Broadband KuTEM Omni-Cell Testing of Small DC Motors for a Low Cost Filter Solution

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Abstract

Four small DC motors with filters or filter network configurations are tested for radiated emissions using a broadband KuTEM Cell. The broadband KuTEM Cell provides good correlation to Open Area Test Sites (OATS) working between 150 kHz to 1000 MHz for most small, in-production or proposed DC motor filter solutions. Testing will compare three typical, multiple component filter configurations and a new single unit, multi-layered circuit architecture that can be packaged in standard passive component, industry specified sizes (0805, 1206, etc.) [1] [2]. The test configuration and methodology allow for analytical comparisons of DUT configurations in order to create a cost vs. suppression performance decision matrix.

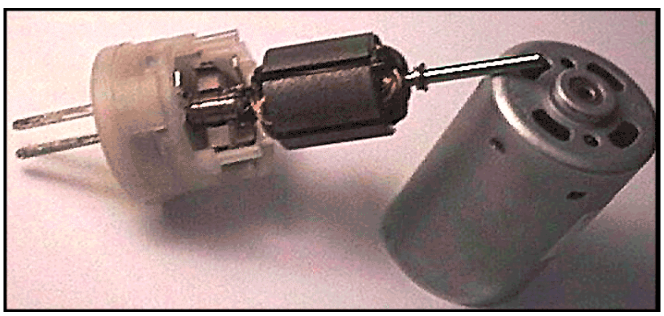

Figure 1. Washer Pump DC Motor Assembly.

Introduction

Use of DC motors in electronic modules has increased dramatically in recent years. Volume application usages range from as many as 100 motors in a typical luxury automobile, to a single motor in a rewind camera or power tool. Other high volume applications include printers, consumer electronics, industrial automation modules, etc. A very common, yet critical problem associated with these types of motors is their RF emissions and the ramifications they produce in the radio wave spectrum. In general, an electrical motor is a very noisy RF source that can easily interfere with other electronic devices through common and differential mode noise on the power lines. Once the common and differential mode noise rises above a certain frequency on the power lines, these lines tend to act like an antenna and radiate energy into free space. Substantial RF noise is generated from a small DC motor by the high speed switching which occurs at angular velocities as high as 23,000 to 24,000 rpm at 12 V DC. The best way to prevent a motor from interfering with the surrounding environment is to suppress its RF noise at the source. Economics, however, commonly place constraints or limitations on what actually can be done with a low cost DC motor to arrive at an acceptable RF emissions level. An unsuppressed small DC motor costs less than $1.00 US.

Recently, regulations and noise allowance thresholds have forced filter and suppression component combination solutions to represent a large percentage of the total cost of an unsuppressed DC motor. An ideal goal for filtering the 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 design or re-tooling changes that can have serious economic impact upon a DC motor's application viability should be minimized. Inherent to any filter solution derived from testing is the prevention of any increase to the motor package size resulting from the need to house these filter components internally. Figure 1 shows the small washer pump DC motor assembly.

Test Methodology

In an earlier paper, "Noise Measurement on a Small Motor using Different Types of Suppression" [3], a miniature current probe was used to take quantitative measurements of the currents (magnetic fields) generated by the electrical motor on the power leads. A current probe was used in a non-shielded room because only the magnetic fields related to the electromagnetic radiation potential of the electrical motor affect the probe and it is relatively insensitive to stray electrical fields. However, because a non-shielded room was used, the ambient noise was high in the AM and FM bands as a result of the local radio stations coupling to the motor power leads.

A broadband KuTEM Cell is used for radiated emissions measurements as a result of several IEEE papers showing good correlations to Open Area Test Sites working up to 1 GHz [4] [5]. The KuTEM Cell provides an effective solution for making accurate and quantitative measurements of various filter configurations with 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 100 kHz to 1000 MHz. The resolution is set to 9 kHz and the video bandwidth is turned off so that the spectrum analyzer does not filter the signals being analyzed. The DUT is run in a steady state condition to minimize variability in the data and the spectrum analyzer is set to capture the signal in peak hold mode. The duration on the motor running is to capture four complete sweeps in peak hold mode on the spectrum analyzer.

