A Partitioned MoM Scheme for Treating EMC Problems on a Series of Geometries with a Predominant Common Part

Faik G. Bogdanov[1], Roman G. Jobava[1], Paata Tsereteli[1], Stephan Frei[2]

[1]EMCoS, Tbilisi, Georgia, Email: roman.jobava@emcos.com

[2] EMC Center, AUDI AG, Ingolstadt, Germany, Email: stephan.frei@audi.de

***Abstract* — A partitioned MoM scheme is suggested to effectively handle series of geometries having a predominant common part. This scheme is based on a partitioned calculation and inversion of unvarying (basis) and differing (additional) parts of impedance matrices to quickly obtain solutions to EM problems on a series of geometries. The suggested scheme was validated to compare characteristics of 2 types of AM antennas mounted in a rear window of the realistic car model. Next, this scheme was applied to develop optimization strategy to solve vehicle antenna engineering EMC problems. An advantage of a new MoM scheme in sufficiently decreasing calculation time is illustrated, and its potential for solution of complicated automotive and other vehicle EMC problems is outlined.**

I. INTRODUCTION

The Method of Moments (MoM) [1] is nowadays the most popular numerical technique for treating the EM and EMC problems on complicated 3-D structures including surfaces and wires. However, although a lot of MoM-based codes exist [2]-[7], most of them are computationally intensive when treating realistic geometries, including those occurred in vehicle design. This drawback may be overcome to a great extent through enhancing MoM scheme [8]-[11]. Thus, new efforts to further develop MoM scheme in situations of practical interest are in very demand.

In solution of EMC problems in vehicle design, especially those related to antenna engineering, it often happens that a considerable part of geometry remains the same at different calculations. For instance, this is the case when comparing characteristics of different antennas mounted in a rear window of the same car model (Fig. 1, Fig. 2). Also, this is the case when considering optimization problem regarding optimal dimensions and position of the certain antenna to be installed inside or on the surface of vehicle.

In this work, a partitioned MoM scheme is suggested to effectively handle series of geometries having a predominant common part. Application of this scheme to compare and optimize characteristics of various antennas mounted on the surface of the realistic car model is illustrated. An advantage of a new MoM scheme over direct MoM scheme in handling series of geometries is demonstrated, and its potential for solution of various automotive and other vehicle EMC problems is outlined.

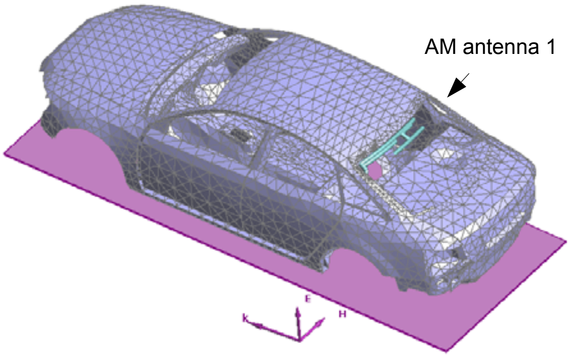


Fig. 1. Grounded car model with AM antenna 1 mounted in a rear window (11,124 triangles, 62 wire segments)

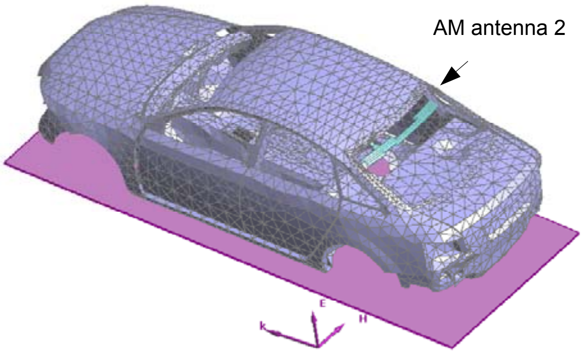


Fig. 2. Grounded car model with AM antenna 2 mounted in a rear window (11,124 triangles, 158 wire segments)

II. DIRECT MOM SCHEME

Let consider first a traditional MoM scheme applied to the boundary-value problem on geometry G

$$L(\vec{J}) = \vec{g} \tag{1}$$

where G is, in general case, a number of surfaces, wires and surface to wire junctions, L is integrodifferential operator, $\vec{g}$ is an excitation on G, and $\vec{J}$ is an unknown current density.

To apply MoM to the equation (1), we perform discretization of geometry G (triangulation of surfaces and segmentation of wires) to consider the following expansion for the unknown current

$$\vec{J}(\vec{r}') = \sum_{n=1}^{N} I_n \vec{f}_n(\vec{r}') \tag{2}$$

where $\left\{\vec{f}_n(\vec{r}')\right\}_{n=1}^{N}$ are sub-domain expansion functions, I_n are unknown coefficients, and N is the total number of unknowns (considered on triangles, wire segments and transitions to triangles and ground).

