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Modeling of electromagnetic field induced by a city tram

Abstract: The focus of this article is to model the electromagnetic fields around the selected type of a tram in the mathematical-physical environment ANSYS. The article describes basic theorems in the area of electromagnetic fields. The experimental part describes creating a tram model and preparation of boundary conditions for simulation. The evaluation part analyzes and compares the modeled situation of different input currents. The article therefore provides the basis for the realization of more extensive measurements and modeling of electromagnetic fields in the vicinity of high-voltage or high-current devices occurring near living residential buildings or humans.

Keywords: modeling; electromagnetic field; ANSYS; KT8D5 tram; traction

I. INTRODUCTION

The electrification of trainsets and their integration into urban public transport has made the transport of people in the city more efficient. The incidence of upgraded tram traffic is probably noticed in every larger European city. It follows that their occurrence will be considered in the future. Based on these facts, this article was created to describe the distribution of electromagnetic fields (EMFs) around the tram. In recent years, the issue of electromagnetic fields distribution has seen a great increase in interest from ordinary people. Tram in simplicity can be defined as a large group of electric machines and devices in one place that are in constant motion and under certain conditions and situations and then they can be the sources of such fields [5].

II. INITIAL EMF MEASUREMENT

The initial EMF parameters in the tram were recorded using the EMF Tester AS1392. It is a device that can measure the magnitude of magnetic induction B and the values shows in units of μT. The main task of the survey was also to find the main current path from the trolley to the traction motors. According to the reading and analysis of the technical documentation [1], it was widely believed that the main trace of the current passes downwards, to the chassis over the rear of the tramway driver's cab, around the window frames, or the rotary section between the A and C tram segment. On the basis of these statements, there were selected some particular measuring points in which EMP values were recorded (Figure 1).

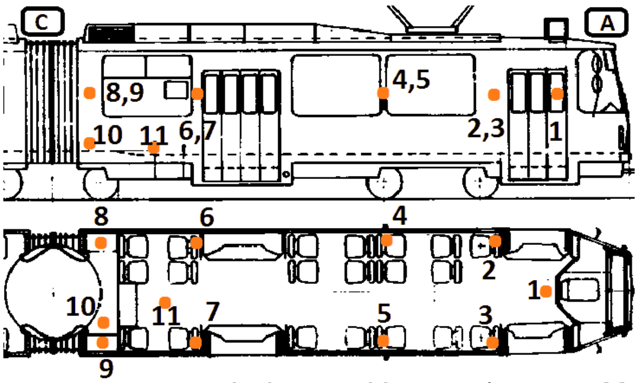


Figure 1 Measuring points distribution in real dimensions of tram KT8D5 [1]

A particular description of the location of the measurement points is as follows. The orientation between the left and right sides is the same as in the direction of the driving (i.e. the left hand of the tram driver is the left side of the tram):

1. Behind the driver's cab
2. Window frame (left door)
3. Window frame (right door)
4. Frame between windows (left side)
5. Frame between windows (right side)
6. Rear door frame (left side)
7. Rear door frame (right side)
8. Place over the regulator (traction circuit)
9. Place over the heating regulator
10. Floor level at the heating regulator
11. Floor level

The sensor of the measuring instrument was applied to the surface of the sheet metal parts of the tram construction. Measurement points 1 through 9 were measured at the height of the human heart (during standing) and at the height of the head (during sitting of a human). The remaining points 10 and 11 are located at the floor level below which the cable duct is stored. After measuring all the measured points, all values ranged from 3 to 140 μT. The highest values were measured at measuring point no. 1 during starting of the tram, that were around 142 μT. At points 2, 3, 4, 5, 6, 7, 8, 9 were recorded values in the range of 3 to 20 μT, where it was not very interesting in terms of modeling. At floor level, represented by points 10 and 11, the measuring instrument showed a maximum value of about 34 μT. From these indicatively measured values, the main current pulse was located behind the driver's cab, which is also logical, because there is a circuit disconnector in the segment.

This preliminary EMF survey pointed to the locations of the possible occurrence of the highest EMF parameters (magnetic induction), where the most significant (highest EMF values) of the measured EMF values appeared at point 1, located behind the driver's cab. Such findings form a suitable background for a more detailed measurement and the next phase – the mathematical modeling.