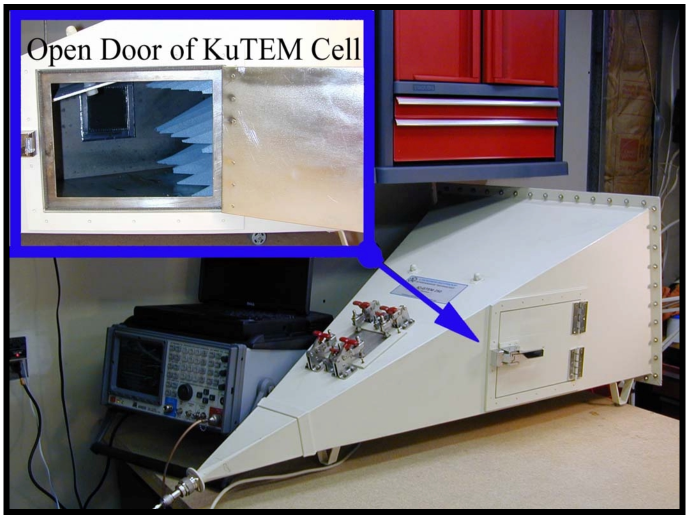

Figure 2. KuTEM Omni-Cell with spectrum analyzer.

Test Configuration

The device under test is a small production washer pump motor, which is tested with four different filter configurations, shown in Figures 5 through 8. The motor is characterized in normal condition and then with the different types of filtering. A 12 V battery connected to a three-meter cable having two conductors (+12 V & ground) is used to power the motor. The test fixture is made out of wood and has wooden dowels to hold the motor and the three-meter cable in place, as shown in Figure 4. The first measurement made is with an unfiltered motor placed in the broadband KuTEM, without the +12 V energy source connected, to get an ambient measurement. Then the test is repeated with the motor powered up to set the baseline. The test is repeated several more times to gather data with all of the different filter configurations.

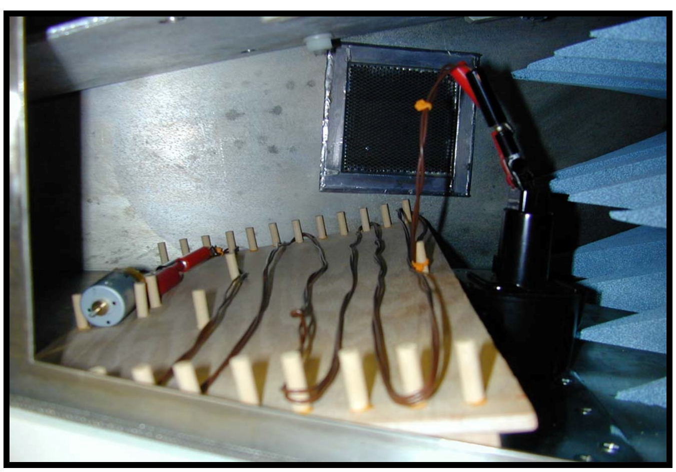

Figure 3. Test fixture inside KuTEM Omni-Cell.

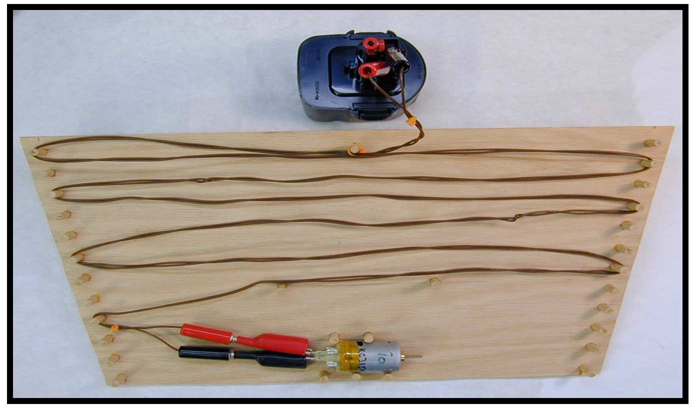

Figure 4. Wooden test fixture.

