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March 5, 2019

John J. Noonan 919.660.4250 (w)
Vice President
Facilities Management
Duke University

Subject: Durham-Orange Light Rail Electrification Impact Study Document Overview

Dear Mr. Noonan:

The objective of this Letter Report is to: 1) Review the LTK EMI modeling and predicted EMF magnetic and electric fields anticipated from the proposed Durham-Orange Light Rail DC traction system, conductors and current flowing from overhead catenary cables; and 2) Provide comments on the LTK emission Zone 3 and predicted magnetic field emissions at various Duke research and medical buildings.

Vitatech performed an initial review of the *EMI Modeling and Evaluation* (Interim Work Product) dated February 2019 for the Durham-Orange Light Rail Transit Project. The interim report is competent and informative; however, there needs to be more detailed information about the potential quasi-static DC electromagnetic interference (EMI) on susceptible ion beam electron microscopy (EM) imaging tools (i.e., TEMs, STEMs, SEMs, FIBs, E-Beams, etc.), medical / diagnostic instrumentation (i.e., NRMs, MRIs, electrophysiology EEGs, EKGs, EMGs, etc.) and sensitive electronic equipment located in nearby commercial, research, medical, and hospital buildings.

As the Light Rail cars travel along the two-track DC electrified catenary Light Rail system, there are three sources of EMI emanating into the adjacent research and medical buildings:

1) Quasi-static DC magnetic fields emanating from the energized catenary (positive) and two (2) rails (negative return) traction system including the propulsion motor(s) in the Light Rail cars. A quasi-static DC magnetic field is a time-varying magnetic field that changes in magnitude over time while the Light Rail cars move. The number of Light Rail cars, speed, acceleration / deceleration, passengers, and demand (i.e., rush hour, etc.) determines the magnitude of the traction current quasi-static DC magnetic field emissions

along the two (2) track alignment. Catenary and return rail traction currents generate quasi-static DC magnetic fields that decay according to the inverse square law.

2) Ferromagnetic mass of each Light Rail car moving through the geomagnetic field of the earth also generates quasi-static DC magnetic fields. This "geomagnetic perturbation" is very similar to throwing a pebble into a pond with the geomagnetic quasi-static DC magnetic field rippling out from the moving ferromagnetic mass decaying according to the inverse cube law; and,
3) Transients (arcs and sparks) with higher frequency noise from the pantograph moving along the overhead catenary cables and metal wheels on the rails.

Electrified Light Rail, subway, and commuter train DC traction current systems deliver direct current (DC) to the motorized passenger cars through a series of substations feeding a "Third Rail" with contact shoe in Diagram #1 or overhead contact wire in Diagram #2. The proposed Durham-Orange Light Rail is an Overhead Contact System (OCS) with fixed messenger / contact cables supply positive power to the sliding pentagraphs mounted on passenger cars with negative return traction currents traveling back through the metal wheels and rails to the substations.

