Broadband testing of low-cost filter solutions for dc motors

The increased use of DC motors in automotive and consumer electronics necessitates the suppression of RF emissions at the source.

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In an earlier paper,[1] four small DC washer pump motors (Figure 1) with EMI filters or EMI filter network configurations were tested for radiated emissions using a broadband KuTEM Cell (Figure 2). Because of the unexpected results achieved with a new single component filter, requests were made to the authors to provide further testing validation in the form of an even more closely scrutinized series of tests. The test series presented in this paper provides a correlation of three earlier test runs 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 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 single component filter, a multilayered circuit architecture packaged in standard passive component, industry specified sizes.[2, 3] Motor #2 was tested using the current production filtering configuration. 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. Motors #4 and #5 were also tested using the single component filter, to insure that earlier test results for this filter were not anomalies. 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.

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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.

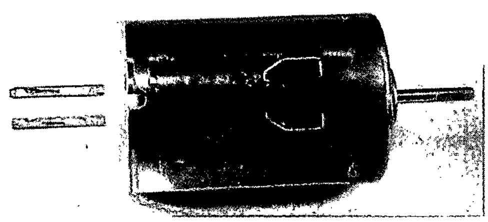

Figure 1. A DC washer pump motor.

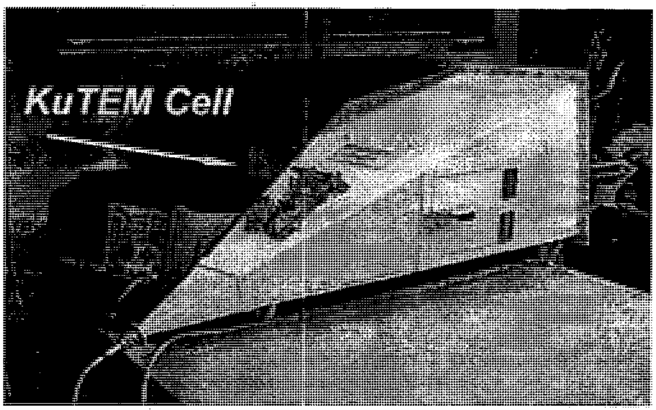

Figure 2. A KuTEM Omni-Cell with spectrum analyzer.

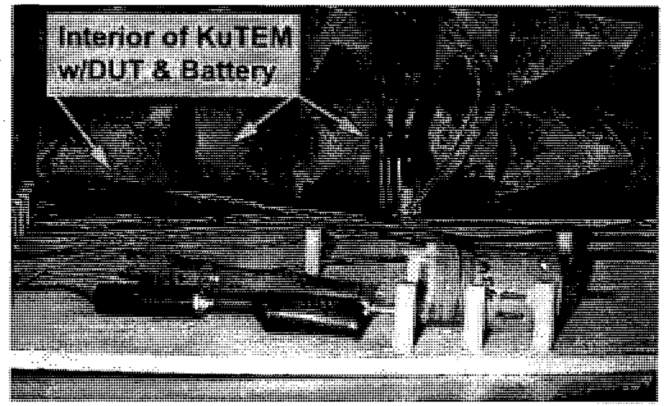

Figure 4. Baseline DUT shown inside KuTEM Omni-Cell.

Other high volume applications include printers, consumer electronics, power tools, industrial automation modules, etc. All have gained dramatically in terms of sales to 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 to 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 VDC.

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 redesign and retooling changes on the motor itself can have serious economic impact upon any DC motor's application viability.

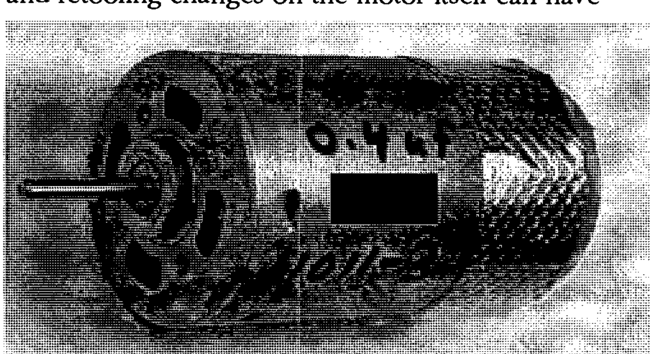

Figure 3. DUT shown with tin-plated copper foil tape applied.

TEST METHODOLOGY

A broadband KuTEM Cell was used for radiated emissions measurements because it can provide good correlation to Open Area Test Sites working at up to 1 GHz.[1, 4, 5] The KuTEM Cell setup provides an effective solution for making accurate and quantitative measurements of various DC filter configurations on small motors because of its characteristically low ambient noise floor. The spectrum analyzer used in this test is an IFR AN920 (9 kHz–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.