Filter Configurations

The first motor filter shown in Figure 5 is a (7) component design that includes (2) 7.5 uH inductors to limit the amount of noise that passes through and then uses (2) X-capacitors, 0.47 uF and 1000 pF, to bypass the noise to ground and to the motor case. The filter network also uses (2) ferrite beads that provide high impedance at the frequencies of the unwanted noise. The beads' ferromagnetic material used in the circuit absorbs the noise and dissipates it as heat, due to a time varying magnetic field. The last component in the network is a 0.47 uF Cap-Varistor placed across the power leads to clamp the noise to 14 Volts and bypass any remaining noise to ground.

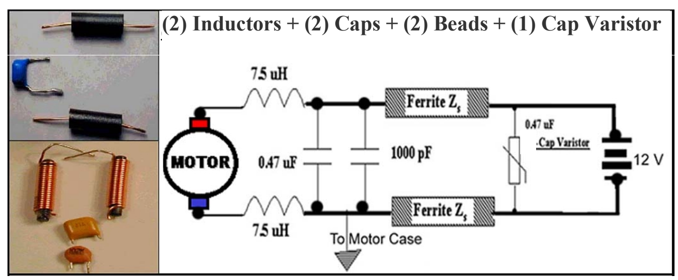

Figure 5. A (7) component motor filter.

The second type of filter shown in Figure 6 is a (5)-component network that starts with (2) ferrite beads that provide high impedance at the frequencies of the unwanted noise and uses a 0.47 uF Cap-Varistor to clamp the noise to 14 volts. (2) 0.47 uF Y-capacitors are also connected from the power leads to motor case ground to bypass the remaining noise to ground.

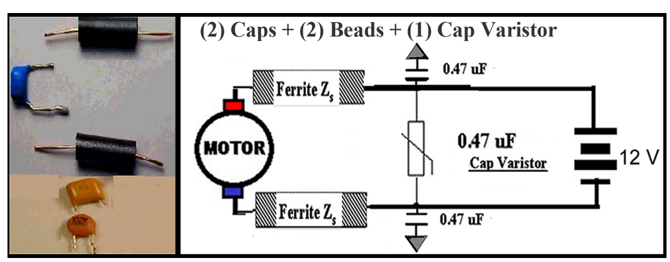

Figure 6. A (5) component motor filter.

The third type of filter network, shown in Figure 7, uses (1) 1000 pF X-capacitor to bypass the noise to ground and the motor case. Then (2) 7.5 uH inductors limit the noise and a second X-capacitor at 0.47 uF bypasses the remaining noise to ground and the motor case.

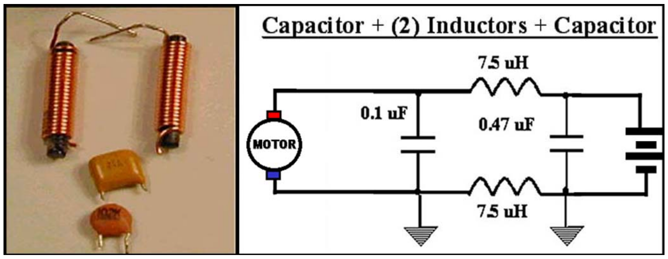

Figure 7. A (4) component motor filter.

The last type of filter, shown in Figure 8, is a 1410 sized (1) single unit chip. This chip is configured in what is called an X2Y® layered architecture that combines an unique electrode layering method and uses 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 out. The mutual inductance can be positive, negative, or even zero. This device was designed to have its' internal mutual inductance fields cancel. [6]

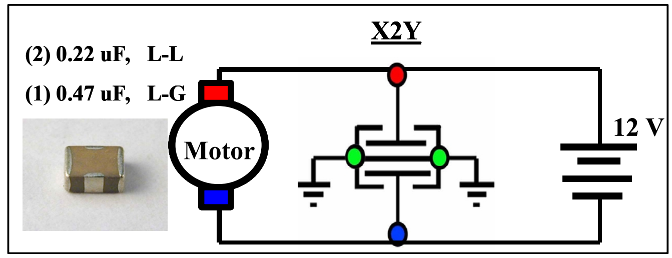

Figure 8. A (1) component motor filter.