III. MEASURING PROPOSAL

The design of the measurement phase was based on the knowledge learned from the initial measurement (from previous chapter). It was also an indicative measurement, which should help to provide a thorough background for the modeling phase. Measurements were made on the KT8D5 tram wagon in Košice, tram line No. 9. During the measurement, one route was chosen from the station "*Social Pavilion*" to "*Važecká*", both of them. For the measurement, the same measurement points were used as in the survey phase (Figure 1). The same measuring meter (EMF Tester AS1392) was also used for this measurement. The main purpose of the measurement was to find out what the EMP layout is in an empty and full tram. The empty wagon's weight is about 38 tons and the weight of the full wagon is about 60 tons. The empty wagon situation was monitored in the evening time at around 21:00 when the entire tram was occupied by 1 ÷ 8 passengers.

On the other hand, the situation of a full tram, the EMF values were measured in the early morning from 7:00, when the tram contained over 90 people. In both cases (full or empty tram), the value of the EMF quantities (E and B) was measured at 11 points during 3 driving regimes. It is necessary to mention in this place, that the measurement of electric field (electric intensity E) was not considered and noted, because of low and not interesting values for the simulation. In the start regime, values were recorded when the tramline stood at the spot and tried to run at least at a speed of 20 to 25 km/h. In the second regime, driving regime, there were measured the values during the running of the tram, at which tram kept the speed from 25 to 65 km/h. During the last regime – braking regime, there were recorded EMF values that occurred when braking the tram from any speed to 0 km/h. During measurements in both situations (full or empty tram) and in all three regimes (start, run, breaking), the maximum values were recorded. In addition, the ambient temperature was also recorded (in ° C).

It should be mentioned that the measurements were carried out during a nice sunny day, when there was minimal humidity and rainfall. The daily temperature ranged from 12 to 16°C and a nighttime temperature was around 7°C, as the measurements were realized through early spring and mid-autumn. Measured values and measurement results are evaluated also in this article.

TABLE I
List of measured magnetic induction values B (in μT) in the empty tramway KT8D5 (Segment A)

Point	Ride regime	1	2	3	4	5	6	7	8	9	10
No. 1	Start	120,21	112,72	128,35	109,98	111,52	118,67	119,56	120,01	116,29	113,87
	Run	17,35	22,11	14,85	14,89	19,41	25,63	21,47	17,81	19,46	17,87
	Brake	78,25	61,87	80,14	76,55	65,49	68,21	67,98	72,47	75,69	76,33
No. 2	Start	15,5	21,12	17,82	16,98	19,54	20,54	21,09	16,77	18,54	19,32
	Run	10,29	8,35	11,15	9,36	8,25	10,17	7,35	8,58	9,24	10,23
	Brake	6,54	6,97	7,28	5,99	7,31	6,57	6,98	5,98	6,49	6,78
No. 3	Start	14,11	15,23	13,87	14,52	13,67	15,47	15,86	14,12	14,52	15,19
	Run	8,94	9,08	9,25	7,67	8,35	8,41	8,56	8,65	8,91	7,99
	Brake	6,72	6,89	5,75	7,22	7,13	6,58	6,49	6,37	6,77	7,04
No. 4	Start	3,8	3,12	2,98	2,77	3,15	3,72	3,54	3,59	3,88	4,03
	Run	2,48	2,55	2,87	2,91	2,24	2,12	2,41	2,53	2,67	2,9
	Brake	5,3	5,34	4,97	6,04	5,45	5,61	5,29	5,72	5,68	5,41
No. 5	Start	2,87	2,49	2,55	2,63	2,87	2,88	2,89	2,75	2,39	2,87
	Run	2,3	2,54	2,45	2,61	2,81	2,35	2,17	2,19	2,22	2,33
	Brake	5,3	5,91	5,64	5,47	5,65	5,28	5,47	3,29	6,24	5,47
No. 6	Start	16,17	14,86	17,05	16,32	16,54	0,16	16,82	14,97	15,38	15,67
	Run	6,7	6,71	6,81	6,54	6,33	6,09	7,23	7,18	6,48	6,57
	Brake	19,28	19,21	20,21	20,03	18,79	19,24	19,65	19,56	18,58	19,22
No. 7	Start	10,29	8,54	9,58	9,63	8,72	10,15	8,62	9,24	9,42	10,05
	Run	8,3	8,38	9,21	7,87	8,24	8,25	8,67	8,47	8,53	8,91
	Brake	9,21	9,67	8,87	10,04	9,65	9,67	9,82	9,23	9,27	9,01
No. 8	Start	3,4	3,45	3,27	3,68	3,57	2,87	3,54	3,98	3,57	3,19
	Run	1,5	1,19	1,87	1,47	1,39	1,54	1,58	1,28	1,67	1,38
	Brake	0,7	0,27	0,87	0,77	0,72	0,69	0,39	0,57	0,62	0,74
No. 9	Start	2,78	2,89	2,57	2,39	2,58	2,47	2,81	2,68	2,39	2,93
	Run	1,38	1,57	1,77	1,68	1,29	1,28	1,27	1,63	1,37	1,61
	Brake	1,03	0,98	0,94	1,05	1,11	1,67	1,26	0,97	1,41	1,36
No. 10	Start	32,41	32,35	31,87	32,67	33,04	32,57	32,69	32,47	31,94	32,09
	Run	31,24	34,36	33,57	32,47	31,67	33,14	33,08	32,58	34,78	34,99
	Brake	35,41	35,21	36,07	34,87	35,47	35,68	35,29	35,64	35,67	35,29
No. 11	Start	32,59	32,48	32,65	32,56	32,14	32,1	31,84	32,46	32,68	31,73
	Run	25,47	25,74	25,68	0,67	26,51	25,34	25,25	25,87	25,41	24,58
	Brake	23,45	23,22	23,57	23,65	23,56	23,14	22,98	23,28	23,39	23,41