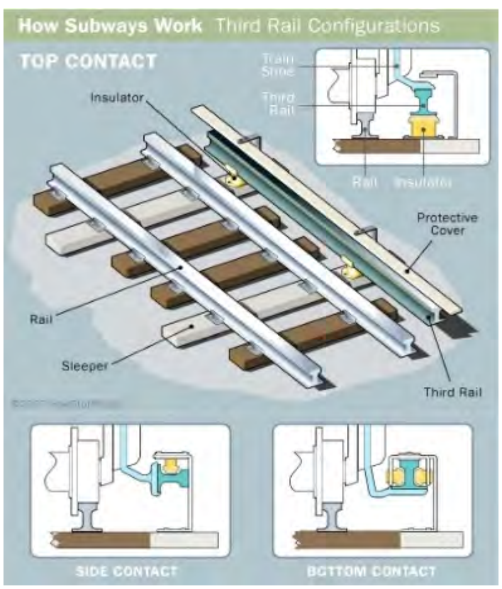

Diagram #1, DC Third Rail

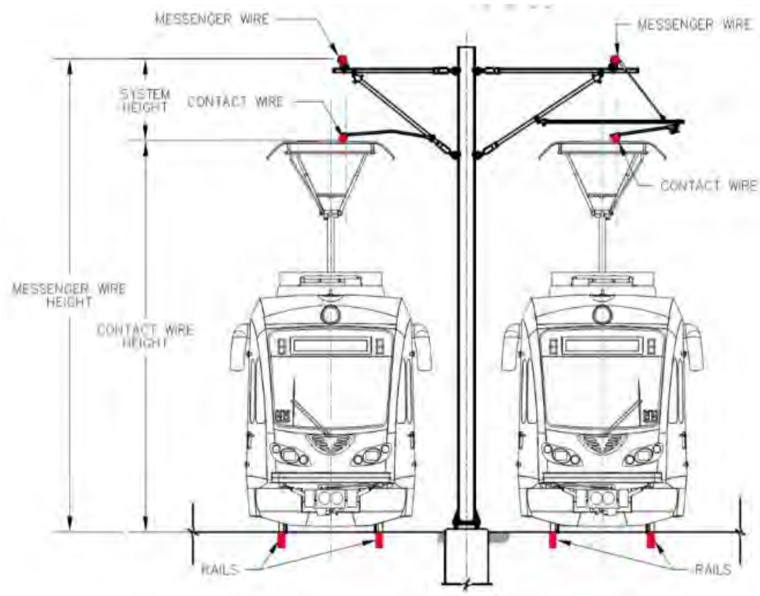

Diagram #2, Durham-Orange OCS & Rails

Light Rail transit systems operate with OCS electrification for easy and safe on-grade egress to and from passenger cars. Third Rail electrification for Light Rail systems is not possible due to the potential threat of electrocution from the energized 600 VDC to 750 VDC Third Rails adjacent to the tracks. Third Rail energized transit systems require elevated station platforms for safe egress and fixed fences / walls along grade level track alignments to minimize pedestrian exposure to the energized Third Rails. Magnetic fields from electrified OCS such as the proposed Durham-Orange Light Rail are generally 2.4 times higher assuming minimal stray/leakage traction currents along the alignment than Third Rail transit systems operating with identical traction currents. This is due to the closer proximity between the Third Rail supply and track return currents which contributes to improved magnetic field self-cancellation.

Recommended Quasi-Static DC EMI Susceptibility Thresholds

Electromagnetic induction (source of electromagnetic interference – EMF) occurs when quasi-static DC and time-varying ELF (60 Hz and higher harmonic) magnetic fields couple with any conductive object including wires, electronic equipment and people, thereby inducing circulating currents and voltages. In unshielded (susceptible) electronic equipment (computer monitors, video projectors, computers, televisions, LANs, diagnostic instruments, magnetic media, etc.) and signal cables (audio, video, telephone & data), electromagnetic induction generates electromagnetic interference (EMI), which is manifested as visible screen jitter in displays, hum in analog telephone/audio equipment, lost sync in video equipment and data errors in magnetic media or digital signal cables.

Placement of each scientific tool/instrument depends on the actual EMI susceptibility under defined thresholds, which are often not easy to ascertain from the manufacturer's susceptibility criteria. Magnetic flux density susceptibility can be specified in one of three terms shown below: B_{rms}, $B_{peak\text{-}to\text{-}peak\ (p\text{-}p)}$ and $B_{peak\ (p)}$:

$$B_{rms} = \frac{B_{p-p}}{2\sqrt{2}} = \frac{B_p}{\sqrt{2}}$$

The simulated quasi-static DC magnetic flux magnetic field levels in the Report are in units of RMS. It must be noted that the RMS term represents the average RMS quasi-static DC level, not the actual peak-to-peak time-varying quasi-static DC emission levels emanating from the energized Light Rail catenary/rail and multiple car system. The quasi-static DC magnetic field emissions from the electrified catenary / rail system add or subtract with the ferromagnetic perturbation of the geomagnetic field when the Light Rail cars are in motion generating a vector sum peak-to-peak time-varying magnetic field which emanates into the adjacent buildings generating EMI in susceptible research tools, medical diagnostic instruments and electronic equipment. Using the simulated Light Rail quasi-static DC data and resultant emission profiles within this report and the correct conversion formula, it is possible to identify the appropriate levels acceptable for each research tool *if the correct EMI susceptibility figure can be ascertained from the manufacturer's specifications. Therein, lies the real EMI challenge.*