Test Results

In Figure 9, the fine gray lines represent the raw data. To clarify the reading of the data, a 10-point moving average was used and displayed with a thick line. A comparison of the different filters used in the motor shows that the one component filter, shown in Figure 8, gave the best performance. This filter, made with the X2Y architecture, provides between 25 to 50 dB of attenuation from 150 kHz to 1000 MHz. The 5-component filter, shown in Figure 6, provides between 25 to 40 dB of attenuation from 150 kHz to 180 MHz, but then the filter starts to lose performance.

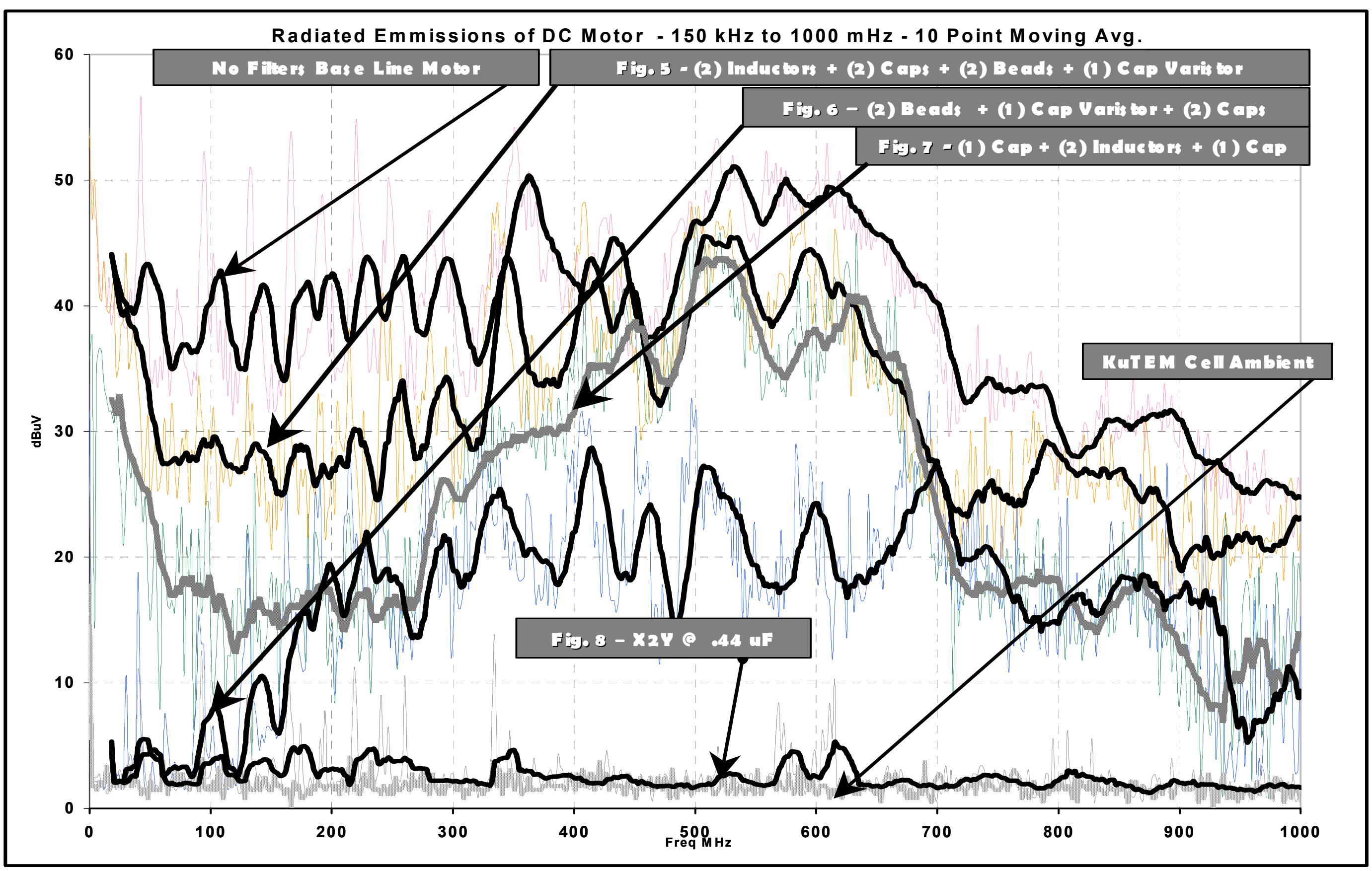

Figure 9. Radiated emission from 150 kHz to 1000 MHz.