Substituting now (2) into (1) and applying testing procedure with testing functions $\{\vec{w}_m(\vec{r}')\}_{m=1}^{N}$ reduces (1) to the set of linier equations written in matrix form as

$$[Z_{mn}][I_n] = [V_m] \tag{3}$$

where $[Z_{mn}]$ is an impedance matrix with elements $Z_{mn} = \left\langle \vec{w}_m, L\vec{f}_n \right\rangle$, $[V_m]$ is an excitation column with elements $V_m = \langle \vec{w}_m, \vec{g} \rangle$, and $[I_n]$ is a column of unknown coefficients in the current expansion (2).

Thus, the traditional MoM scheme reduces the initial boundary-value problem (1) to the solution of matrix equations (3), which may be formally found as

$$[I_n] = [Z_{mn}]^{-1}[V_m] \tag{4}$$

III. PARTITIONED MOM SCHEME

Let now G is a series of geometries $G_1, G_2, ..., G_K$, each of which is considered in general as a set of surface triangles, wire segments and a ground (if any). Let also these geometries have a predominant common (basis) part $G^b = \bigcap_{k=1}^{K} G_k$ being an intersection of geometries G_k.

EM treating of the geometries G_k, $k = 1, 2, ...K$, using the direct MoM scheme of section II, requires CPU time that K times exceeds that needed to handle a single geometry. Our purpose is to enhance MoM scheme in such a way to essentially minimize total CPU time needed to handle a series of geometries.

Let geometry G_k is partitioned on the basis G^b and additional G^a parts, so that $G_k = G^b + G^a$. Considering again boundary-value problem (1) and introducing the partitioned sets of expansion and testing functions for basis G^b and additional G^a geometries reduce (1) to the matrix equations with the following block structure

$$\begin{bmatrix} Z^{bb} & Z^{ba} \\ Z^{ab} & Z^{aa} \end{bmatrix} \begin{bmatrix} I^b \\ I^a \end{bmatrix} = \begin{bmatrix} V^b \\ V^a \end{bmatrix}, \tag{5}$$

where first superscript is associated with testing procedure, and second one with expansion procedure, so that total number of unknowns $N = N^b + N^a$.

Considering now LU decomposition of the partitioned impedance matrix

$$\begin{bmatrix} Z^{bb} & Z^{ba} \\ Z^{ab} & Z^{aa} \end{bmatrix} = \begin{bmatrix} L^{bb} & 0 \\ L^{ab} & L^{aa} \end{bmatrix} \begin{bmatrix} U^{bb} & U^{ba} \\ 0 & U^{aa} \end{bmatrix}, \tag{6}$$

one can see, that decomposition of basis block matrix $Z^{bb} = L^{bb}U^{bb}$ is the same as that would obtained for the problem on purely basis geometry G^b. Therefore, considering first boundary-value problem on the basis geometry G^b and storing the inverted matrices $\breve{L}^{bb} = (L^{bb})^{-1}$ and $\breve{U}^{bb} = (U^{bb})^{-1}$ for this geometry, one should calculate then only additional blocks of partitioned impedance matrix of (5) to determine the additional blocks in LU decomposition (6). Then, solution of the initial boundary-value problem on the total geometry G_k is found to be

$$\begin{bmatrix} I^b \\ I^a \end{bmatrix} = \begin{bmatrix} U^{bb} & U^{ba} \\ 0 & U^{aa} \end{bmatrix}^{-1} \begin{bmatrix} L^{bb} & 0 \\ L^{ab} & L^{aa} \end{bmatrix}^{-1} \begin{bmatrix} V^b \\ V^a \end{bmatrix}, \tag{7}$$

or after inversion of block matrices,

$$\begin{bmatrix} I^b \\ I^a \end{bmatrix} = \begin{bmatrix} \breve{U}^{bb} & \tilde{U}^{ba} \\ 0 & \breve{U}^{aa} \end{bmatrix} \begin{bmatrix} \breve{L}^{bb} & 0 \\ \tilde{L}^{ab} & \breve{L}^{aa} \end{bmatrix} \begin{bmatrix} V^b \\ V^a \end{bmatrix}, \tag{8}$$

where

$$\tilde{U}^{ba} = -(\breve{U}^{bb}\, U^{ba})\, \breve{U}^{aa}, \; \tilde{L}^{ab} = -(\breve{L}^{aa}\, L^{ba})\, \breve{L}^{bb}.$$

In (8), a predominant part of calculations is associated with determining the inverse block matrices $\breve{L}^{bb}$ and $\breve{U}^{bb}$ for the basis geometry G^b, which should be stored at the first stage of calculations. If the additional part G^a of the total geometry G_k is much less than basis geometry G^b, calculation of additional blocks of LU decomposition needs much less operations than that required for calculation of the total geometry. This fact allows performing additional calculations to obtain the sought solution without considerable spending CPU time.