In hospitals, clinics and medical research facilities electrophysiology instruments such as EEGs, ECGs, and EMGs are susceptible to quasi-static DC EMI noise when the input amplifiers are DC coupled at 0.36 mG RMS (1 mGp-p). Vitatech recommends 2 mG RMS (5.6 mGp-p) for most NMRs and MRIs although some models of magnetic resonant imaging equipment can tolerate between 5 mG RMS (14 mGp-p) and 20 mG RMS (56 mGp-p). Siemens 3T MRI recommends 40m (131 ft.) separation distance to the nearest electrified rail system to ensure optimal performance; however, the gradient magnetic field inside the MRI bore determines the difference between research imaging (40 nTp-p/m) resolution and clinical imaging (100 nTp-p/m) resolution. A summary of quasi-static DC EMI thresholds by units of RMS and peak-to-peak are presented in Table 1 on the next page:

Quasi-Static DC EMI Research Tool Thresholds In RMS (Peak-to-Peak) Units of Milligauss (mG)
5 mG RMS (14 mG p-p) high resolution CRT monitors (legacy) (Note: no EMI issues in LCD monitors)
2 mG RMS (5.6 mG p-p) nuclear magnetic imaging (MRIs, NMRs). Note: higher EMI thresholds possible
1 mG RMS (3 mG p-p) scanning electron microscopes (SEMs) & lower resolution TEMs and legacy tools
0.36 mGp-p (1 mGp-p) DC coupled only electrophysiology instruments (EEGs, EKGs, EMGs, etc.)
0.18 mG RMS (0.50 mG p-p) typical scanning / writing tools (E-Beams Writers, FIBs, etc.)
0.10 mG RMS (0.30 mG p-p) higher resolution TEMs, STEMs, and improved performance imaging tools
0.04 mG RMS (0.10 mG p-p) higher resolution TEMs, STEMs with GIF (Gatan Imaging Filter)
0.02 mG RMS (0.06 mGp-p) super high resolution NION STEM (most sensitive EM instrument)
Conversions: 1000 nT = 10 mG   100 nT = 1.0 mG   10 nT = 0.10 mG

Table #1, Quasi-Static DC EMI Thresholds

Vitatech will apply Table #1, Quasi-Static DC EMI Thresholds to evaluate the EMI impact on susceptible research tools and medical / diagnostic instruments. Applying a simplified dipole magnetic field model shown on page 9 of the Report, we can quickly calculate the Light Rail quasi-static DC magnetic field at selected distances (in meters) operating at a 1500 A maximum load:

B(mG) RMS = 2(1500A)(6.9m)/r^2 where distance r is in meters.

The Report listed magnetic flux density levels in mG RMS at selected distances in feet. For example: 22.3 mG RMS at 100 ft (30.5m), 5 mG RMS at 250 ft. (89.3m), 2 mG RMS at 350 ft. (106.7m) and 1 mG RMS at 500 ft (152.4m). Most high end TEMs without GIFs require an ambient quasi-static DC level of 0.1 mG RMS (0.3 mG p-p) along the entire tool column which is 1,491 ft. (455m) from the Light Rail.

Initial Assessment: Durham-Orange Light Rail Electrification Impact Study

Page 2, 5th paragraph:

The Report is trying to minimize the impact of the train system by saying there are already other local EMI building sources (i.e., electrical power, etc.) of disturbances in the environment. However, Vitatech is aware from multiple Light Rail projects the last several decades, the quasi-static DC train EMI disturbances are vastly different than that of moving elevators or trucks on the street. Light Rail quasi-static DC EMI emissions are problematic and normally require mitigation to control (i.e., Active Compensation System (ACS) technology, Magnetic Compensation System technology, etc.).