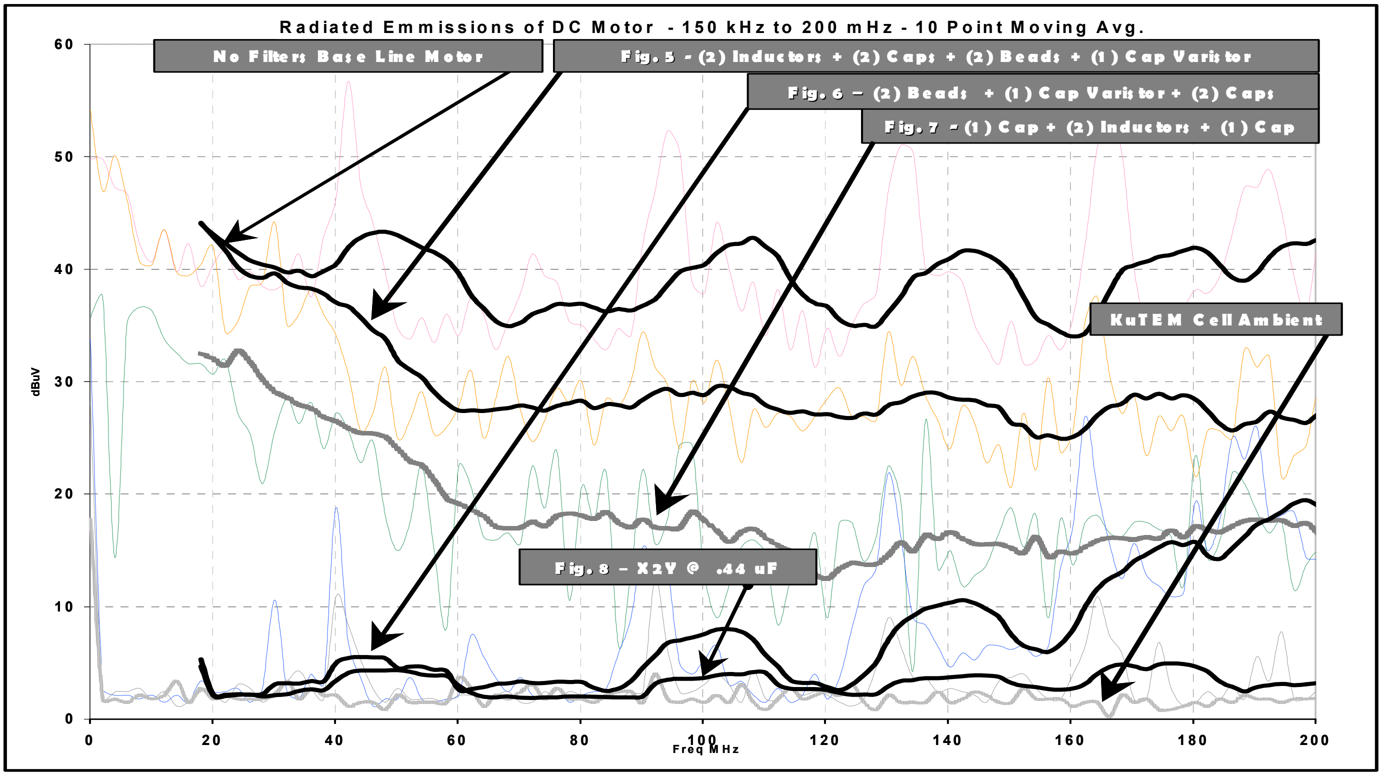

Figure 10. Radiated emission from 150 kHz to 200 MHz.