TABLE II
List of measured magnetic induction values B (in μT) in the full tramway KT8D5 (Segment A)

Point	Ride regime	1	2	3	4	5	6	7	8	9	10
No. 1	Start	143,25	128,67	152,31	138,69	143,57	142,57	145,62	147,35	148,27	135,68
	Run	31,27	32,87	30,87	31,57	32,68	31,87	30,97	31,58	31,49	32,07
	Brake	85,67	87,24	86,37	87,12	82,14	85,36	86,47	86,53	87,03	87,33
No. 2	Start	16,47	15,27	16,87	15,74	17,08	16,27	17,27	16,35	17,11	16,84
	Run	11,3	9,56	10,87	11,67	10,51	11,22	11,87	10,57	10,65	11,14
	Brake	8,32	7,25	8,69	8,24	7,17	8,39	8,5	7,36	9,04	7,87
No. 3	Start	15,11	15,63	15,24	14,97	14,59	15,02	14,78	14,68	15,41	15,23
	Run	9,04	9,25	8,79	9,27	9,47	9,36	9,47	8,47	9,14	9,21
	Brake	7,66	8,32	7,21	7,45	7,65	7,61	7,83	7,48	7,65	7,56
No. 4	Start	4,21	4,02	4,41	4,11	4,22	4,09	4,16	4,7	4,35	3,98
	Run	3,01	3,25	2,87	3,06	3,36	2,94	2,93	3	3,04	3,08
	Brake	5,3	5,45	5,87	5,21	5,11	5,31	5,61	5,29	5,18	5,44
No. 5	Start	2,79	2,99	3,05	3,02	3,08	2,88	2,96	2,93	2,76	2,67
	Run	2,41	2,35	2,25	2,27	0,21	2,78	2,61	2,53	2,47	2,39
	Brake	5,3	5,17	5,64	6,03	5,47	5,29	5,43	5,64	5,46	5,27
No. 6	Start	17,21	18,01	17,29	17,22	17,08	17,65	17,56	17,54	17,39	17,82
	Run	6,35	6,74	6,84	6,41	6,39	6,51	6,28	6,27	6,34	6,47
	Brake	20,18	19,63	19,35	19,54	19,87	19,24	19,26	19,28	19,37	19,64
No. 7	Start	11,05	10,29	10,24	10,38	10,45	10,41	10,71	10,68	10,47	10,31
	Run	9,03	8,75	8,64	8,35	8,47	8,94	8,27	8,35	8,68	8,67
	Brake	9,04	9,66	8,27	8,67	9,07	9,045	9,54	9,57	9,61	9,67
No. 8	Start	3,35	3,68	3,47	3,59	3,91	3,48	3,57	3,62	3,46	3,47
	Run	1,29	1,61	1,36	1,87	1,44	1,52	1,09	1,91	1,58	1,37
	Brake	0,67	0,84	0,55	0,59	0,54	0,57	0,67	0,39	0,71	0,54
No. 9	Start	2,87	2,64	2,69	3,01	2,54	2,09	3,07	2,56	2,77	2,81
	Run	1,42	1,56	1,34	1,67	1,52	1,91	1,62	1,38	1,45	1,63
	Brake	0,98	1,03	1,05	0,87	1,11	1,16	1,21	0,94	0,96	1,15
No. 10	Start	35,24	35,21	35,64	35,44	34,98	35,27	35,67	35,64	35,81	35,62
	Run	33,11	33,54	33,14	33,02	32,87	34,02	33,68	33,47	33,65	33,41
	Brake	37,02	37,55	36,41	37,22	37,54	37,64	37,28	37,54	37,61	37,27
No. 11	Start	33,09	33,26	33,45	33,27	33,39	32,79	33,47	33,58	33,61	33,09
	Run	27,04	27,22	26,56	26,65	26,39	26,68	27,22	27,31	26,59	26,47
	Brake	25,61	25,84	25,73	24,94	25,38	25,49	25,45	25,55	25,63	25,84