Page 2, 6th paragraph:

Vitatech disagrees with the statement, "Most electronic equipment is unaffected by typical light rail magnetic field transients, even relatively close to the alignment". Based upon previous Vitatech LTR projects, we have recorded serious EMI issues from elevated and high transient magnetic fields emanating from Light Rail systems impacting electron microscopes, NMRs, MRIs and DC coupled electrophysiology instruments.

Page 4, 3rd paragraph:

Vitatech agrees that X-ray, PET, CT scanner, Optical Microscopy, Atomic Force Microscopes (AFM) and particle accelerators / cyclotrons are not impacted by Light Rail quasi-static DC magnetic fields.

Page 7,3rd paragraph & Page 8, 1st paragraph:

Vitatech has worked on several Siemens 3T and 7T MRI projects. According to Siemens the MRI magnets can tolerate between 20 mG RMS at the bore and 40 mG RMS lateral to the bore. However, the paramount issue is the gradient field along the open bore which defines acceptable imaging resolution: 0.40 mGp-p/m for research imaging and less than 1 mGp-p/m for clinical imaging. **The control and mitigation of elevated quasi-static DC gradient fields is paramount for high resolution MRI research imaging – this can only be achieved with a special MCT Magnetic Field Cancellation System.**

Report Simulation Modeling & Vitatech Modeling– Initial Assessment
Vitatech generated a simplified quasi-static DC magnetic field simulation model and overlay based upon the worst-case OCS 1512 A current shown in Diagram #1 below:

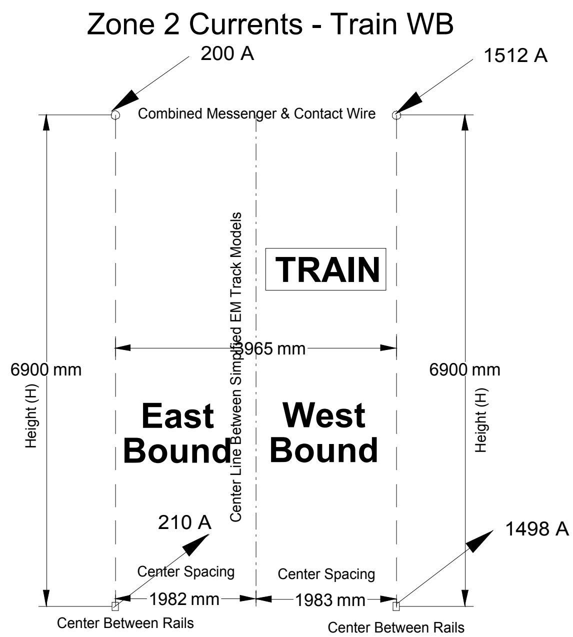

Diagram #1, Zone 2 OCS Current – Train WB

Figure #1 on the next page shows an elevation view of Vitatech's Diagram #1 simulation model at 1500A. The horizontal 0.5 mG RMS isoline is 200m (656 ft.) along the X-axis and the vertical 0.5 mG RMS isoline is 237m (777 ft.) along the Y-axis. This is the worst-case 0.5 mG RMS quasi-static DC extent boundary as the Light Rail cars travel along the alignment. Figure #2, Zone 3, quasi-static DC magnetic field isolines shown on the next page are based upon the 2m elevation (y-axis) slice of Figure #1.

