Light Rail Transit

Electromagnetic Field Study

April 2013

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Issue and Revision Record

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C	2013-03-19	E. Papadopoulos	J. Cosgrave	J. Cosgrave	Draft Review
D	2013-04-02	E. Papadopoulos	J. Cosgrave	J. Cosgrave	Final

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Executive Summary

The City of Hamilton instructed Hatch Mott MacDonald to perform an Electro Magnetic Field (EMF) Study of the B-Line LRT at the western end of the terminus in order to determine the EMF impacts and possible mitigation measures for the Canadian Centre for Electron Microscopy's (CCEM) Scanning Electron Microscopes (SEMs) found at McMaster University.

Hatch Mott MacDonald's in-house TRAIN traction power system simulator was used to obtain detailed information about the system performance and mainly the magnitude and direction of the currents flowing on the different parts of the OCS and the running rails in order to calculate more accurately the produced magnetic fields.

After obtaining the relevant data from the simulation, a number of calculations regarding the EMF from the LRT system were performed. It is clear that the magnetic fields that are likely to be produced by the proposed LRT project will not comply with the specified level of sensitivity of the Titan SEM as suggested by the CCEM.

A list of possible mitigations along with a rough order of cost magnitude is presented in the report. These mitigations are based on the analysis undertaken with the information as known at this time. A more detailed investigation will be required during future phases of design when specifics related to the vehicles, OCS design, traction power design and alignment have been finalized and individual components have been selected. At that time the optimum solution based on the impact on the produced electromagnetic fields and a life-cycle cost assessment of the proposed solution can be further defined.

1 Introduction

The City of Hamilton has embarked on a plan to implement rapid transit, with a long term vision encompassing five corridors, connecting key destinations across the City. This proposed system is referred to as “B-L-A-S-T” (Figure 1). In 2011, the city completed the Transit Project Assessment Project (TPAP) for Light Rapid Transit (LRT) on the primary east/west B-Line Corridor, Main/King between Eastgate Square and McMaster University.

The city has expressed interest in continuing to move the B-Line forward with the completion of a number of activities including the following:

- An Electro Magnetic Field (EMF) Study of the B-Line LRT at the Western end of the terminus
- Determining the EMF impacts and possible mitigation measures for McMaster University’s Departments including Scanning Electron Microscopes (SEMs) operated by the Canadian Centre for Electron Microscopy (CCEM).

Figure 1: B-L-A-S-T System

2 Study Area

For the purposes of this study, the planning and technical analysis and associated recommendations are confined to the key study areas:

- McMaster University Campus, bounded by the natural area to the north, Forsyth Avenue to the east, Main Street to the south and Cootes Drive to the west

Analysis requirements outside the key study area are considered to be outside the scope of the study.

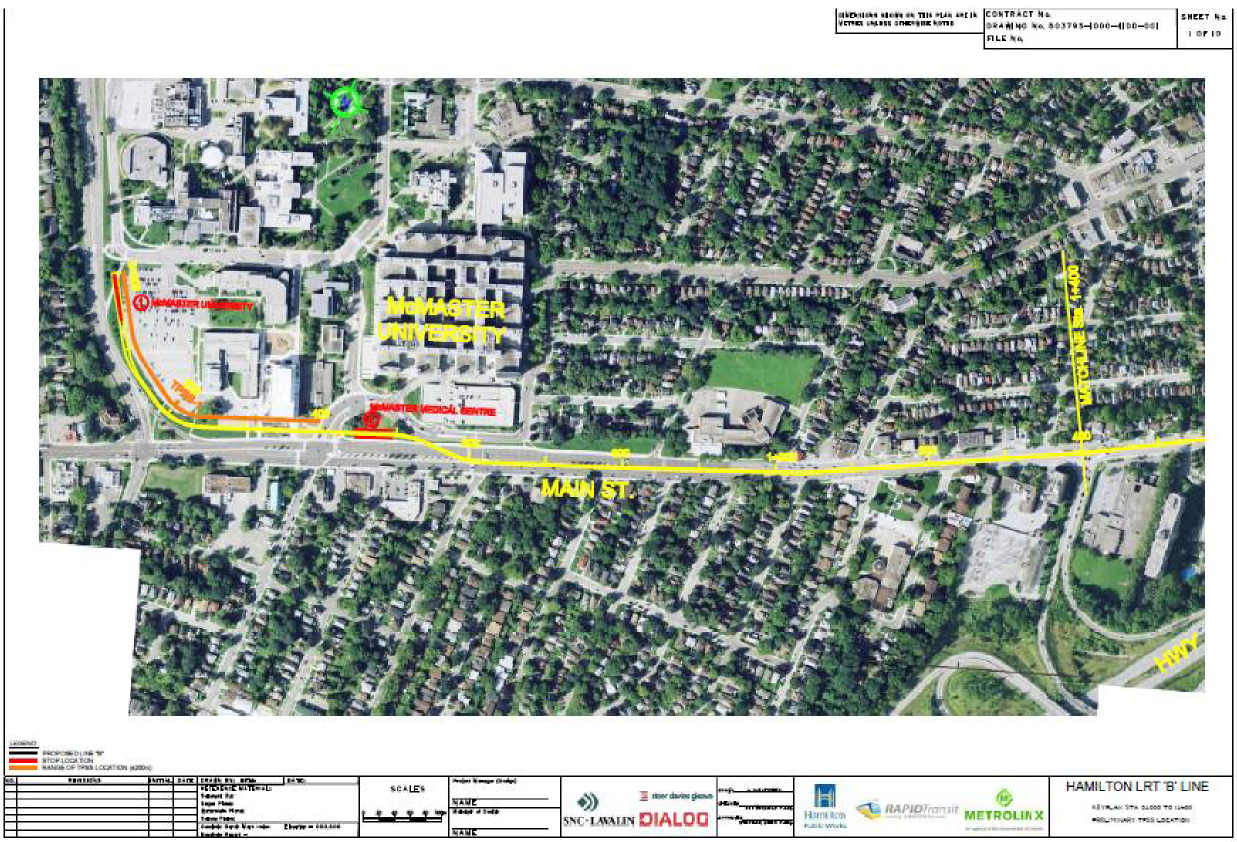

Figure 2: McMaster University Study Area

Source: Hamilton Rapid Transit Preliminary Design and Feasibility Study

3 Electromagnetic Field Study

3.1 Scope of the Report

The scope of this report is:

- To determine the electromagnetic field generated by the proposed Light Rail Transit and check if it is compliant with the level of sensitivity of the most sensitive Scanning Electron Microscope (SEM) located at the CCEM.
- Investigate any technical modifications to the LRT to prevent interference with the SEM.
- Propose and develop mitigation measures to reduce the effects if the level of the produced magnetic fields is not compliant with the sensitivity of the SEM.

