

Achieving Correlation of Radiated RF Immunity Testing Performed in an Absorber Lined Shielded Enclosure and a Mode Tuned Reverberation Chamber

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I. INTRODUCTION

Today, automotive, military and aerospace specifications allow for the use of either an Absorber Lined Shielded Enclosure (ALSE) or a Mode Tuned Reverberation Chamber (MTRC) to perform radiated RF immunity testing on electronic modules. Even though both methods are acceptable to the industry, they can provide significantly different test results. In using these alternative methods, it is important that both methods correlate with each other. This study shows that the MTRC radiated immunity equations currently used in the automotive industry do not provide adequate correlation with radiated immunity testing performed in an ALSE. Therefore, correlation issues exist between the two methods which need to be remedied.

This paper first evaluates the correlation of results between the ALSE and the MTRC radiated RF immunity testing performed to automotive industry standards. Further, this paper provides data which supports the use of a reference ground plane in a MTRC without adversely effecting test results. Finally, this paper addresses possible causes for the lack of correlation and the use of innovative equations which achieve correlated results between the two test methods.

II. APPLICABLE STANDARDS

Automotive, Military and Aerospace standards allow the user to select either ALSE or MTRC methods for the execution of radiated RF immunity testing on an electronic module. The standards that will be referenced and/or discussed in this paper include the following:

- GMW3097 [1]
- Ford ES-XW7T-1A278-AC [2]
- MIL-STD-461E [3]
- RTCA DO-160E [4]
- ISO 11452-2 [5]
- ISO WD 11452-11 [6]
- SAE J1113-28 [7]
- IEC 61000-4-21 [8]

III. ALSE and MTRC TESTING OVERVIEW

The automotive OEM standards (GMW3097 and Ford ES-XW7T-1A278-AC) reference ISO 11452-2 for ALSE field calibration and test methods. The automotive standards (GM, FORD and SAE J1113-28) utilize portions of both IEC 61000-4-21 and RTCA DO-160E for Mode Tuned Chamber characterization and test procedures.

ALSE TESTING: During ALSE testing, the DUT and wiring harness are typically placed on and elevated 5 cm above a reference ground plane. The required test RF field intensity is measured and characterized prior to application to the Device Under Test (DUT). The field calibration is performed without the DUT and wiring harness located on the reference ground plane. The required field is generated and measured with an Isotropic Field probe. Typically the vector sum (root sum square) of the three axes of the isotropic probe is used as the value for determination of the field being generated. The forward power to the antenna is measured and recorded at the required test field intensity. The power determined during the field calibration is then applied to the antenna during the test on the DUT (substitution method). The GMW3097 ALSE test is performed with the DUT oriented in three orthogonal axes and with the transmitting antenna in horizontal and vertical polarizations. At frequencies below 1 GHz, the antenna is positioned at a location 0.75 meters down the wiring harness. At frequencies above 1 GHz, the antenna is positioned at a location to directly illuminate the DUT. The ALSE radiated immunity test setup is illustrated in Figure 1.