Figure 10 shows the frequency range from 150 kHz to 200 MHz so that motor noise affecting AM, FM and Two-way radio bands can be analyzed.

Figure 11 shows the variation in radiated emissions of two small DC motors built up with the X2Y filter. The filter has been measured and shown to have a worst-case tolerance of 2.9% from line to line.

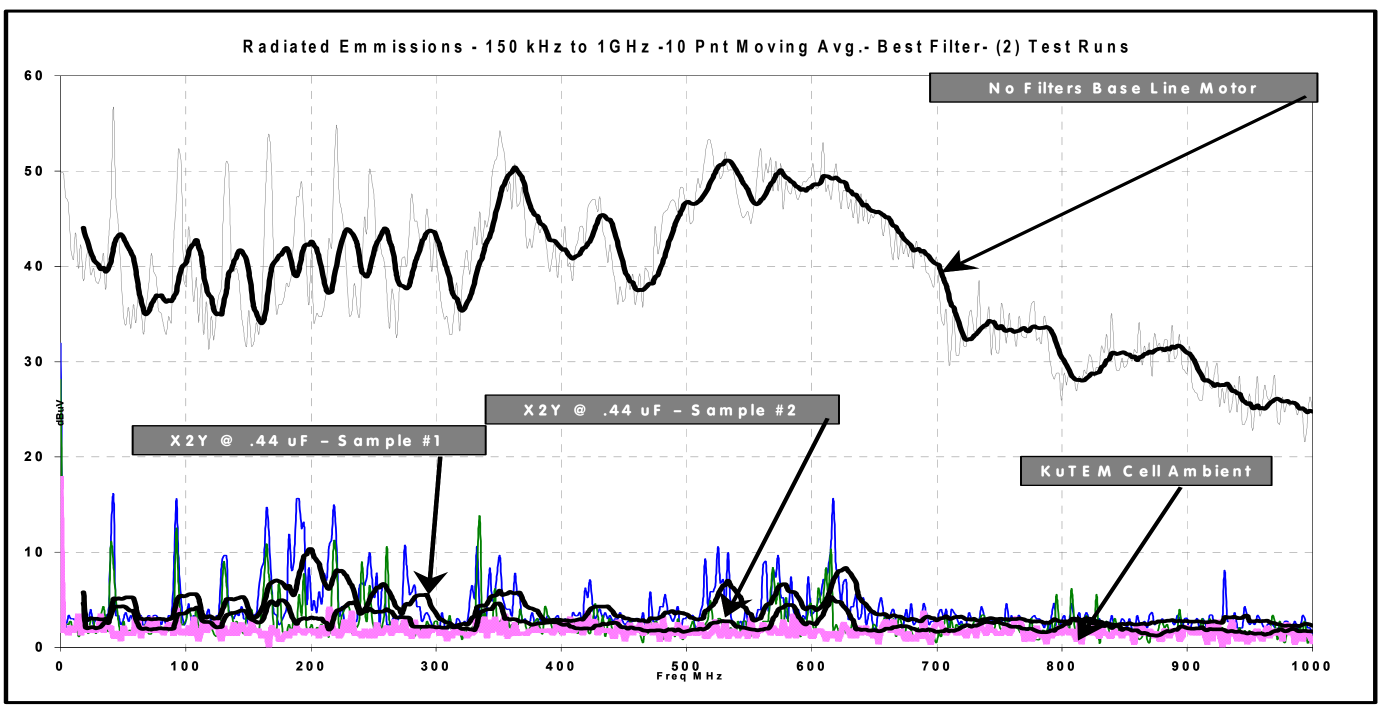

Figure 11. Radiated emission of (2) different DC motors using X2Y architecture.

In a normal dual line filter, 1% tolerance parts would be required to match the worst-case tolerance of the one-component filter.

The difference in the radiated emissions data 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 commutator 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. 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.

Filtering Techniques

In order to obtain the filtering results shown in Figures 9 through 11, the brush card holder (large motors) or end cap (small motors) needs to have the power leads as shown in Figure 12, so X2Y architecture can cancel the noise before it leaves the motor.