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Figure #1, OCS Durham-Orange Light Rail 1500A Simulation Profile

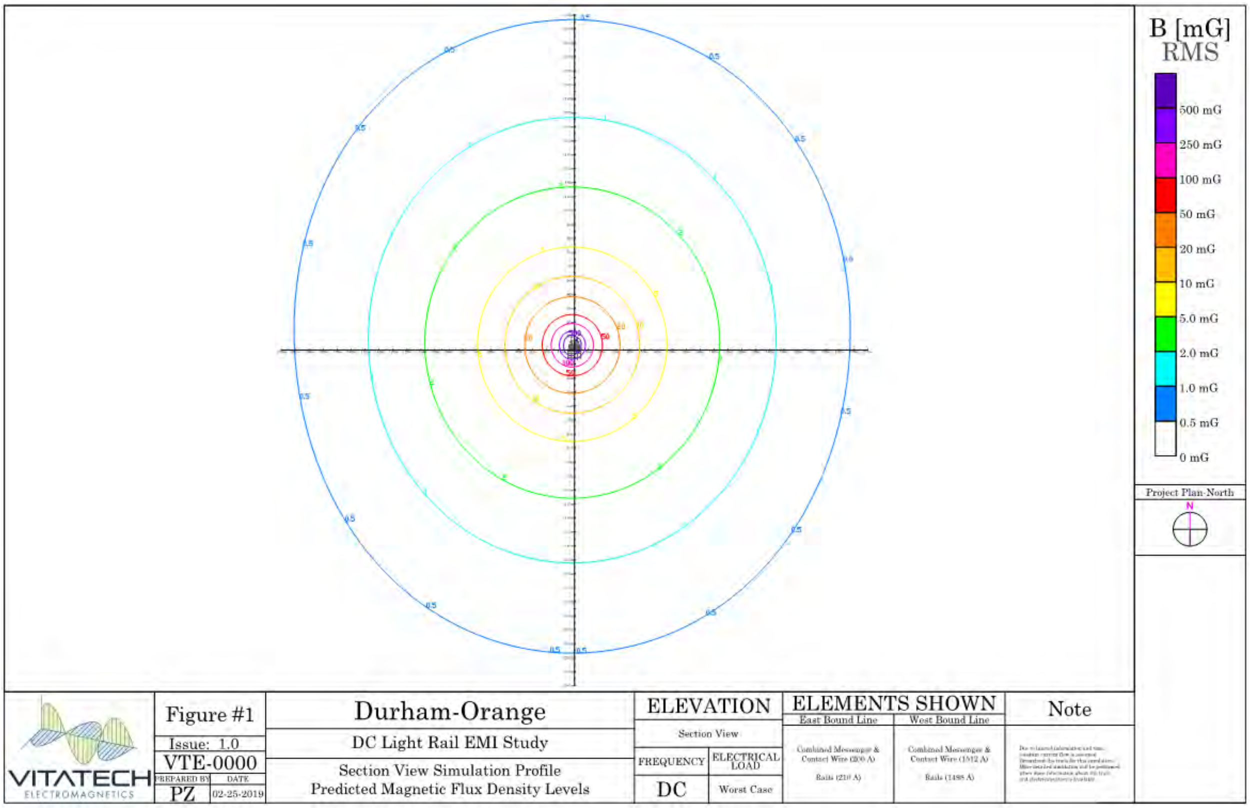
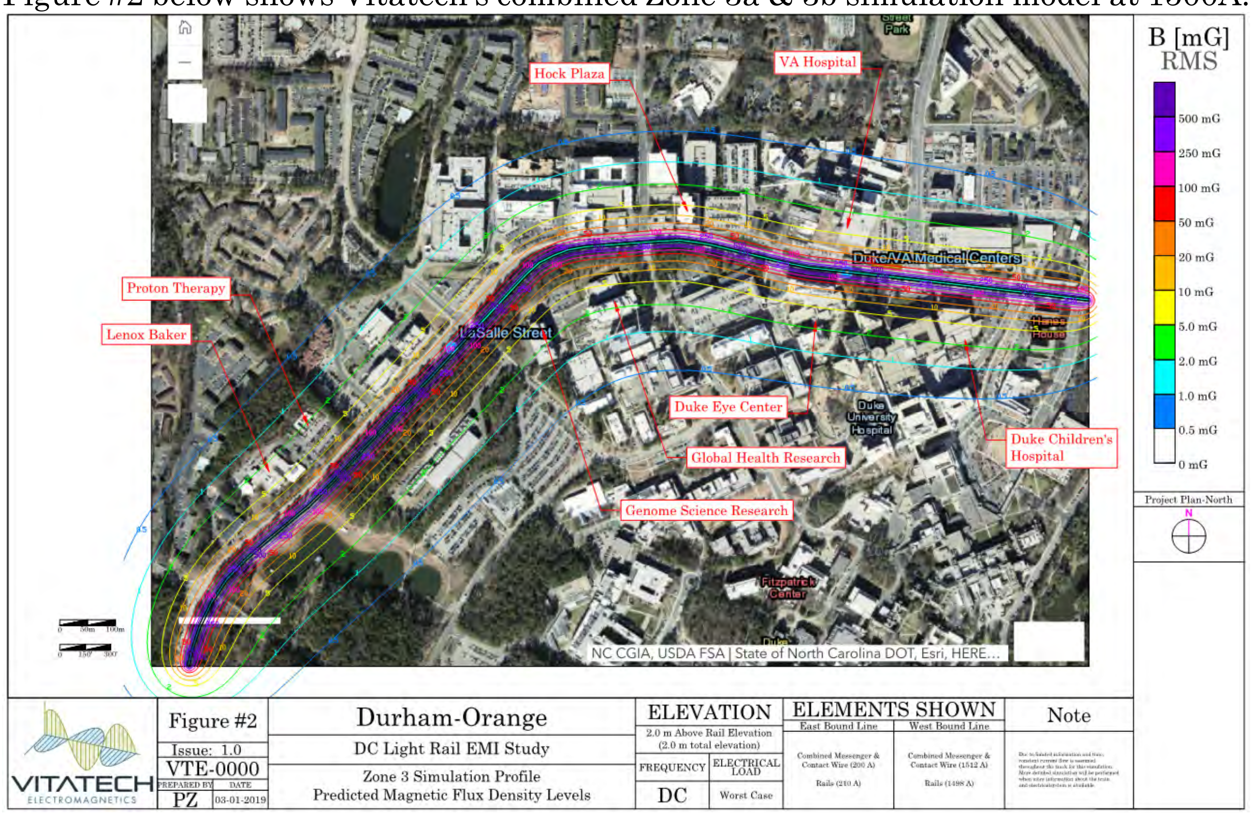