TEST CONFIGURATION

The DUTs are five randomly chosen, small production washer pump motors. Motors #2 and #3 had a total run time documented at 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 run time 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 (Figure 4). When the DUTs were switched-out, the cable assembly, connections, and the fixture itself were not moved. Only the DUT was changed for each test run. To begin the test procedure, an ambient measurement was required. The unfiltered Motor #1 was placed in the broadband KuTEM and attached to cabling but the + 12 V 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 step was taken to provide a complete explanation of the tape's effectiveness for this motor test series and the previously run test series, as well. All other motors (#1 through #5) tested afterward also used the tin-plated copper foil tape (Figure 3).

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.

Motors #1, #4, and #5 were configured with the proprietary single component filter (Figure 8) placed external to the noise source, directly attached on top of the conductive tape already in place (Figure 5). Solder connections were made to the tape as well as to the two power pins, to attempt to capture and to 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 (Figures 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 12 V battery

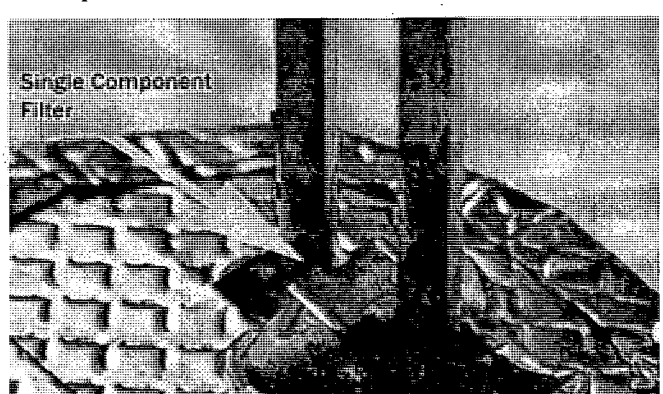

Figure 5. Attachment external to DUT.

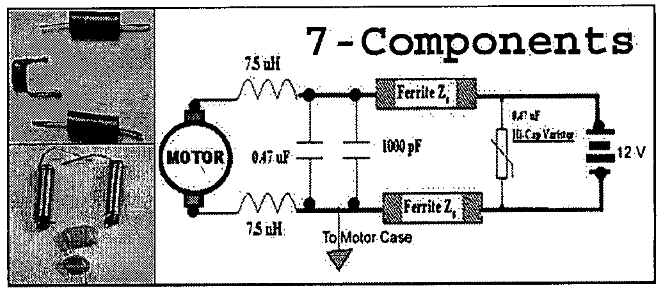

Figure 6. Component motor filter network.[1]

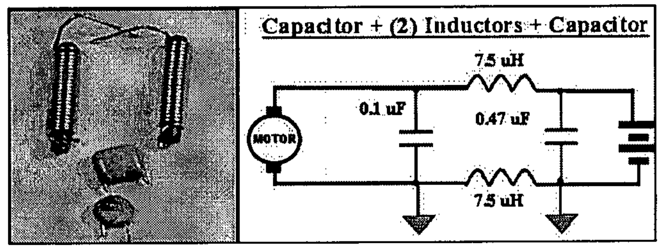

Figure 7. 4-component motor filter network.

was connected to a three-meter cable having two conductors (+12 V & ground) (Figure 4).

THE FILTER CONFIGURATIONS

The filter used on Motor #3 (Figure 6) was a 7-unit component design placed internally. It included two 7.5 µH inductors to limit the amount of noise that passed through. It also used two X-capacitors, 0.47 µF and 1000 pF, to bypass the noise to ground and to the metal motor case. The filter network also used two 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 µF MOV Cap-Varistor placed across the power leads to clamp the noise to 14 V and to bypass any remaining noise to ground. This type of filter network in a small motor cap leaves no remaining space.

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

The filter placed in Motors #1, #4, and #5 (Figure 8) was a 1410-sized 1-unit chip. This 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,

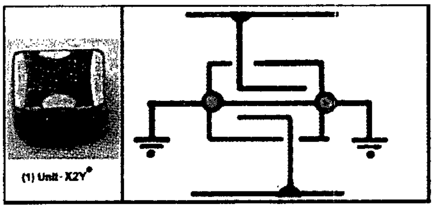

Figure 8. Single component motor filter unit.

negative, or zero. This device was designed to have its internal mutual inductance fields cancel (Figure 9).