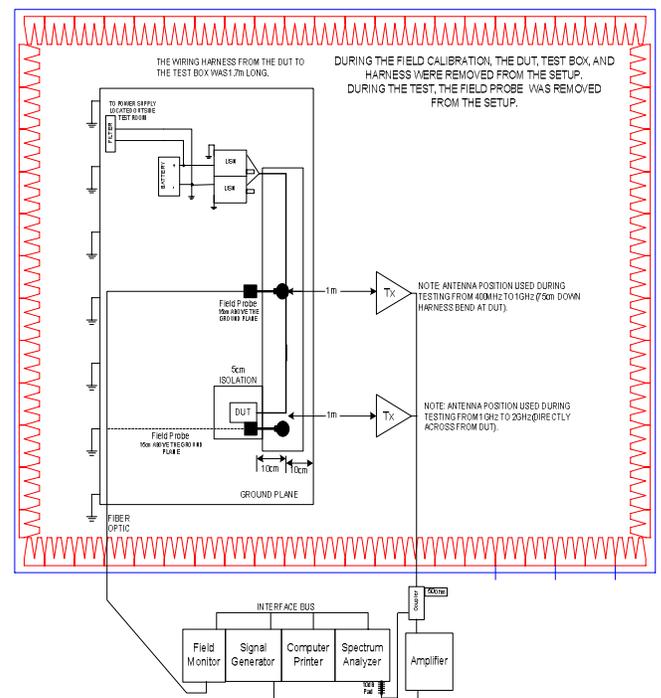


Figure 1 – Setup for GMW/Ford Radiated Immunity Testing in an ALSE

MTRC TESTING: During MTRC testing, the DUT and wiring harness are typically located on low dielectric (Styrofoam) blocks which are 1 meter high (no ground plane).

An extensive characterization of the MTRC is required prior to any testing on a DUT. The chamber characterization only needs to be done once in the lifetime of the chamber. If internal modifications are made to the chamber, characterization should be repeated.

At each frequency and tuner position, the characterization procedure collects Isotropic E-field probe data (maximum data only), chamber input power, and the maximum and mean received power from a reference antenna placed within the working volume. Probe data are collected from nine locations that form the corners of the “volume of uniform field” or “working volume”. Each time the probe is moved to a new location, the reference antenna is moved to a new location within the working volume. The probe data is used to determine the field uniformity. The probe data and chamber input power is used to determine the chamber calibration factor. Both the mean-received-power from the reference antenna and the chamber input power is used to determine the Antenna Calibration Factor (ACF). The ACF is used as a reference value when determining if the chamber has been loaded by a DUT. The maximum received power from the reference antenna is used to verify the probe readings. The uniformity of the field will depend upon the number of tuner positions (N) used to collect the data. For a relatively modest number of tuner steps (i.e. 12), a reasonably uniform field can be obtained. The number of tuner steps may need to be increased to optimize performance and meet specified field uniformity requirements. The minimum number of tuner steps should not be less than twelve.

Using the minimum twelve (12) tuner steps and nine (9) isotropic probe/receive antenna positions within the working volume, a total of 108 measurements of Tx Power, Rx Power, Probe X Field, Probe Y Field, Probe Z Field at each frequency will result. If the number of tuner steps needs to be increased to improve field uniformity, this will result in more data points.

Once the chamber data is recorded throughout the frequency range of interest, the results are used with the equations of the applicable standard to determine the power that must be delivered to the chamber to generate the required test RF field intensity.

Illumination of the entire DUT and wiring harness is possible without the need of multiple DUT orientations and antenna polarizations. The MTRC radiated immunity test setup is illustrated in Figure 2.

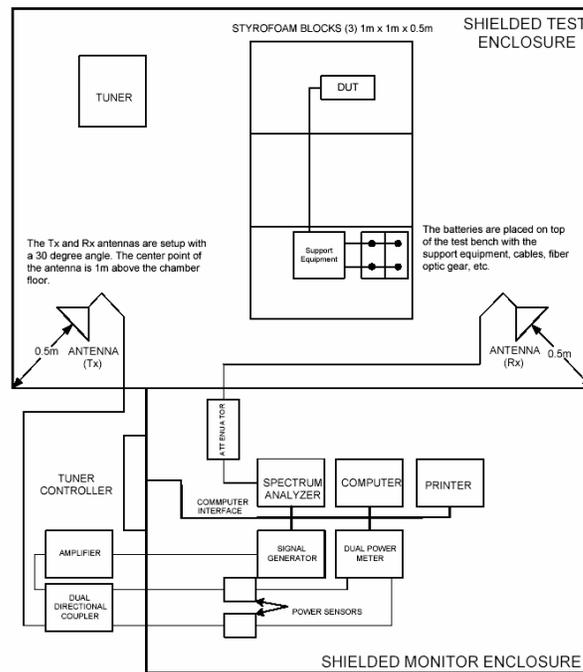


Figure 2 – Setup for GMW/Ford Radiated Immunity Testing in an MTRC

IV. ISSUES

ISSUE #1: Currently, automotive industry standards allow the use of either ALSE or MTRC testing to determine compliance. Although the different methods are allowed, utilizing one or the other should not produce substantially different results. Does the present use of the ALSE and MTRC test methods produce equivalent data?