Figure #2 below shows Vitatech's combined Zone 3a & 3b simulation model at 1500A.



Based upon the Light Rail alignment proximity to the Zone 3a and 3b in the Report, Vitatech is very concerned there will be quasi-static DC EMI compliance issues with many of the electron microscopes and MRIs / NMRs. (see Table #1 tool EMI threshold criteria):

Zone 3 Buildings

- Lenox Baker Children's Hospital (Duke Building #7583)
- Snyderman Genome Science Research Building (Duke Building #7540)
- Global Health Research Building (Duke Building #7555)
- Duke Medial Sciences Research Building (Duke Building # 7516)
- Duke Medical Sciences Research Building 2 (Duke Building #7514)
- Alexander H. Sands, Jr. Building (Duke Building #7530)
- Duke Pavilion East at Lakeview (Duke Lease Space)
- Hock Plaza - Duke Image Analysis Laboratory (Duke Building #8140)
- Duke Albert Eye Research Institute (Duke Building #7514)
- Eye Center: Hudson Building (Duke Building #7561)
- Joseph Wadsworth Eye Center (Duke Building #7531)
- Duke University Hospital
  - Duke Hospital Bed Towers (Duke Building #7596)
  - Brain Imaging & Analysis Center (BIAC) (Within Duke Medical Center)
  - Duke Hospital North Ancillary (Duke Building #7547)
  - Duke Center for Cardiovascular Magnetic Resonance Imaging (Within Duke Hospital Center) including Magnetic Resonance #1, 2, 3
  - McGovern-Davidson Children's Health Center (Duke Building #7548)
- Duke Family Medicine Center (Duke Building #7515)
- Duke Division of Abdominal Transplant Surgery (Within Duke Medical Center)
- Erwin Terrace II (Duke Leased Space)
- Erwin Terrace I (Duke Leased Space)
- CARL Clinical Research Building (Duke Building #7576_
- Duke Univ. School of Nursing Building (Duke Building #7550)
- New Physical Therapy Building (Duke Building #5764)
- Hanes House Building (Duke Building #7511)
- Trent Dr. Hall Building (Duke Building #7512)
- Future Proton Therapy Building (Duke Building #7001)