During the measurement all directives of DPMK and timetables were respected. None of the passengers were restricted, threatened or exposed to any risk. There was also no disruption to the operation of the tram.

It is clear from Table 1 (respectively Table 2), that the highest values were registered at measuring point No. 1, averaged 117.12 μT (full tram 142.60 μT), which corresponds to the space behind the tramway driver's cab. This is validated by the fact that in the area behind the driver's cab is a circuit disconnector placed in the tram structure. Highest values of magnetic induction were measured during the startup regime. It is possible to reason it by using a simple theory of Newton's inertia law, when a tram that is in a state of staying is trying to run but it has to exert considerable force to overcome this state of affairs. Therefore, the tram takes a higher current value (max. 1200 A when the fully loaded tramway can rise into the hill), which logically also causes an increase in magnetic induction around the current path (electrical equipment). On the other hand, if the tram is already in motion (according to the table 1 in the run regime), lower power (from 400 A to 800 A) is taken to maintain constant motion.

It follows from this that during the run regime, in measuring point no. 1 there were not exhibited high magnetic induction values, i.e. an average of 19.09 μT (full tram 31.72 μT).

IV. RESULTS OF EMF DISTRIBUTION ON DESIGNED 3D MODEL IN ANSYS

From the results below (Figure 3) it can be seen that the magnetic field distribution values in the tram space are too high and reach almost unrealistic values. For example, close to a person standing 30 cm from the cable duct behind the tram driver's cab, the values are about 250 μT and on the surface of the metal sheet is about 550 μT. In real terms, this is not even possible, because the thickness of the cable duct sheet was considered (modeled) of 1 cm, which should represent a perfect shielding barrier (because of speed up calculation time in ANSYS it was so thick).

TABLE III
Table list of used materials

Material	Description	Rel. permeability	Resistivity [Ω·m]
Structural Steel	Construction of a tram made of iron	50 ÷ 200	$1{,}7\cdot10^{-7}$
Copper Alloy	Current path (copper)	0,99999	$1{,}697\cdot10^{-8}$ (20°C)
Silicon Anisotropic	Insulator	1	0,0001
Air	Ambient air	1,05	–
Head	Simulation of human brain	0,99991	–
Torso	Simulation of stomach organs	0,9999	–
Legs	Simulation of bone marrow	0,99998	–