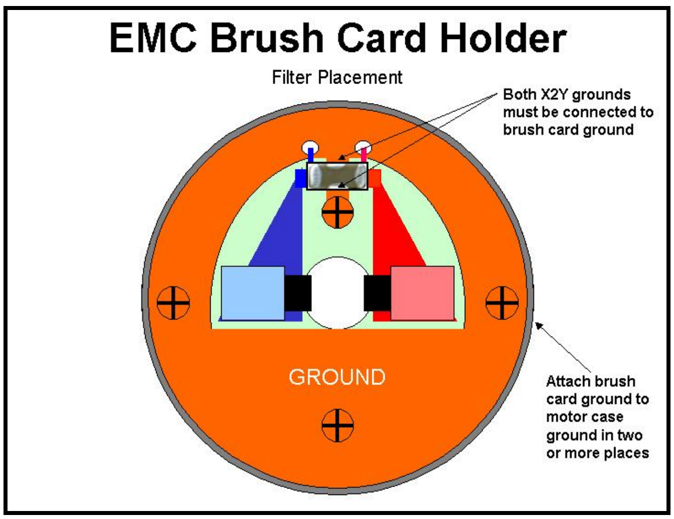

Figure 12. EMC brush cardholder.

Conclusion

The test methodology used to measure the radiated emissions of the small DC motors in a broadband KuTEM Omni-Cell proved to be very repeatable and easy to run. The wooden test fixture was very instrumental in allowing the DC motors to be changed and placed back in the same location in the KuTEM Omni-Cell. The test results shown in this paper illustrate the different types of DC motor filters and how they react in an open field site.

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 mutual inductance internal to the X2Y architecture cancels, which allows the common and differential mode noise to cancel. This cancellation effect is the reason the one-component filter does not emulate a normal filter at 20 dB per decade. The layered architecture allows a combination of cancellation and bypassing of common and differential mode noise at the source.

After analyzing the test data and packaging requirements, the X2Y architecture filter proved to have the best performance, lowest cost, and least significant impact on the additional space required to house the suppression circuit.

References

[1] U.S. Patent 5,142,430, U. S. Patent 5,903,350, U.S. Patent 6,018,448

[2] Morrison, D., *Capacitive Technology Filters and Decouples with Fewer Parts*, Electronic Design - February 7, 2000 Volume 48, Number 3.

[3] Muccioli, J.P., *Noise Measurement on a Small Motor using Different Types of Suppression*, November 1, 1999, Interference Technology Engineer's Master (ITEM ™), Robert D. Goldblum, Editor, R & B Enterprises 20 Clipper Road, West Conshohocken, PA 19428-2721, USA

[4] Clay, Stephen, *Improving the Correlation between OATS, RF Anechoic Room and GTEM Radiated Emissions Measurements for Directional Radiators at Frequencies between approximately 150 MHz and 10 GHz*, IEEE 1998 International Symposium on Electromagnetic Compatibility, Denver CO, IEEE 1998 Electromagnetic Compatibility Symposium Record, August 1998, Volume 2, pg. 1119-1124

[5] Kim, Soo-hyung, Nam, Jung-young, Jeon, Hynn-goo, Lee, Sung-kook, *A Correlation Between The Results of The radiated Emission Measurements in GTEM and OATS*, IEEE 1998 International Symposium on Electromagnetic Compatibility, Denver CO, IEEE 1998 Electromagnetic Compatibility Symposium Record, August 1998, Volume 2, pg. 1105-1109

[6] Walker, C. S., *Capacitance, Inductance and Crosstalk Analysis*, p.102, Artech House, Inc., Norwood, MA, 1990

[7] Muccioli, J.P., Anthony, A.A., *Dynamic Testing Of A Dual Line Filter For Common And Differential Mode Attenuation using a Spectrum Analyzer*, April 1, 2000, Interference Technology Engineer's Master (ITEM ™), Robert D. Goldblum, Editor, R & B Enterprises 20 Clipper Road, West Conshohocken, PA 19428-2721, USA