It should be noted that the Vitatech Zone 3 simulation model is similar in magnitude to the Report Zone 3a and 3b models; however, our Figure #2 simulation is easier to read with 1 mG RMS and 0.5 mG RMS quasi-static DC isolines for additional detailed resolution and potential EM tool EMI impact susceptibility assessment.

Conclusions

Quasi-Static DC EMI emanating from the Durham-Orange Light Rail Electrification Project will impact selected EMI sensitive research tools such as ion-beam electron microscopes (i.e., TEMs, STEMs, SEMs, FIBs, I-Beam, etc.), MRI/NMR magnetic resonant imaging instruments and DC coupled electrophysiology monitoring devices (i.e., EKGs, EEGs, EMGs, etc.) located in Zones 1, 2, 3a and 3b. Vitatech's simplified quasi-static DC magnetic field simulation models for all Zones were similar in magnitude to the simulated Report models. Vitatech included 1 mG RMS and 0.5 mG RMS isolines to our figures for additional EMI impact information.

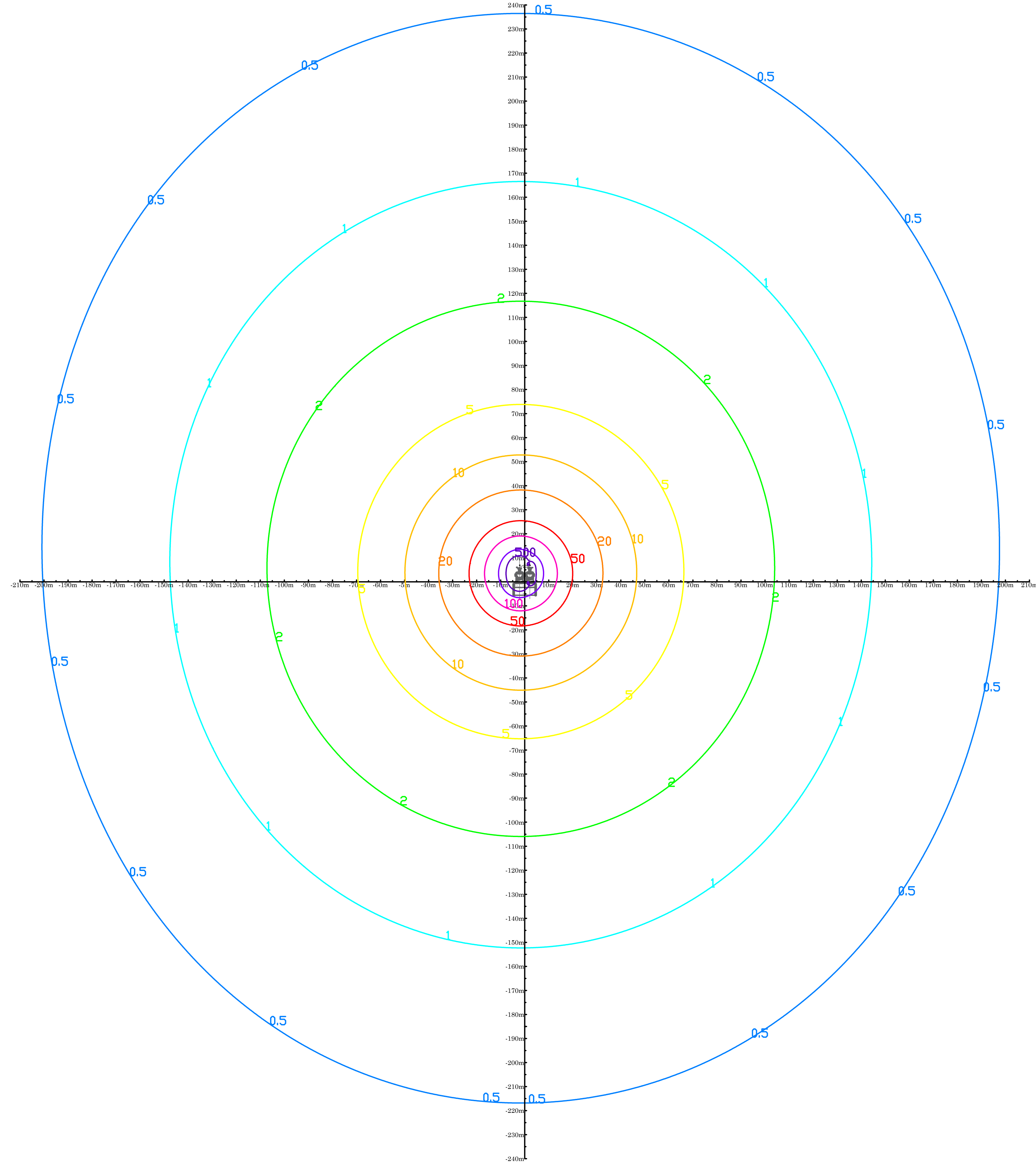
Note: All spurious quasi-static DC (0.01 Hz to 3 Hz) and AC ELF (3 Hz to 3000 Hz) EMI magnetic fields due to the proposed Light Rail traction currents, geomagnetically generated perturbation emissions from moving Light Rail cars, pantograph / rail transients (arcs and sparks) including Radio Frequency Interference (RFI), supply feeders and power station / rectifier EMI emissions is the sole responsibility of the Durham-Orange Light Rail Electrification Project to identify and appropriately mitigate at the project's expense with the review and approval of Duke University.