It should be noted that no measurements of the existing levels of magnetic field disturbance have been taken as part of this study, either within, or outside, the CCEM buildings. It is recommended that these measurements are made at a later stage.

The scope of the study excludes the assessment of geomagnetic perturbation effects which will be the basis of any existing disturbances present and which will, together with the electromagnetic effects which are considered in this study, be a feature of the proposed LRT system.

3.2 Canadian Centre for Electron Microscopy (CCEM) Requirements

A meeting was held on the 18th of July at the Canadian Centre for Electron Microscopy (CCEM) with the representatives of the City of Hamilton, CCEM staff, Hatch Mott MacDonald and John Coulter & Associates in order to understand and clarify the following:

- The sensitivity of equipment to electromagnetic (EMF) fields including all operating conditions of the equipment, identifying those modes of operation where it is most sensitive to EMF
- The materials used in the construction of the facility in order to determine their shielding effectiveness with regard to EMF
- Existing mitigation in place at equipment and facility level to suppress low frequency electromagnetic interference
- Susceptibility to conducted electromagnetic interference due to stray DC current, for which details need to be provided regarding the earthing and bonding at the facility

Following the meeting with staff from CCEM, it has become evident that the detailed consideration of multiple items of equipment is unnecessary and that the possible mitigation measures at the receptor (i.e. local to the CCEM equipment affected) are unlikely to be acceptable to the CCEM; although the City of Hamilton wish to continue investigating all options at this stage.

The suggested acceptability criterion specified by CCEM, was provided in the CCEM EMF, Vibration and Acoustics spec [1], sent by Dr Gianluigi Botton, Scientific Director of the CCEM at the 10th of August. The document states that the EMF level produced by the proposed LRT must not be above the current level of **0.02mG** or **2nT**, in the vicinity of the most sensitive equipment, meaning the Titan SEMs. Therefore the computer modeling will demonstrate what EMF levels would be generated by the LRT system in the vicinity of the CCEM building for comparison with the suggested acceptability criterion specified by CCEM as being **2nT**.

4 Radiated Magnetic Fields from Proposed Alignment

4.1 Problem and Methodology Description

In order to ensure the normal operation of the SEM located in the CCEM the radiated magnetic field from the proposed LRT must be calculated. Therefore a 3D model of the OCS and track equipment was designed in order to calculate the radiated fields. The model represents in scale the OCS conductor and rail geometries in xyz coordinates relative to the location of the sensitive equipment. A 3-D model is illustrated on Appendix A.2

The methodology for the calculations is based on the Biot-Savart law which allows calculating the levels of magnetic fields from current carrying conductors of finite length. The methodology for this problem is given in detail in Appendix A. It must be noted that the two driving factors for the magnitude of the field are the current levels, the length of energized conductor and the distance (on all dimensions) from the point of interest. Since no detailed coordinates were provided for the position of the sensitive SEM equipment, the field is calculated in the middle of the SEM room, at 1m height. All the relative dimensions are derived from the drawings in reference [2] and [3].

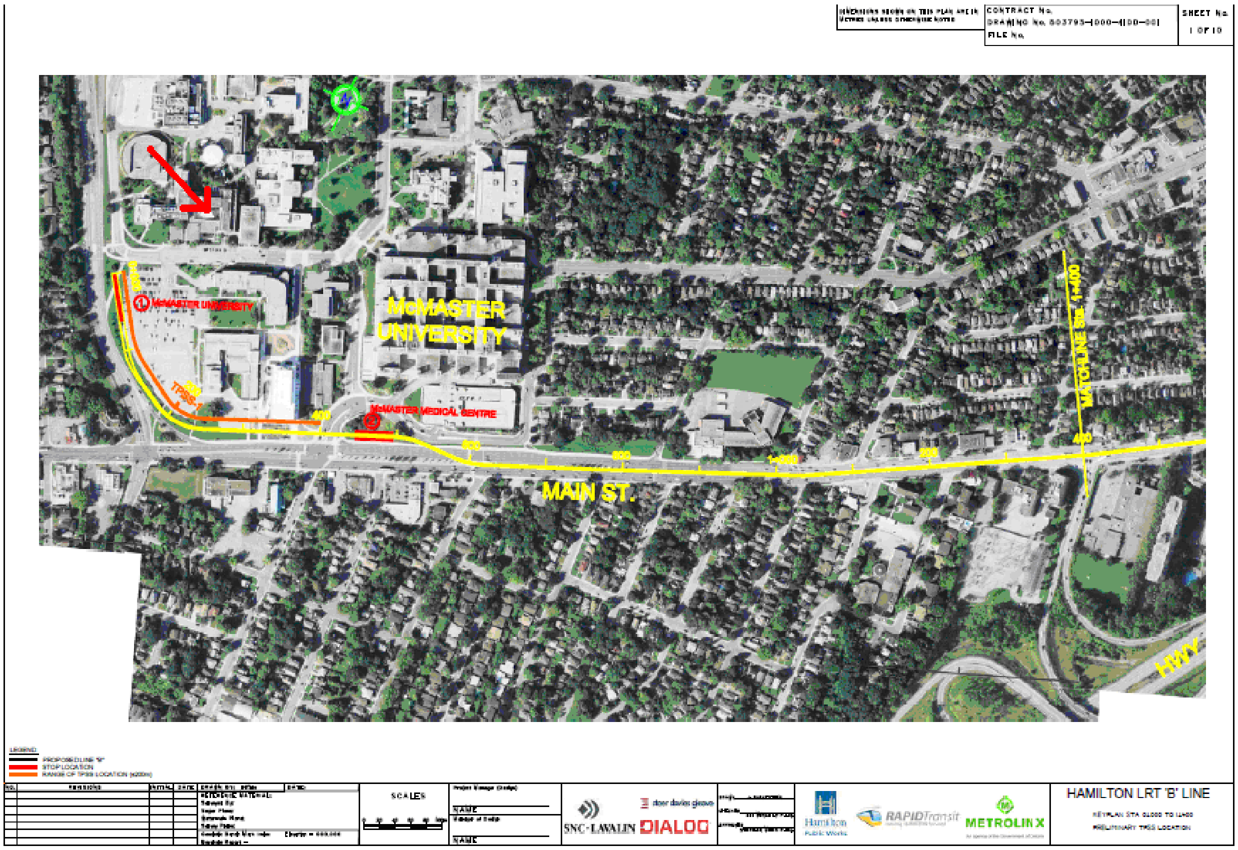

Figure 3: Location of TITAN Microscope and Associated Points of Interest

Source: Hamilton Rapid Transit Preliminary Design and Feasibility Study

Hatch Mott MacDonald's in-house TRAIN traction power system simulator was used to obtain detailed information about the system performance and mainly the magnitude and direction of the currents flowing on the different parts of the OCS and the running rails in order to calculate more accurately the produced magnetic fields that will affect the sensitive equipment located in the CCEM. Through a step-by-step observation of the simulation the worst case scenarios were identified and the respective values were used for the calculations. The input data for the TRAIN model are given in Appendix B.