ISSUE #2: The test setups are different between Automotive ALSE and MTRC radiated immunity testing. One key difference between the two methods is the use of a reference ground plane during ALSE testing. No reference ground plane is used during MTRC testing. How does the presence or absence of a reference ground plane affect the test results when using the MTRC method?

ISSUE #3: The lack of correlation in results between the two test methods may be found in the equations used to process the MTRC data obtained during chamber characterization. All the standards take the same data during the MTRC chamber characterization. However, the equations used to process the MTRC data are inconsistent between the MIL, DO-160 and Automotive standards. This inconsistency can result in a large variance of the RF power required to achieve the same test field intensity. Which MTRC formulas achieve the best correlation with ALSE testing? Figure 3 shows the calculated field intensity (Present Automotive vs MIL-STD vs DO-160) with 1 watt delivered to the MTRC. The MIL-STD and DO-160 equations result in calculated fields that are quite similar. The equations and data reduction used in the automotive standards results in considerably lower calculated fields.

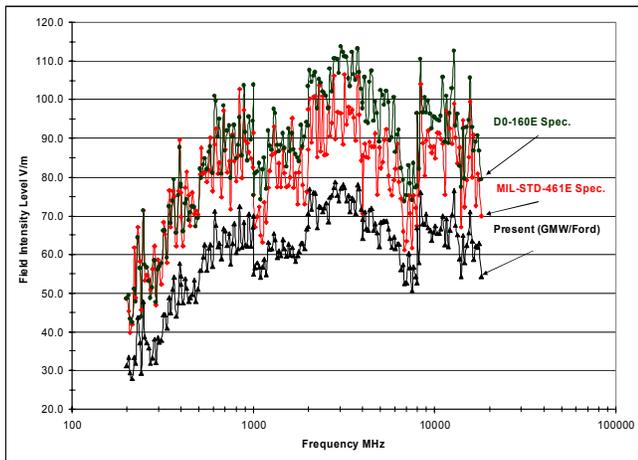


Figure 3 – MTRC Normalized Electric Field V/m/W Present Automotive(GM/Ford) vs MIL-STD vs DO-160

V. TESTING PERFORMED AND RESULTS

DO PRESENT ALSE AND MTRC METHODS CORRELATE (Section IV, Issue #1)?

An electronic module with known susceptibility to the GMW3097 ALSE radiated immunity test was selected as the correlation test sample. The module was a 12 Vdc sensor that was cylindrical in shape. It had a diameter of 2 cm and a length of 9 cm. The output of the sensor was a variable duty cycle pulse signal. The module showed responses in the 400 MHz to 1 GHz frequency range during the ALSE radiated immunity testing. The lowest thresholds measured on the device, in all three DUT orthogonal axes, and both antenna polarizations, are shown in Figure 4. Testing on other samples submitted for testing produced similar results.

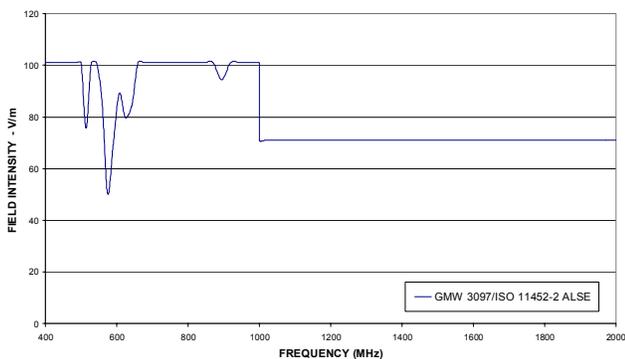


Figure 4 – GMW 3097 ALSE Radiated Immunity Results on Correlation Sample (Minimum Thresholds all DUT Axis and Antenna Polarizations)

The same sample and wiring harness was then tested in a MTRC using the equations of GMW 3097 specification. It is to be noted that the MTRC equations in the Ford and SAE standards are the same as the formulas used in the GMW 3097 standard. The MTRC data (plotted with the ALSE data) are shown in Figure 5. As can be seen, the MTRC testing showed many more frequencies of response and the measured thresholds levels were much lower.