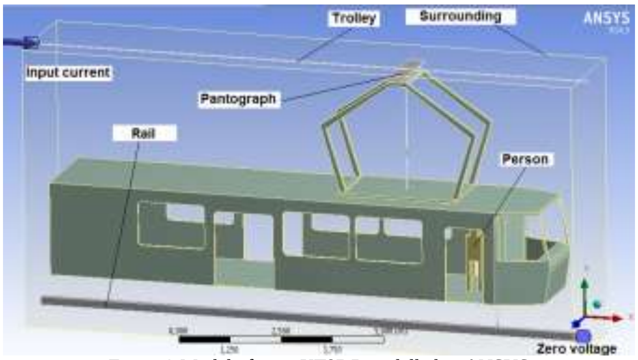


Figure 2 Model of tram KT8D5 modelled in ANSYS

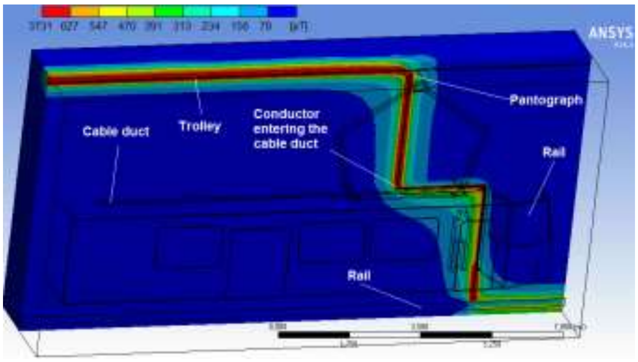


Figure 2 Longitudinal section of magnetic induction distribution around the current conductor (visually customized side view)

Similarly, another disadvantage of the 3D model was its extensiveness and sophistication of shapes for successful computation in ANSYS. Network generation (using an ANSYS direct access on the server, that was, 12 processor cores and 96 GB RAM) took about 8 hours, and the EMP values in the individual elements alone lasted over 2 days (about 60 hours). Since the simulation still had a long response during calculation, a measure was adopted to create a simpler but more detailed model of the situation behind the driver's cab in 1D.

V. 1D MODEL

Based on several deficiencies of the 3D model, next the 1D model alternative was considered.

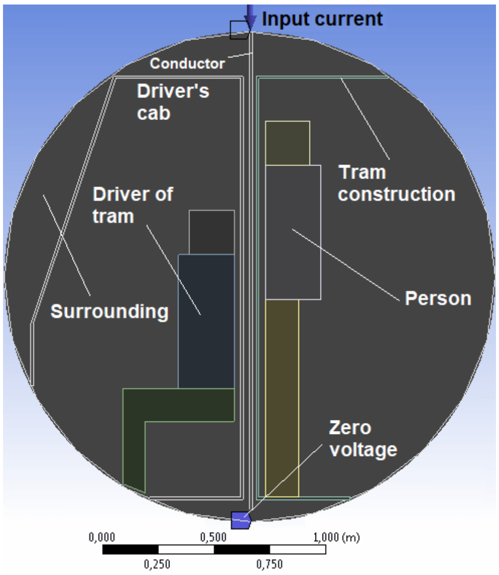
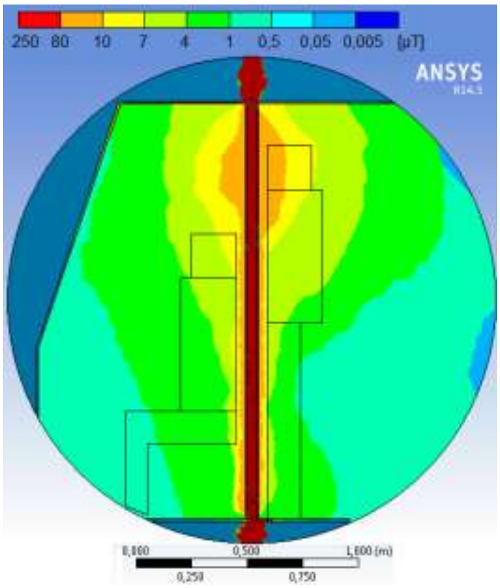


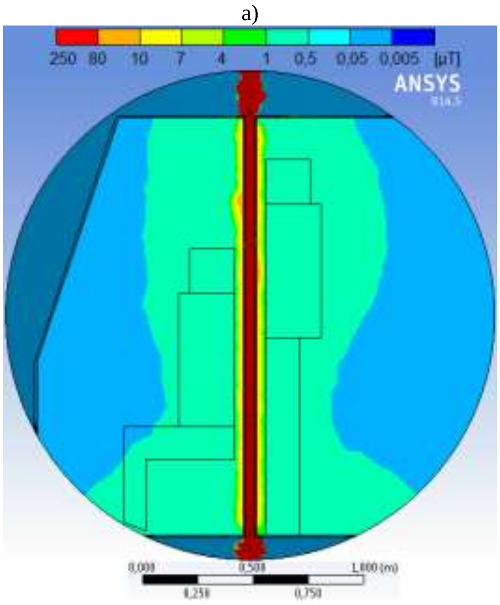
Figure 3 Description of the 1D model situation around the driver's cab (side view)