Since the LRT is in the early design phase, a number of logical assumptions along with the known data were necessary in order to specify some of the required parameters; due to the limited volume of existing information. It must be noted that most of the required information used as input data on TRAIN and magnetic field calculations, are taken from the Traction Design Brief v2.0 [2] based on the Hamilton Rapid Transit Preliminary Design and Feasibility Study. It must be noted that the following results are not definite but demonstrate the relative magnitude of the fields that are likely to be produced.

4.2 Simulation Results

A TRAIN model of the proposed LRT was created covering the areas of interest for the EMF study, which is the western part of the proposed "B" line from McMaster University station up to the 3rd substation to the east (TPSS near MacNab station). This selection was made to accommodate for the two possible outage scenarios in the area of interest, meaning an outage at the first and second substations respectively. Although the possibility of an outage is low, the magnitude and direction of the currents may vary and consequently these scenarios must be taken into consideration.

An operational headway of **4 minutes** was modeled [2]. The simulations were observed step by step in order to identify the worst case scenarios. It was expected that the higher currents will be drawn during the acceleration phase from a station and during the regenerating braking of the LRT vehicles before stopping. This criterion along with the length of the relative energized conductors was taken into consideration for the assessment of the worst case scenario. Due to the alignment of the system and the proposed location of the first substation it is expected that the worst case scenario will occur when a LRT vehicle accelerates or regenerates at the start of the line, mainly due to the proximity of the sensitive equipment.

4.2.1 Normal Operation

After a step-by-step observation of the simulation, several potential worst-case scenarios were identified. It must be noted that the time-steps associated with the highest current in the LRT vehicles might not lead to the highest magnitude of the field because the relative position of the LRT vehicles and consequently the length of the current carrying conductors also contribute to the magnitude of the field.

For the normal operation scenario the worst case was identified at time step 21:58. A snapshot from the TRAIN simulation showing the current levels and directions are given below:

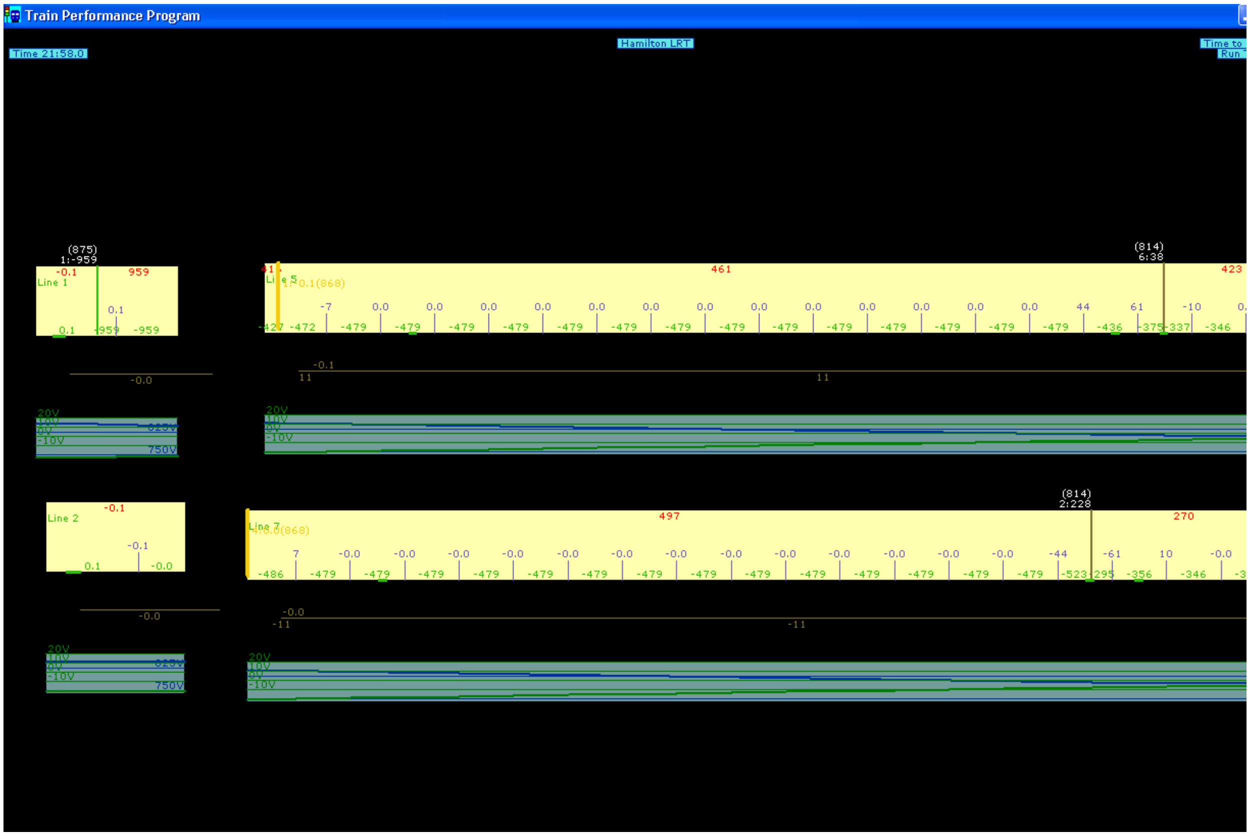

Figure 4: Normal Operation, Time Step 21:58

Source: Mott MacDonald

The green vertical line represents an LRT vehicle adjacent to the end of the line near McMaster University. The red numbers show the current in the OCS and the green numbers the return current through the running rails. The vertical blue lines show the position of the cross-bonds along the track. During this time step the LRT vehicle is regenerating during braking and the flow is from the LRT vehicle to the first substation (yellow vertical line). The other LRT vehicles do not contribute to this calculation since they are far away from the area of interest due to the proposed 4 minute headway and have only a marginal impact to the results. The current flow can be represented by the following diagram:

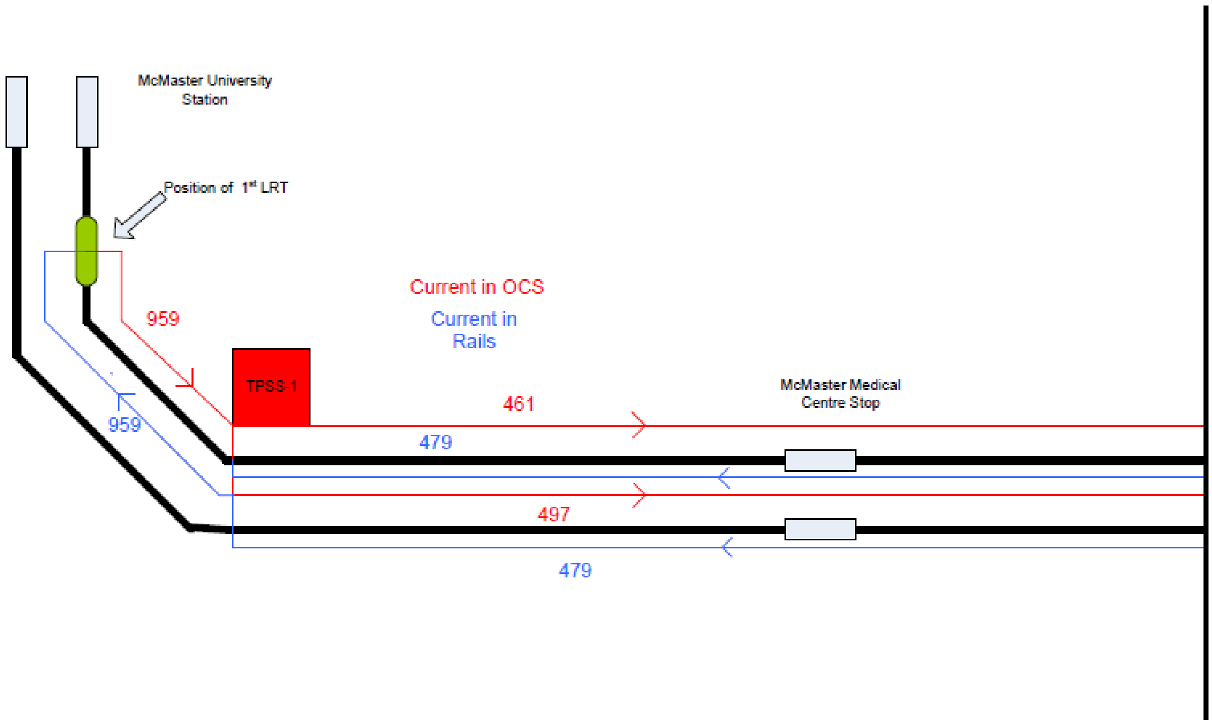

Figure 5: Current Magnitude and Direction, Normal Operation

Source: Mott MacDonald

The magnitude of the resultant magnetic field is calculated as **17nT**. The detailed calculation and methodology are given in appendix A.2. It must be noted that all adjacent time-steps throughout the simulation were checked and the featured time step resulted in the worst case scenario[1]. It is clear that the level of the field is higher than the limit of sensitivity defined by the CCEM (2nT) and consequently the LRT will not comply with the CCEM's suggested levels unless mitigation measures are taken for the reduction of the electromagnetic field.

4.2.2 Outage of 1st Substation

The same approach was used for the outage of 1st substation scenario. Here, the worst case scenario was defined at time-step 46:6 and the snapshot is provided below.

[1] The magnitude of the field in the adjacent time-steps were very close but lower compared to the featured worst case scenario

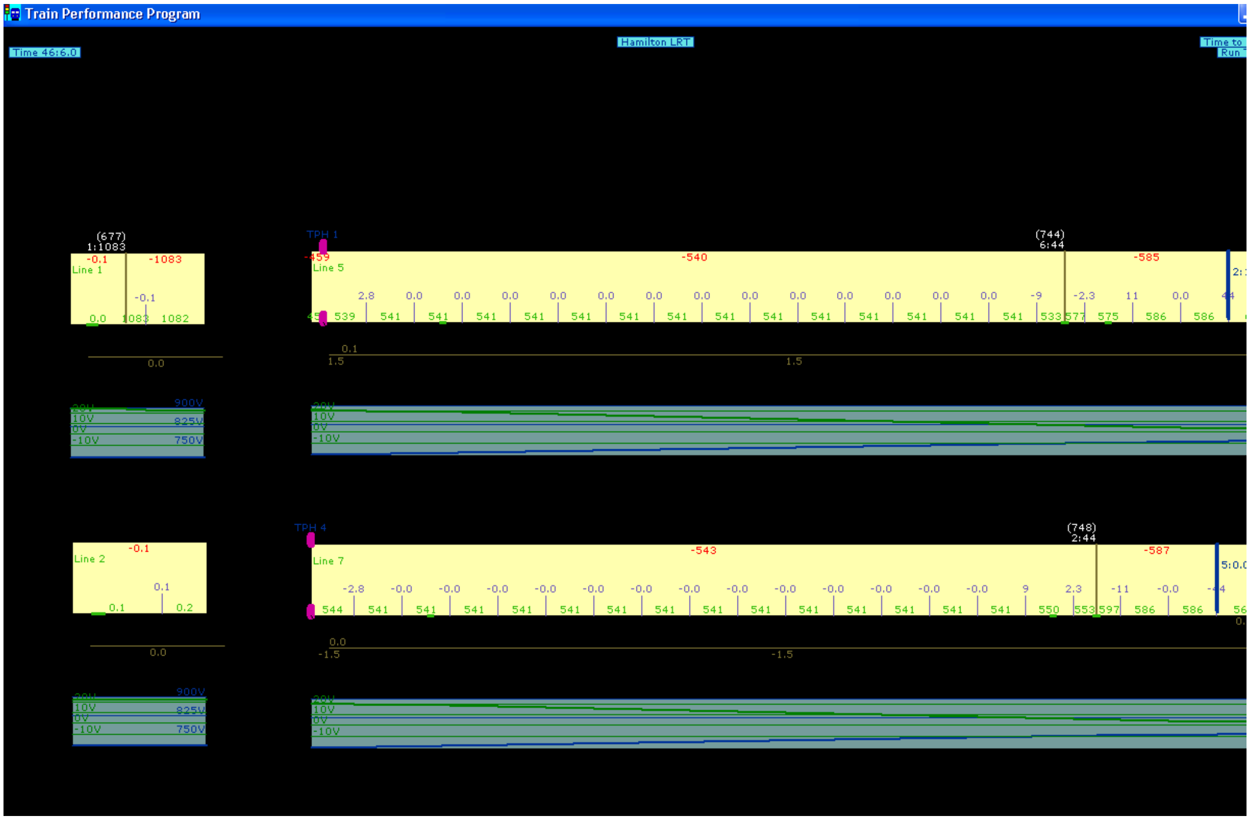

Figure 6: Outage of 1st Substation, Time Step 46:6

Source: Mott MacDonald

For this operational scenario the worst case occurs when a LRT vehicle is accelerating from McMaster University stop in the eastbound direction. The 1st substation that is out of service is shown in pink in the above snapshot. The direction of the current flow is opposite compared to the normal operation and is depicted in the following diagram.

