3 - (7) Filters
BASELINE RUN
MOTOR #1 - NO Tape / NO Filter
MOTOR #2- FIG. 4 - (4) Filters
KuTEM CELL AMBIENT
MOTOR #1- FIG. 8- (1) 0.44 uF X2Y
MOTOR #4- FIG. 8- (1) 0.44 uF X2Y
MOTOR #5- FIG. 8- (1) 0.44 uF X2Y
dBuV
Freq MHz
500
600
700
800
900
1000
0
5
10
15
20
25
30
35
40
45
50
55
60

VIIII. References and Footnotes

[1] U.S. Patent 5,142,430, U. S. Patent 5,903,350, U.S. Patent 6,018,448; U.S. Patent 6,097,581 and other US and International Patents Pending owned by X2Y Attenuators, LLC.

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Anthony A. Anthony is the inventor of the X2Y Circuit and Layered Technology, which is contained in (2) issued U.S. Patents. Additionally, Tony is sole inventor or co-inventor of (5) issued and (51) filed International and US patents and patents pending, all of which are related to X2Y Technology. He is the founder and managing partner of *X2Y Attenuators, LLC*. (http://www.x2y.com)He has enjoyed a 35-year career in the electronic components industry and was formerly with *Erie Technological Products, Murata/Erie* and *Spectrum Control, Inc*. as a National Sales/Applications Engineer. Mr. Anthony has extensive experience in EMC design applications and holds a B.S.E.E. from the United States Naval Academy. Tony can be reached by e-mail at: tony@x2y.com

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James P. Muccioli is senior vice-president of *X2Y Attenuators, LLC*. (http://www.x2y.com) He has extensive experience in EMC design, analysis, and testing. He is a NARTE certified EMC and ESD engineer, an active member of SAE J-1113 and J-551 EMC committees, and chairman of the SAE Integrated Circuit EMC Task Force. Mr. Muccioli was a member of the Board of Directors of the IEEE EMC Society (1993-1998) and was selected as an IEEE Fellow in 1998 for contributions to integrated circuit design practices to minimize electromagnetic interference. He is inventor or co-inventor of over 25 issued and pending US and International Patents. He teaches seminars on EMC through his consulting firm, *Jastech EMC Consulting, LLC* (http://www.jastech-emc.com), and taught undergraduate courses on EMC at Lawrence Technological University and the University of Michigan-Dearborn. Jim can be reached by e-mail at: jastech@telocity.com.

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