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 single component filter (Figure 8), used on Motors #1, #4, and #5, gave the best performance. This filter provided between 25 to 50 dB of attenuation from 150 kHz to 1000 MHz. The 4-component filter, used in Motor #2 (Figure 7), provided between 20 to 35 dB of attenuation from 40 MHz to 250 MHz, but then the filter performance starts to degrade.

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. Figure 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 not economically viable today. Of the three separate motor units configured for this test using the single component filter (placed externally on Motors #1, #4 and #5), it should be 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 commutator segments, rather than to the filter.

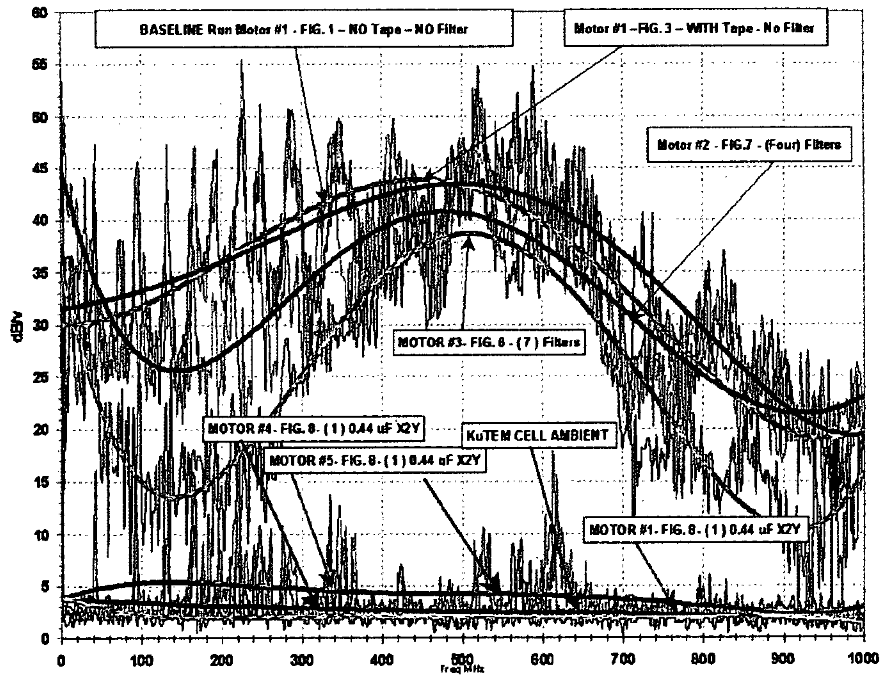

Figure 10. Radiated emission from 150 kHz to 1000 MHz.

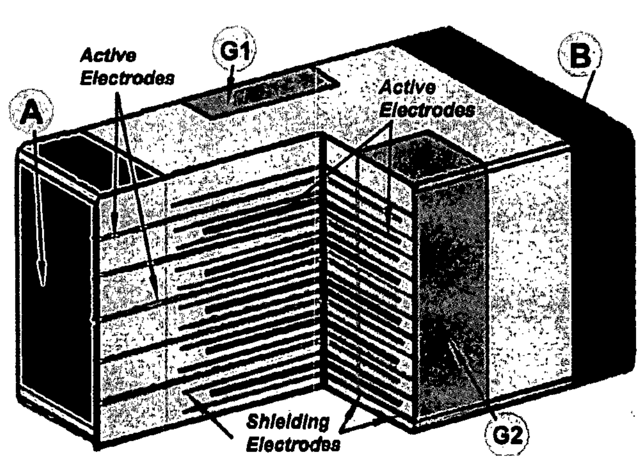

Figure 9. Internal, shield-active electrode architecture.

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 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.

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 single component filter internally within the motor itself. If one or both connections of G1 and G2 are not made, the filtering will not be optimized.

When placing the unit on the brush card holder (large motors) or end cap (small motors), differential power leads should be placed as close as possible to the unit. (Placement is exaggerated in Figure 13). The G1 & G2 attachments are