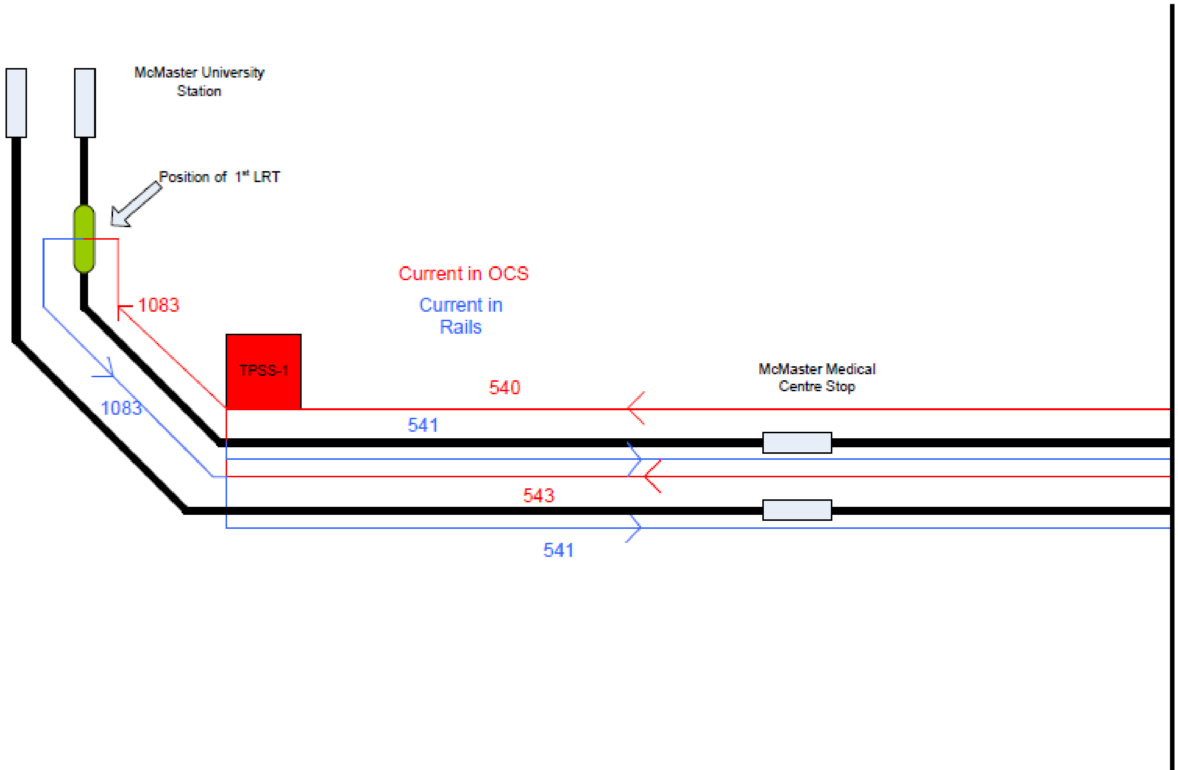

Figure 7: Current Magnitude and Direction, Outage at 1st Substation

Source: Mott MacDonald

The magnitude of the resultant magnetic field is calculated as **18.2nT**. The results are slightly worse for this scenario and still do not comply with the CCEM's suggested levels. The detailed calculation and methodology are given in Appendix A.3.

4.2.3 Outage of 2nd Substation

Similar to the two previous scenarios the worst case scenario was defined at time step 22:6. The snapshot is provided below:

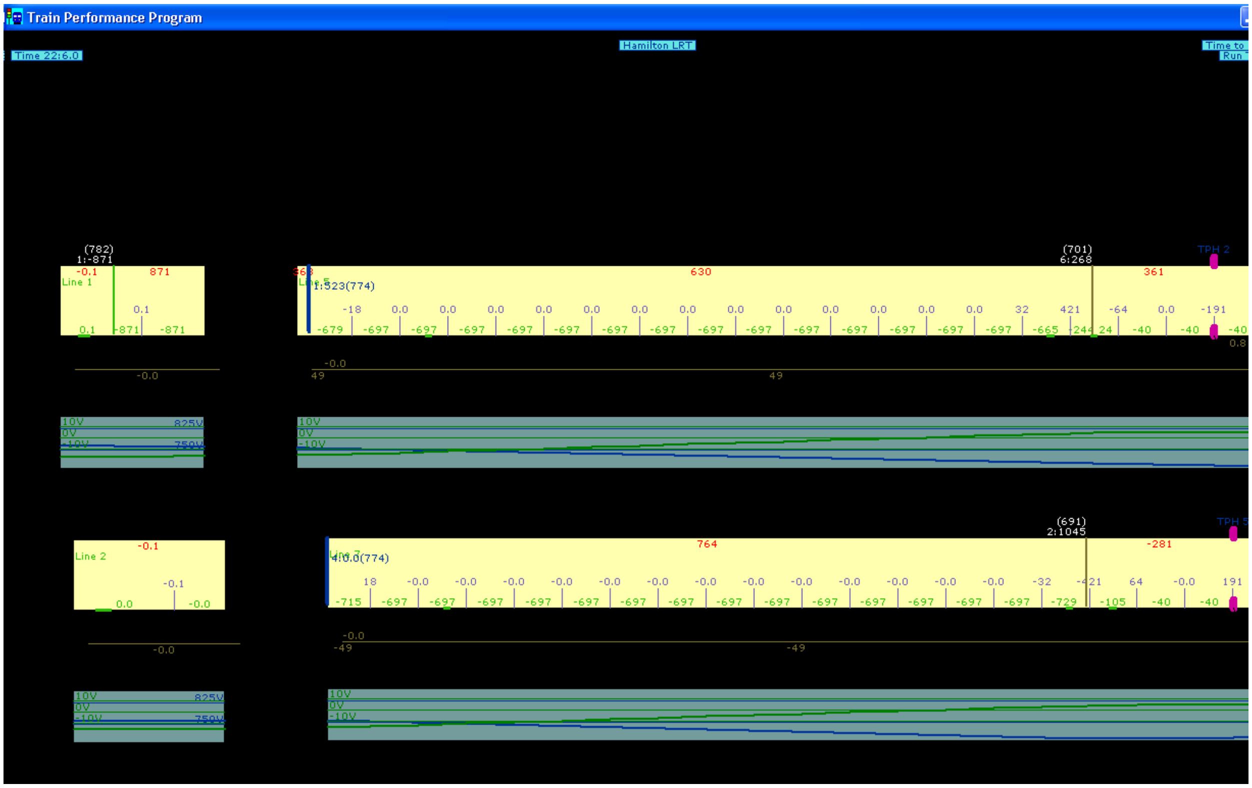

Figure 8: Outage of 2nd Substation, Time Step 22:6

Source: Mott MacDonald

For this operational scenario the worst case occurs when a LRT vehicle is regenerating during braking and the flow is from the LRT vehicle to the first substation similar to the normal operation. The current flow and direction is depicted on the following diagram.

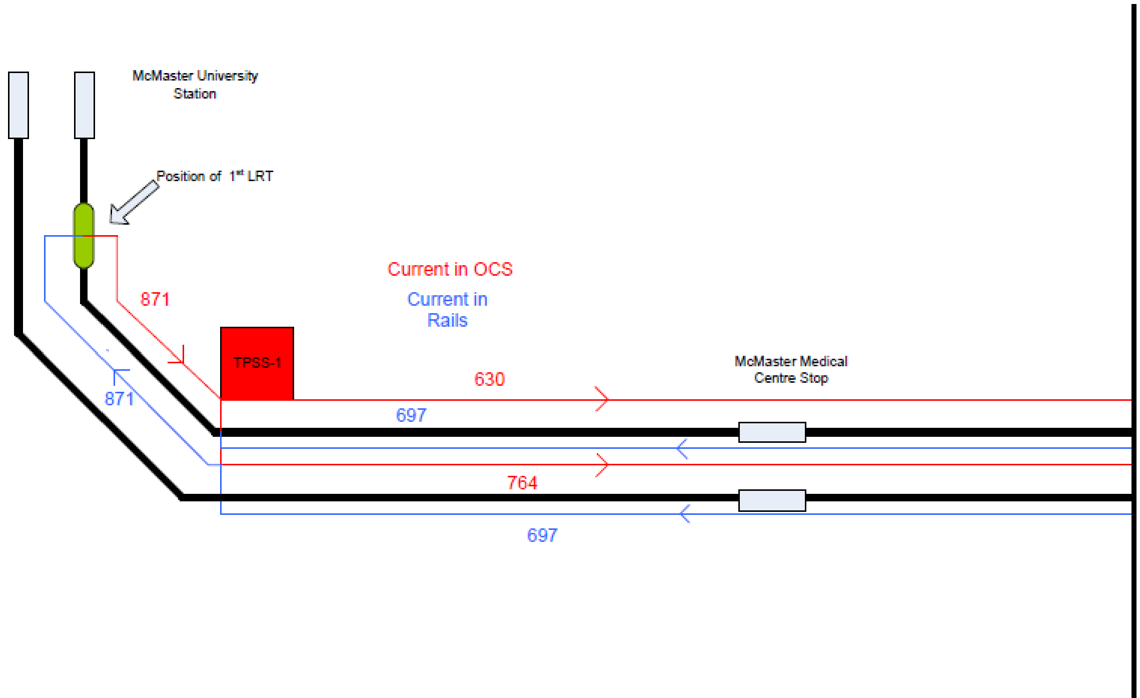

Figure 9: Current Magnitude and Direction, Outage at 2nd Substation

Source: Mott MacDonald

The magnitude of the resultant magnetic field is calculated as **19.1nT**. The results are the worst for this scenario and still do not comply with the CCEM's suggested levels. The detailed calculation and methodology are given in Appendix A.4.

5 Mitigation Measures

5.1 Introduction

It is clear that the magnetic fields that are likely to be produced by the proposed LRT project will not comply with the suggested level of sensitivity of the Titan SEM as suggested by the CCEM. In order to meet the proposed requirements some mitigation will need to be applied. There are numerous possible mitigation solutions which may be applied singly, or in certain combinations, to address this non-compliance. The specific options are considered in the following sub-sections.

5.2 Possible Mitigations

A list of possible mitigations along with a rough order of cost magnitude is presented in the table below. The figures are indicative and actual costs may vary.

No.	Mitigation	Assessment
1	Separate the OLE and track into shorter electrical sections – this would limit the length of the current carrying conductors which would limit the magnetic field generated.	Otherwise unnecessary substations and extra equipment required, greatly increasing the project budget Conclusion: unrealistic – not worth further consideration.
2	Increase DC voltage for traction supply – a move to 1500V DC, for example, would halve the currents, if all other parameters (vehicle powers, service pattern and substation location) remained unchanged and hence – in principle – halve the magnetic fields generated.	750V is generally accepted internationally as the standard for street running LRT systems. The use of higher voltages may be problematic in terms of acceptance with respect to safety and there may be extra costs for the electrical infrastructure and vehicles which will be non-standard compared with, probably, all other LRT systems worldwide. Conclusion: problematic and probably insufficient without additional mitigation measures being applied but worth considering further, particularly as there are no issues around compatibility with an existing system to be addressed.
3	Use alternating current for traction supply	In itself this offers no advantages since the CCEM equipment is just as susceptible to main frequency (60Hz) interference as time-varying DC. In conjunction with a move to a higher voltage it may be beneficial but unless very much higher voltages were considered (e.g. 25kV) the effects would probably not be significant and the issues outlined above with respect to safety acceptance for street running will be even more significant. A change to AC supply would also add cost and complexity to the vehicles in that they would require AC-DC conversion equipment and almost certainly a transformer, neither of which is normally fitted to LRT vehicles Conclusion: unlikely to offer real advantages in any reasonably foreseeable application – not worth further consideration.
4	Automatic reduction in traction current demand from vehicles possibly in combination with super-capacitors/traction batteries on-board the vehicles	The effectiveness would depend on the extent of the current reduction which is feasible. The possibility that speeds in the area of interest may not need to be especially high with the relatively close proximity of stops and the fact that the terrain is largely flat in this area indicate this may be feasible. An example of such mitigation has been evaluated as part of this work.