The data in Figure 5 confirms that the two methods are not equivalent and correlation is not achieved using both methods. While the MTRC test found more responding frequencies and lower threshold levels, the ALSE radiated immunity testing has been successfully used for many years to evaluate automotive electronic modules. Although MTRC radiated immunity has been around for several years, it is relatively new to the automotive industry. Radiated immunity test levels established for component testing in a laboratory environment have been correlated with radiated immunity testing done at the vehicle level and real life situations. If ALSE radiated immunity testing at the component level is sufficient to show acceptable performance in the vehicle, a more stringent MTRC test is not needed. In fact, a more stringent MTRC test may result in unnecessary added cost to the DUT. The fields established during the ALSE calibration are based upon actual fields measured with an isotropic probe while the fields generated in a MTRC are based upon the chamber characterization, data reduction and calculations. Are the equations used for data reduction and field calculation correct?

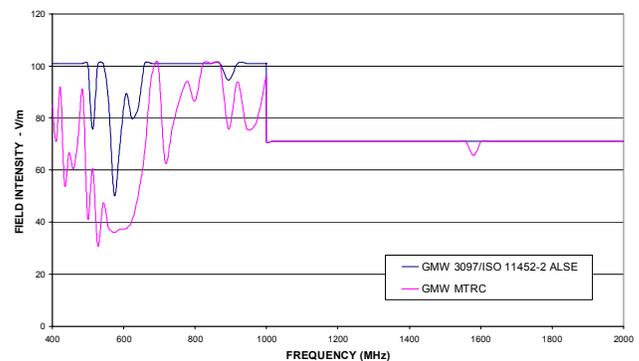


Figure 5 – GMW 3097 Radiated Immunity Results ALSE vs MTRC on Correlation Sample

WHAT IS THE EFFECT OF THE REFERENCE GROUND PLANE (Section IV, Issue #2)?

To show how the reference ground plane affects the test results, the GMW MTRC radiated immunity test was performed again with the DUT and wiring harness elevated 5cm above a reference ground plane (ALSE setup). The use of a reference ground plane is typical for ALSE and MTRC testing performed to the MIL-STD and DO-160 standards.

The MTRC data obtained with and without the reference ground plane is shown in Figure 6. The data shows that, although the frequencies of response and thresholds shifted slightly, the reference ground plane did not significantly affect the test results. This test data provides information recently requested by the ISO committee regarding the use of a reference ground plane for MTRC radiated immunity testing. The ground plane does not significantly change the test results, and therefore could be used within the MTRC.

A reference ground plane would be beneficial in cases where a DUT had a metal case and required local grounding. This would also allow for grounding of support equipment if necessary.

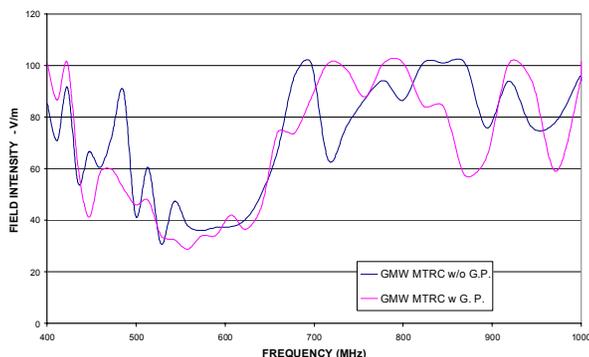


Figure 6 – GMW 3097 MTRC Radiated Immunity Results on Correlation Sample With and Without a Reference Ground Plane

WERE THE EFFECTS SEEN DURING THE MTRC TESTING DUE TO DUT ORIENTATION, CASE PENETRATION AND PCB COUPLING (Section IV, Issue #2)?

During GMW3097 radiated immunity testing in the ALSE, tests are performed with the DUT oriented in three orthogonal axes and with the transmitting antenna in horizontal and vertical polarizations. At frequencies below 1GHz, the antenna is positioned at a location 0.75 meters down the wiring harness. At frequencies above 1GHz, the antenna position is centered on the DUT.