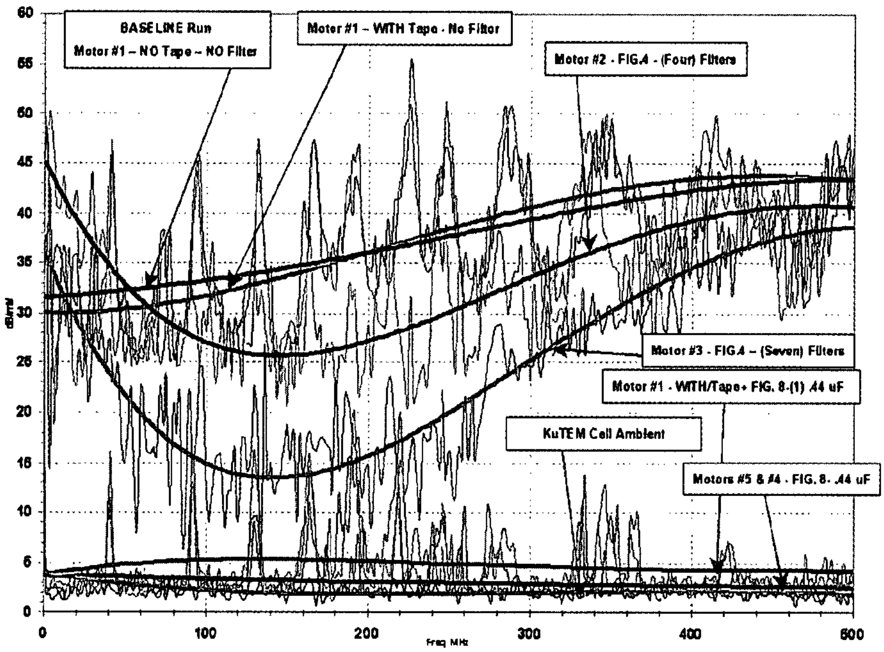

Figure 11. Radiated emission from 150 kHz to 500 MHz.

vital to any filter solution: and both terminals must be attached to the same voltage-potentialed ground area, usually on the brush card or the internal motor case.

CONCLUSION

When all of the different variations are taken into account, the single component filter 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[1], the one-component filter did not need additional components to enhance filtering performance. The attenuation results attributed to the single component filter 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.

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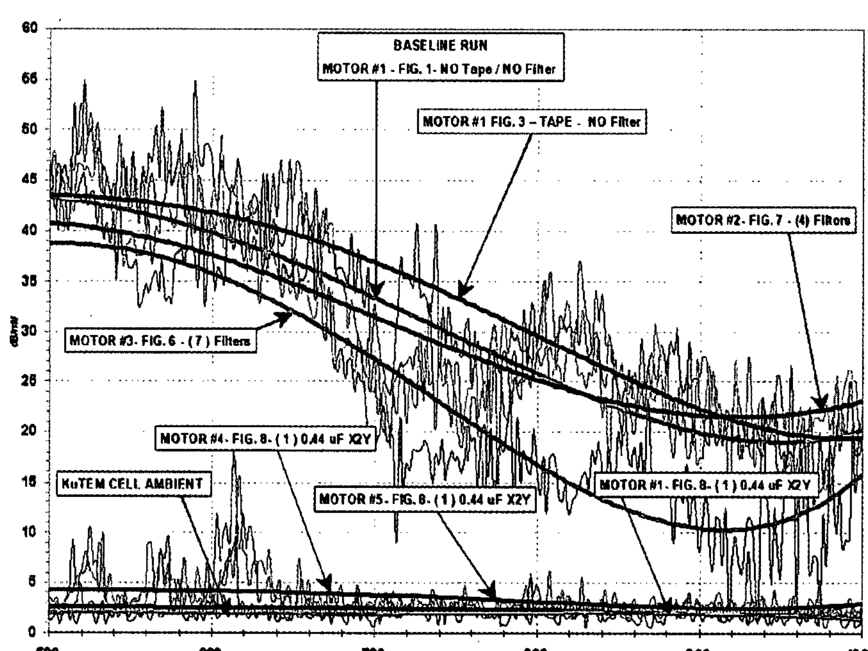

Figure 12. Radiated emission from 500 MHz to 1000 MHz.

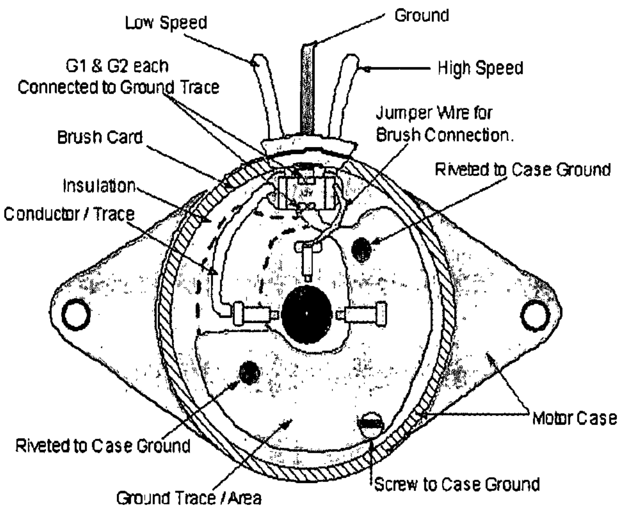

Figure 13. Typical single component filter placement inside a DC Motor.

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