		The addition of super-capacitors/traction batteries would minimise any operational impact in enabling the vehicles to maintain possibly up to full performance whilst avoiding or minimising traction current flow in the OCS. With, or without super-capacitors, such a system is technically feasible. However, if super-capacitors are required this will add considerable cost and complexity to the vehicles; of the order of $500k per vehicle for super-cap equipment. It is estimated that costs of $35k would be associated with equipment to automatically limit traction demand, Equipment life times of 10 years are expected for super-capacitors meaning that these would likely need to be replaced a number of times over the expected life of the vehicles.
5	Third rail system in the street (e.g. APS) – this would have the benefit of locating the positive and negative traction conductors physically closer together which will tend to reduce the magnetic field emissions generated.	Have been used and/or are being investigated for areas where the use of OCS is to be avoided for aesthetic reasons. Historical systems with either buried power rail or stud contact have suffered from reliability problems and/or safety problems. More modern alternatives such as APS may provide a practical solution but are largely unproven in extreme climatic conditions (e.g. snow/ice) and are likely to add significant cost to the project. It is unlikely that the system could be justified in other areas of the route and hence the vehicles would require a changeover system from one power supply to the other adding further cost and complexity. Conclusion: not recommended for further consideration.
6	Hybrid system with batteries and/or super-capacitors on the LRT vehicles. No OCS system in the McMaster area, but the rest of the line would have an OLE system.	This would be the ultimate extension of option 4, reducing the current in the OCS to zero since there would be no OCS in the area of interest. Radiated emissions from the vehicles will remain. However, these will be significantly less than from the traction distribution system (OCS and running rails) and it is likely that the emissions will be compliant with the CCEM suggested levels. Possible speed restrictions may be required if either batteries or super-capacitors are used, rather than a combination. Batteries are likely to have a higher storage capacity but take longer to charge and this may be excessive (typically >5 minutes). It is noted that the recharging point should preferably be located outside the McMaster area and use the OCS on the remaining system; although an isolated charge point at the terminal stop may be feasible without generating excessive magnetic field emissions – this would need to be confirmed when more technical details of such a system had been established.

		Capital costs would be of the order of $400k-$600k/vehicle. Expected life times of 5-10 years for batteries, 10-15 years for super-capacitors, so the comments above (option 4) on the need for replacements would also apply here.
7	Hybrid system with an internal combustion (fuel) engine. No OCS system in the McMaster area, but the rest of the line would have an OCS system	This would eliminate magnetic field emissions from the traction distribution system, as with Option 6. Depending on the vehicle systems employed, some residual EM emissions may remain. However, these are unlikely to be of any significance. The negative aspects will be the additional complexity and costs of the vehicles and the local air pollution from the fuel engine. Suitable technology is readily available and well proven. However, its use in LRT vehicles is somewhat unusual. Alstom and Siemens have both produced diesel hybid LRVs for tram train application in Germany. Additional costs are difficult to estimate as the number of systems in revenue service are limited. It is estimated that the incremental increase could be in the order of $1M to $2M/vehicle plus increased maintenance costs. There is also some concern that this might not be feasible due to the small size of proposed LRT vehicles
8	Hybrid system with mechanical flywheel As option 6 but with mechanical rather than electrical energy storage.	It is not clear that the stored energy would be sufficient to move the vehicles for the distances and operational speeds required. The time required to charge the flywheel would also need to be considered. Higher maintenance costs compared to super-capacitors/flywheels. No proven record on LRT systems in revenue service. Costs are estimated to be of the order of $300k-$500k/vehicle. Equipment life times of 5-10 years are estimated for flywheel energy storage systems. Hence, as with option 6, replacements would need to be considered over the vehicle life times.
9	Hybrid system with trolley-type dual OCS in the McMaster area, or alternatively throughout the system. This is the converse of option 5 with both positive and negative conductors in the air rather than in the ground.	The effectiveness is considerable, as shown by the evaluation included in this report. However, whilst dual OCS is used extensively on trolley bus systems, where it is essential, it has rarely been used on LRT rail-based systems. It will add complexity and cost to the OCS and require non-standard current collection systems on the vehicles: either a split pantograph or trolley bus-style dual collector poles. Although trolley poles were used historically on rail-based LRTs as well, they are not used any longer on modern LRVs where, compared with trolley buses, the fact that the vehicles operate in both directions, gives added complexity. The increased electrical resistance of the distribution system compared with using the running rails is also

		likely to mean that additional substations could be required. Costs: On the basis of a hybrid system with the dual OCS only applying in the McMaster area, the costs are likely to be dominated by the additional vehicle equipment and are estimated at around $100k/vehicle. Where dual OCS is required, it is suggested that the existing OCS cost is multiplied by 1.5 to give a first approximation of the impact. If widespread adoption of dual OCS was envisaged, it is envisaged that the provision of traction power substations may need to increase by around 50%. This measure is considered technically feasible but gives added complexity to the system. From an operational perspective it is recommended that this system not be considered.
10	Inductive power supply system using loops buried in the ground	Whilst it has not been formally investigated here, the fact that this system relies on the generation of large magnetic fields, albeit intentionally localised to the vehicles themselves, to transmit traction power to the vehicles indicates that this is not likely to offer significant advantages in this context. It is mainly considered where OCS-free operation is required for aesthetic reasons and is not proven as yet. It is not recommended for further consideration.
11	Passive shielding of the equipment	Theoretical effectiveness is significant, with a reduced magnetic field of up to 1000-2000 times depending on the thickness and the number of layers of the shielding material. However, the likelihood of successfully applying passive shielding to the equipment at the CCEM is low. In order to meet the requirements of the CCEM, it is likely that whole rooms would need to be shielded and the practical difficulties in implementing this and the associated costs will be considerable. Base costs of $1k-$20k/equipment depending on size of the equipment and levels of shielding. It should be noted that passive shielding of DC and low frequency magnetic fields is generally accepted to be the most difficult to achieve with specialist materials such as Mu-Metal being required to achieve the required attenuation. The quantity of such materials required to shield a typical room would likely cost of the order of $70k-$200k
12	Active shielding of the sensitive equipment	These systems generate EM fields to counteract the interfering external fields. By definition, they can only provide cancellation in relatively confined volumes and will tend to increase the interfering field strengths in other parts of the room/building. Experience reported elsewhere indicates that they are fundamentally unsuitable for applications such as this. For example, a cancellation system applied