During radiated immunity testing in the MTRC, the entire DUT and wiring harness is illuminated with RF from all directions. This eliminates the need for multiple DUT orientations and antenna polarizations.

It was possible that the DUT case/PCB board was not sufficiently illuminated during the ALSE testing in the 400 MHz to 1 GHz frequency range. Most of the responses on the correlation sample occurred below 1 GHz during both the ALSE and MTRC tests. The antenna is located 0.75 meters down the cable during ALSE tests in the 400 MHz to 1 GHz frequency range. To determine if the correlation issue was due to DUT case penetration and PCB coupling, the DUT was setup and tested again in the ALSE chamber. The test was repeated in the 400 MHz to 1 GHz frequency range with the following conditions:

a) The transmitting antenna was positioned directly in front of the DUT (same position typically used above 1 GHz). Sweeps were performed with all six sides of the DUT (six axis test) facing the transmitting antenna. Both transmit antenna polarizations were utilized.

b) Step (a) was repeated with the transmitting antenna positioned 0.25 meters down the wiring harness.

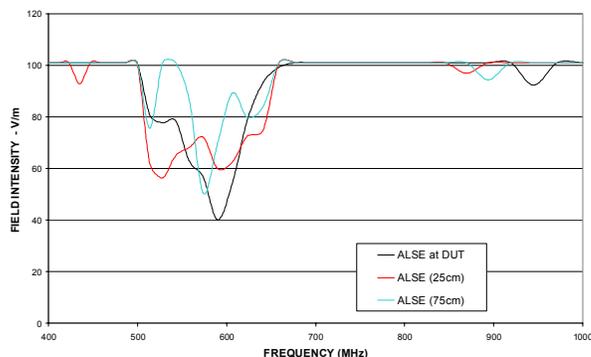


Figure 7 – GMW 3097 ALSE Radiated Immunity Results on Correlation Sample (Minimum Thresholds all DUT Axis and Antenna Polarizations) Transmit Antenna at DUT vs 0.25 cm vs 0.75 cm Down Harness

The 6 DUT axis test data (along with the original ALSE data) is shown in Figure 7. The data in Figure 7 shows that some thresholds measured were lower than the original data. However, this data did not result in a significant change that would show correlation with the GMW 3097 MTRC data.

Ultimately, this very thorough ALSE test did not show the susceptibilities observed during the MTRC test. This data further reinforces the theory that the equations used in the automotive (GMW, Ford and SAE) standards do not accurately calculate the field generated inside the MTRC chamber.

CAN THE CORRELATION BETWEEN METHODS BE IMPROVED BY USING ANOTHER SET OF PUBLISHED MTRC EQUATIONS (Section IV, Issue #3)?

All experiments to this point show that the equations and calculations used in the automotive MTRC specifications may not accurately calculate the field generated inside the MTRC chamber. Although the MIL-STD and DO-160 equations for determining the field generated inside the MTRC are different, the calculated field with 1 watt into the chamber are relatively close (see Figure 3). The difference between the Automotive and DO-160 calculated fields is a consistent 3 dB (+/-0.6 dB). For this reason, a test was performed on the correlation sample in the MTRC using the field calculations of DO-160.

The data from this test (along with the original ALSE data) is shown in Figure 8. The data in Figure 8 shows that, there was an improvement in the correlation. The difference was still significant enough to investigate further.

Table 1– Radiated Immunity Results on Correlation Sample
GMW 3097 ALSE vs MTRC (Proposed MNRSSFC Method)

Frequency (MHz)	FIELD INTENSITY GMW 3097/ISO 11452-2 ALSE (V/m)	FIELD INTENSITY MTRC "MNRSSFC" METHOD (V/m)
400.0	101.0	101.0
411.2	101.0	101.0
422.8	101.0	101.0
434.7	101.0	101.0
446.9	101.0	101.0
459.5	101.0	101.0
472.4	101.0	101.0
485.7	101.0	101.0
499.3	101.0	82.6
513.4	75.6	101.0
527.8	100.9	54.3
542.6	101.0	93.7
557.9	86.4	65.2
573.6	50.4	64.0
589.7	69.6	66.6
606.3	89.2	64.0
623.3	79.8	73.2
640.9	84.0	92.0
658.9	101.0	101.0
677.4	101.0	101.0
696.4	101.0	101.0
716.0	101.0	101.0
736.2	101.0	101.0
756.8	101.0	101.0
778.1	101.0	101.0
800.0	101.0	101.0
822.5	101.0	101.0
845.6	101.0	101.0
869.4	101.0	101.0
893.8	94.4	101.0
919.0	101.0	101.0
944.8	101.0	101.0
971.4	101.0	101.0
998.7	101.0	101.0
1000.0	101.0	101.0