A theoretical gain in solving time obtained when using the partitioned MoM scheme (when stored LU matrices for the basis geometry) may be evaluated as

$$G = \frac{8/3(N^b + N^a)^3}{N^b N^a (2N^b + 1) + 8/3(N^a)^3} \tag{9}$$

For $N^a << N^b$, this formula may be simplified as

$$G = \frac{4/3(N^b + 3N^a)}{N^a}, \quad \text{if } N^a << N^b \tag{10}$$

These formulas predict the sufficient advantage of using the Partitioned MoM scheme when applied to series of geometries with predominant common part.

IV. VALIDATION OF PARTITIONED MOM SCHEME

The suggested scheme was validated to compare characteristics of 2 types of AM antennas mounted in the rear window of realistic car model (Fig. 1, Fig. 2).

MoM models for EMC simulations were represented by the grounded car bodyshell modelled by 11,124 triangles, and 2 AM antennas: AM antenna 1 modelled by 62 wire segments, and AM antenna 2 modelled by 158 wire segments. AM ports of each antenna were loaded by the resistance 100 kOhm and capacity 20 pF taken in parallel. Radii of wire segments were taken to be 0.3 mm. To compare EMC characteristics, we were interested in voltages coupled in AM ports of mounted antennas when exposed to vertically polarized plane wave with E^{inc}=1V/m incident from the rear window direction (see Fig. 1, Fig. 2).

To perform EMC simulations using the suggested scheme, basis geometry represented by a car bodyshell over conducting ground was first calculated, and inverted matrices for this geometry were stored. Further, calculations of additional blocks of impedance matrices for the total geometries (car bodyshell and AM antennas) were successively performed, and unknown solutions for these geometries were obtained.

Fig. 3 shows comparison of voltages coupled in AM ports of both AM antennas mounted on the car model surface. The solid and dashed lines in Fig. 3 were obtained using the suggested scheme, and markers correspond to the results obtained by direct MoM scheme. Fig. 3 illustrates identity of the results obtained by both schemes. However, since now $N^a << N^b$, additional calculations need much less CPU time than that required for the total geometry (in our case, 210 sec for AM antenna 1 and 350 sec for AM antenna 2, upon 17% CPU usage, versus 1.9 hours per 1 frequency on 2.5 GHz processor).

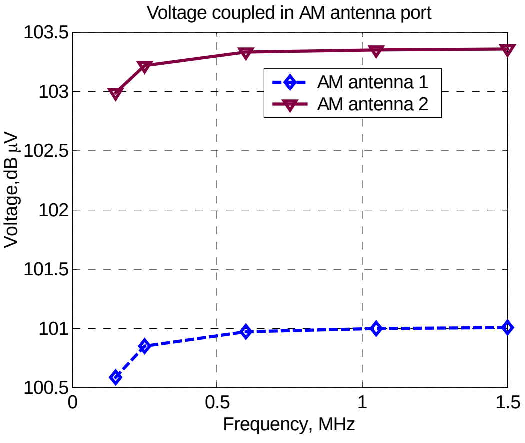


Fig. 3. Comparison of characteristics of 2 types of AM antennas mounted on the car model rear window

The results above validate the Partitioned MoM scheme and verify advantage of applying this scheme over direct MoM scheme.

V. Application of Partitioned MoM Scheme

Further, the suggested scheme was applied to develop optimization strategy for solution of vehicle antenna engineering EMC problems.

Let we compare characteristics of 2 different antennas (Fig. 4) for the same car bodyshell (Fig. 5) to optimize construction or location of $2^{\text{-nd}}$ antenna by such a manner to achieve improved coupling characteristics at resonance frequency band of $1^{\text{-nd}}$ antenna.

a b

Fig. 4. FM antennas for the car model: a - rod antenna (0.486 m length, 37 wire segments), b - original antenna in a rear window (1201 wire segments, 80 triangles)

For optimization purposes, we first refine car bodyshell model (Fig. 5) to allow performing calculations for different mounted antennas without changing the bodyshell triangulation.

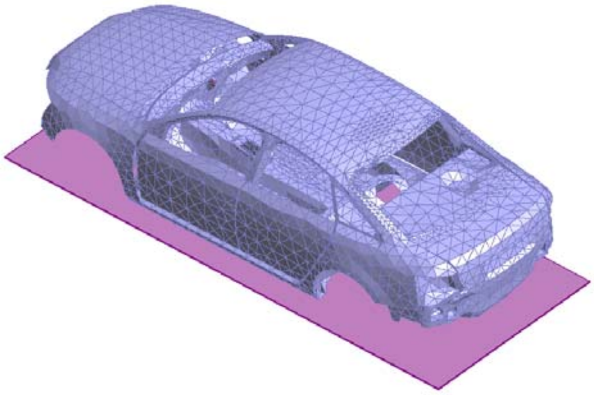
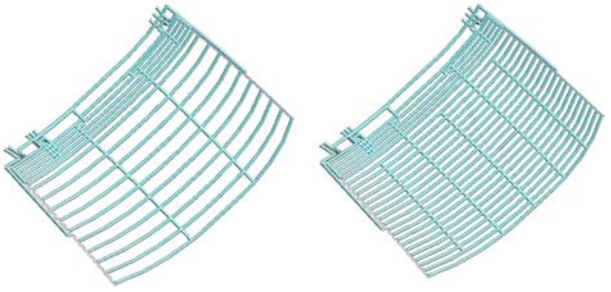