The model was located in the space behind the tram cabin. There were 2 people in the tram (regular traveler and tram driver). On the mentioned model, the driver sits in the cab and controls the running of the tram and the passenger stand behind the cabin, in the door area. The persons are in real dimensions of the human body at a height of 175 cm and a chest length of 25 cm. Head dimensions are 20 × 20 cm. The length of the leg in height is 90 cm and the width is 15 cm. An electric conductor of circular shape with a radius of 0.5 cm is placed between them. The current path leads from the top of the tram to the bottom. The thickness of the metal sheet construction was considered in the model 1 cm. The free space between the wire and the construction is 1.5 cm wide. Both persons are spaced from an electrical conductor plate 4 cm (situation, when someone is in close proximity of conductors or leans).

Description of Figure 4: The situation is defined by the maximum possible input current of 1200 A. Lesser half of the head of a passenger standing behind the driver's cab is exposed to values of magnetic induction about 16 µT. In the torso section, magnetic induction values that can be observed are from 1 to 16 µT. The legs of the passenger's feet almost copy the value of 10 µT. The rest of the legs record from 0.5 to 7 µT. The tram driver is once again in “better” condition (because he is sitting). At the top of the head, magnetic induction values that can be observed are around 10 µT and in the bottom are from 4 to 7 µT. Through the torso leads a border that diagonally divides the abdominal part into two equal sections. The first segment defines values ranging from 4 to 7 µT and the second section up to 4 µT. The top of the leg to the knees describes the field distribution by values ranging from 1 to 4 µT. The magnitude of magnetic induction also drops from the knees and below (less than 1 µT). Again, maximal magnetic induction values were observed on the surface of the structure when the ANSYS program computed a maximum value of 240 µT.



a)



b)

Figure 4 Magnetic field distribution around the driver's cab at (a) 1200 A flow and (b) with EMF shielding

The EMP shielding proposal consisted in modifying the relative permeability of the construction material to a suitable value so that the magnitude induction magnitude dropped significantly. The chosen relative permeability value of 20,000, corresponding to a shielding film of 1 mm thickness, significantly suppressed the distribution of the magnetic field. For example, during a situation where the conductor passed a 1200 A current, the magnitude of magnetic induction value, which is 0.5 cm from the sheet behind the tramway cab, was 69.08 µT. After shielding, the value dropped to 6.47 µT. At a distance of 10 cm from the metal sheet, it reached 0.242 µT, where it was 10.57 µT in the case of unshielded state.

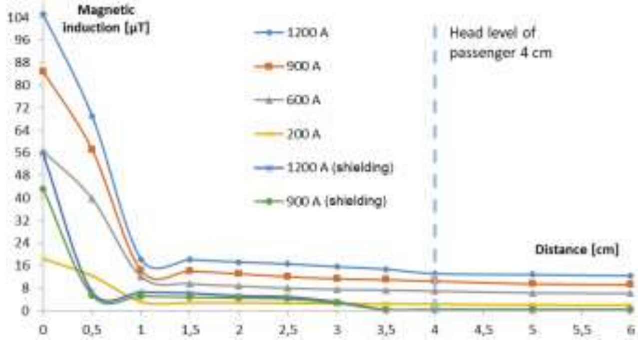


Figure 5 Magnitude of magnetic induction depending on distance from construction

VI. CONCLUSION

This paper was concerned on the modeling of electromagnetic fields on the selected type of tram KT8D5 in 3D and 1D situation using the ANSYS program. None of the measured or modeled values in all 11 measurement points exceeded the dangerous, legally specified values listed in the tables. It should be noted that e.g. literature [4] also addresses the risk group of people for whom are other legislative values applied (lower values of EMF). For example, a person wearing a pacemaker (cardio-stimulator) may interact with values above 500 µT. In the measurement and modeling phase, during the start of the tram, values of up to about 150 µT (on the surface of the metal sheet) are present in the area where normal passengers will also arrive. Although the measured and modeled values do not exceed the table values, they informally inform the general public about the distribution of EMF in commonly available high-voltage or high-current devices – means of transport.

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