Note: Data points showing levels less than 101 V/m were frequencies in which DUT effects were observed and the associated threshold amplitude at that frequency. No DUT effects were occurring at the 101 V/m test levels shown.

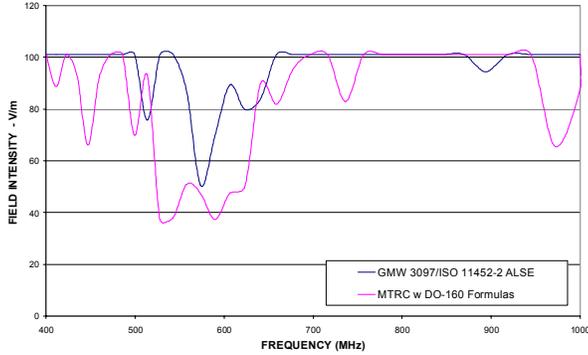


Figure 8 – Radiated Immunity Results on Correlation Sample
GMW 3097 ALSE vs MTRC (DO-160 Calculations)

CAN THE CORRELATION BETWEEN METHODS BE IMPROVED WITH A NEW SET OF EQUATIONS FOR THE MTRC (Section IV, Issue #3)?

Several attempts were made to modify the equations to achieve correlation between ALSE and MTRC methods. After using several variations of the published equations and retesting the correlation sample in the MTRC, a set of equations that correlated very well with the ALSE test results were discovered. For this paper, the new set of equations has been named the “Maximum Normalized RSS Field Computation (MNRSSFC)” method.

The MTRC data obtained used with new MNRSSFC equations (along with the original ALSE data) is shown in Figure 9 and Table 1. The data supports the theory that very good correlation between ALSE and MTRC results can be achieved with the use of the MNRSSFC equations.

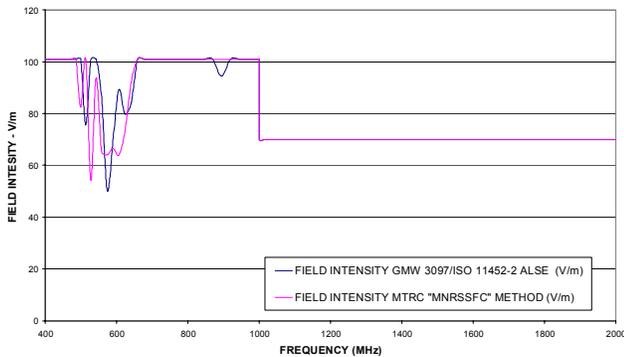


Figure 9 – Radiated Immunity Results on Correlation Sample
GMW 3097 ALSE vs MTRC (Proposed MNRSSFC Method)

VI. MODE TUNING “MAXIMUM NORMALIZED RSS FIELD COMPUTATION” METHOD FOR ALSE CORRELATION

The formulas for “Maximum Normalized RSS Field Computation” are described in Steps (1) through (6). These equations can be applied to existing chamber data. Re-characterization of the chamber is not required as long as the chamber data required for MNRSSFC computation was obtained during the initial characterization.

The formulas are to be applied to the data obtained at each chamber characterization frequency. The computations will determine the power needed at each frequency to achieve the required test field intensity.