Fig. 5. Grounded car model (10,566 triangles)

Next, we perform basis calculations for car bodyshell of Fig. 5 with storing inverted matrices for appropriate frequencies. Further, we make additional calculations for mounted antennas of Fig. 4, using the Partitioned MoM scheme. Next, we prepare modifications of antenna model of Fig. 4b (Fig. 6) and analyze them using the suggested MoM scheme.



a b

Fig. 6. Modifications of the car antenna in a rear window: a – simplified model (874 wire segments, 80 triangles), b – complicated model (1254 wire segments, 80 triangles)

Fig. 7 shows comparison of the voltages coupled in FM ports of initial and improved antenna models of Fig. 4 and Fig. 6 mounted on the grounded car model of Fig. 5 exposed to vertically polarized plane wave with E^{inc}=1V/m from rear window direction. FM ports of each antenna were terminated by 50 Ohm resistance. Radii of wire segments for all antennas were taken to be 0.3 mm.

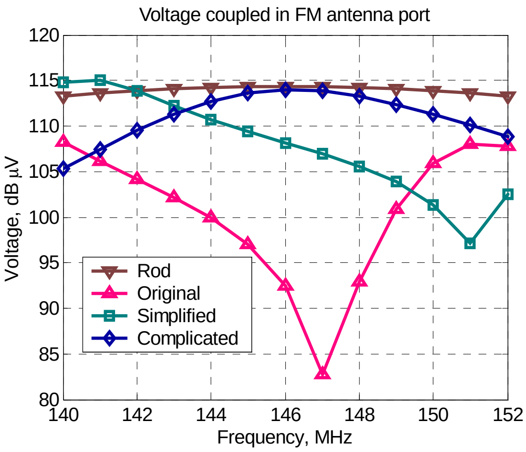


Fig. 7. Comparison of characteristics of 4 types of FM antennas mounted on the roof and rear window of the car model

Analysis of Fig. 7 shows that the original car antenna mounted in a rear window displays the resonance characteristics differing from those for a mounted rod antenna. Also, the coupling characteristics of original antenna are much worse than those for the rod antenna at its resonance frequency band. The simplified antenna displays more appropriate characteristics at the considered frequency band, but has lower resonance frequency. The complicated antenna possesses just the desired resonance and coupling characteristics.

TABLE I illustrated a detailed comparison of coupling characteristics of the initial and improved antenna models at resonance frequency of a mounted rod antenna being 146 MHz. From TABLE I, it is clearly seen that coupling characteristics of the complicated antenna at resonance frequency are very close to those for a mounted rod antenna, that was an aim of the optimization process.

N	Antenna description	Voltage, dB µV
1	Rod	114.3
2	Original in rear window	92.4
3	Simplified in rear window	108.1
4	Complicated in rear window	114.0

TABLE I
VOLTAGE COUPLED IN FM PORTS OF DIFFERENT ANTENNAS MOUNTED ON THE CAR MODEL SURFACE

Thus, analyzing modifications of the original antenna has allowed us to find antenna configuration, which is more appropriate for practical purposes. And, what is more, optimization process using the suggested MoM scheme requires CPU time, which is much less than that needed using the direct MoM scheme.

So, additional calculations needed to handle mounted antennas require CPU time as much as 1 minute for a rod antenna (N^a=25), 34 minutes for an original antenna (N^a=1348), 22 minutes for a simplified antenna (N^a=994), and 39 minutes for a complicated antenna (N^a=1348) per 1 frequency on 2.5 GHz processor, versus 2.0 up to 2.5 hours, dependent on antenna type, needed to handle the total geometry (when N^b=15,601).

The results above demonstrate advantage of the suggested Partitioned MoM scheme to effectively solve complicate vehicle EMC problems. Now, this scheme is included in a new version of a MoM-based code “TriD” [7].

VI. CONCLUSION

A partitioned MoM scheme has been suggested to effectively handle series of geometries having a predominant common part. An advantage of a new MoM scheme over direct MoM scheme in sufficiently decreasing calculation time has been illustrated. Application of this scheme to efficiently solve complicated vehicle EMC problems has been demonstrated.

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