		to equipment in one room has interfered with equipment in an adjacent room and, if a cancellation system is applied to that equipment as well, the two cancellation systems will tend to interfere with each other resulting in a lack of cancellation for either piece of equipment. The likelihood of successfully applying active cancellation to the equipment in the CCEM is considered to be low and further consideration is not recommended. For information, base costs of up to \$400k/equipment for active shielding systems are noted (with an expected life time of 40 years).
13	Moving the sensitive equipment/laboratories	Clearly this can eliminate any incompatibility by simply eliminating the interface. However, with no other mitigation applied, it is concluded that the minimum distance required to mitigate all cases is 500m. Cost is the most significant factor here and, based on assessments elsewhere, an estimate of costs involved is in the order of \$10M. The cost may be lower if suitable buildings for sitting the laboratories already exist elsewhere but, here, the comprehensive measures which the CCEM have taken to develop an environment in which their equipment will operate to the required performance levels needs to be considered. The likelihood of a building existing which readily meets these exacting requirements is considered to be negligible.
14	Change the alignment and route of the LRT	As with option 13, this will eliminate incompatibility by effectively eliminating the interface. However, with no other mitigation applied, it is concluded that the minimum distance required to mitigate all cases is at least 500m. An estimate of costs involved is order of \$1M (to find and design alternative routes) with the additional issue that the case for building the line may be weakened by the line not serving the University. Of course, redesign of the alignment might not be feasible, as Main Street is the only arterial street through this part of the City and contains the highest amount of population generators in the area. All other east-west streets are residential.

Some of the mitigations assessed above have been considered quantitatively, for examples of how they might be implemented.

It must be noted that the impact of the proposed mitigations is very difficult to quantify at this early stage but some indicative calculations in the proposed system can be performed to demonstrate the possible effects. For example, a reduced current strategy (option 4 above) can be imposed on the system and for the normal operating scenario described in section 4.2.1 if a value of 300A is utilised the produced magnetic field will drop to approximately **5nT**. The system will be just above the suggested level as identified by the CCEM. However, the reduced current will have great impact on the line operation because of lower LRT vehicle speeds and lower timetable capacity. The detailed calculation for this scenario is given in Appendix A.5

A second mitigation option that can be quantified at this stage is the trolley-type OCS in the affected area. According to this proposal the LRT vehicle current will not return through the rails but from a second parallel conductor close to the OCS (option 9 above). This will lead to greater field cancellation due to the proximity of the current carrying conductors. If a trolley-type OCS is used for the normal operation scenario the field will be reduced to approximately **1.6nT.** The detailed calculations are given on Appendix A.6. The system will be compliant with the CCEM's suggested levels but a number of technical/operational challenges must be overcome to successfully implement this mitigation proposal. The main challenges are the systems required for the changeover from a typical OCS to the trolley-type OCS and how to implement this method on a typical LRT vehicle that is designed to return the current from the wheels and therefore the running rails. Some methods that could be considered to overcome these issues are using block joints on sections on the rails along with parallel by-pass conductors connected to the rails that return the current on a second overhead parallel conductor. These methods will require more detailed investigation on how they can be implemented on the proposed system at a future phase of design. While this mitigation measure is technically feasible, there are practical and operational issues with using this technology on a modern LRV with bi-directional operation. In addition, if the final track design makes use of embedded rail, the block joint sections noted above will create installation and maintenance challenges.

For energy storage on the vehicle (mitigation 6), the technology that is more developed today is the use of batteries/super-capacitors or a combination of them. These systems store energy onboard during regenerative braking, from the OCS wires (e.g. from the regenerative braking of other vehicles on the system) and/or from charging stations and use it in sections where OCS might not be available for EMI or aesthetic reasons. In addition, the stored energy can be utilised along with regenerative braking in the OCS areas in order to reduce the peak power demand and can lead to a high energy saving by compensating for non-receptivity of the line. Similar LRT projects that are currently in service are claiming a reduction of the peak power demand by up to 50% and energy savings up to 30%. These factors along with the costs associated with the "OCS-free" sections can have a very beneficial impact on the life-cycle-cost of the project despite the high capital expenses for the implementation of the energy-storage systems. However, the life cycle costs for battery/supercapacitor replacement and maintenance is currently expensive, but costs for these items are expected to reduce considerably in the coming years, driven mainly by the automotive industry where technology is being developed to meet an ever increasing demand. An energy-storage system implemented on the LRT vehicles could lead to "OCS-free" operation in the vicinity of the CCEM and consequently avoid any EMI problems between the LRT and the sensitive equipment. It must be noted that the energy storage system will still radiate emissions but they are expected to be much lower compared to a standard traction power system and are very likely to be compliant with CCEM's suggested levels. Many available options already exist on the market and the dimensioning and layout of the system can vary based on the system specifications and the stored energy requirements.

It is understood that it is not possible to realign the system to avoid any interference with the sensitive equipment. Although it is difficult to accurately calculate the minimum required distance due to the complexity of the system, without mitigation measures and based on the afore-mentioned calculations and results, it can be estimated that the minimum separation distance between the line and the SEM should be at least **500m**. Hence, relocation of the CCEM – were this to be feasible – would need to ensure that this minimum separation distance was met.

6 Conclusions

It is clear after the completion of the calculations that a typical LRT system with a normal OCS infrastructure is going to exceed the CCEM's suggested level of 2nT during normal and outage operational scenarios. The results indicate that the highest field levels are at least 10-15 times higher than the above mentioned suggested level and measures are required to mitigate interference. Based on this suggested level, the simulations have shown that the SEM's operation will be disturbed whenever an LRT vehicle is accelerating or regenerates during dynamic braking near the end of the line and more specifically the McMaster University station. According to the CCEM's instruction the experiments in the SEM last from a few minutes to several hours [1] and consequently they will be frequently disturbed by the proposed LRT during operation.

A number of possible mitigations are proposed in this document along with their associated costs and impact on the LRT system regarding its operation and the produced electromagnetic fields. Although most of the proposed mitigations are technically challenging and will lead to the increase of the associated costing, some of them seem really promising.

These mitigations are based on the analysis undertaken with the information as known at this time. A more detailed investigation will be required during future phases of design when specifics related to the vehicles, OCS design, traction power design and alignment have been finalized and individual components have been selected. At that time the optimum solution based on the impact on the produced electromagnetic fields and a life-cycle cost assessment of the proposed solutions can be further defined.

7 References

No.	Reference
[1]	Vibration and Acoustics spec [1], sent by Dr Gianluigi Botton, Scientific Director of the CCEM at the 10th of August.
[2]	Hamilton Rapid Transit Preliminary Design and Feasibility Study
[3]	Hamilton LRT 'B' Line- Preliminary Design Plan and Profile sheets from TPAP package