1. Compute the Root Sum Square (RSS) E-field for each tuner step at all probe positions using the individual probe (x, y and z) axis readings.

$$E_{RSS(TunStep)} = \sqrt{E_{X(TunStep)}^2 + E_{Y(TunStep)}^2 + E_{Z(TunStep)}^2} \quad (1)$$

$TunStep = Tuner\ step$

2. Find the maximum RSS E-Field of all tuner steps for each probe position.

$$E_{MaxRSS(PPos)} = MAX(E_{RSS(1)}, E_{RSS(2)}, \dots, E_{RSS(TotSteps)}) \quad (2)$$

$PPos = Probe\ position$
 $TotSteps = Total\ tuner\ steps$

3. Compute the average forward input power to the chamber for all tuner steps at each probe position.

$$P_{TxAve(PPos)} = \frac{\sum_{TunStep=1}^{TotSteps} P_{Tx(TunStep)}}{TotSteps} \quad (3)$$

$PPos = Probe\ positions$
 $TotSteps = Total\ tuner\ steps$

4. Compute the maximum normalized RSS E-Field for each probe position.

$$E_{MaxNormRss(PPos)} = \frac{E_{MaxRss(PPos)}}{\sqrt{P_{TxAve(PPos)}}} \quad (4)$$

$PPos = Probe\ positions$

5. Find the maximum normalized RSS field of all probe positions.

$$E_{TotMaxNormRss} = MAX(E_{MaxNormRss(1)}, E_{MaxNormRss(2)}, \dots, E_{MaxNormRss(TotPPos)}) \quad (5)$$

$TotalPPos = Total\ probe\ positions$

6. The required forward test power is then computed with the formula:

$$P_{TxReq} = \left[\frac{E_{Req}}{E_{TotMaxNormRss} * \sqrt{CLF}} \right]^2 \quad (6)$$

$E_{req} = Required\ test\ field$
 $CLF = Chamber\ Loading\ Factor\ obtained\ from\ DUT\ loading\ calibration$

Figure 10 shows the calculated field intensity (Present Automotive vs MIL-STD vs DO-160 vs Proposed MNRSSFC Automotive) with 1 watt delivered to the MTRC. The data in Figure 10 shows that the MNRSSFC method results in a much higher field than the calculations currently used in the automotive industry. Not only does this method of calculating the field in the MTRC better correlate with the ALSE data, much less RF power is required to achieve the test field intensity.

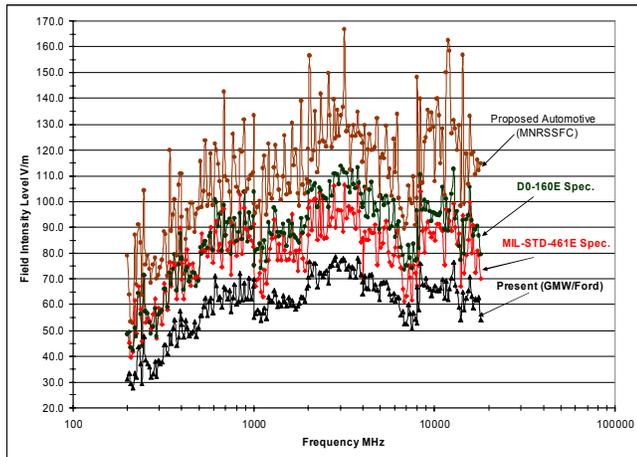


Figure 10 – MTRC Normalized Electric Field V/m/W Present Automotive(GM/Ford) vs MIL-STD vs DO-160 vs MNRSSFC

VII. CONCLUSION

This study has shown that very good correlation can be achieved between ALSE and MTRC radiated immunity testing by using the MNRSSFC equations discussed in Section VI of this document. The main focus of this study was the correlation of methods used in the automotive industry. More research would be required to determine the correlation of MIL-STD and DO-160 ALSE and MTRC radiated immunity methods currently considered equivalent.

This study has also provided data needed by the ISO committee currently working on ISO WD 11452-11. This project has showed that the equations currently used in the automotive industry are not adequate to provide correlation with ISO 11452-2. Equations were developed that will provide correlation between ISO 11452-2 (ALSE) and the ISO 11452-11 (MTRC) specifications. This paper provided test data which supports the use of a reference ground plane in a MTRC without adversely affecting the test results. This will allow automotive suppliers to better test a DUT that has a metal case which requires local grounding. This would also allow for grounding of support equipment if necessary.

ACKNOWLEDGMENT

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