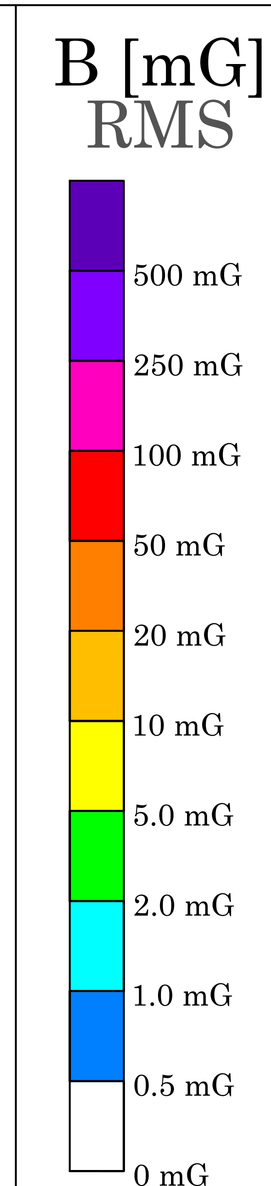
Furthermore, Vitatech recommends a detailed ambient (before LTR construction) wideband quasi-static DC (0.01 to 3 Hz), AC ELF (3 Hz to 3000 Hz) and LF (3000 Hz to 30,000 Hz) magnetic field site survey with electric field strength RF measurements from 14kHz to 6 GHz in all EMI / RFI impacted research rooms with ion-beam imaging tools, nuclear magnetic imaging tools and DC coupled electrophysiology instruments. The recommended EMI / RFI measurement study would define the ambient magnetic and electric field environment within critical research and clinical rooms.

Best regards,

Louis S. Vitale, Jr.
Chief Operating Officer (COO) & Founder

Attachment: Figures #1 & #2 Quasi-Static DC LTR Simulation Models





Project Plan-North

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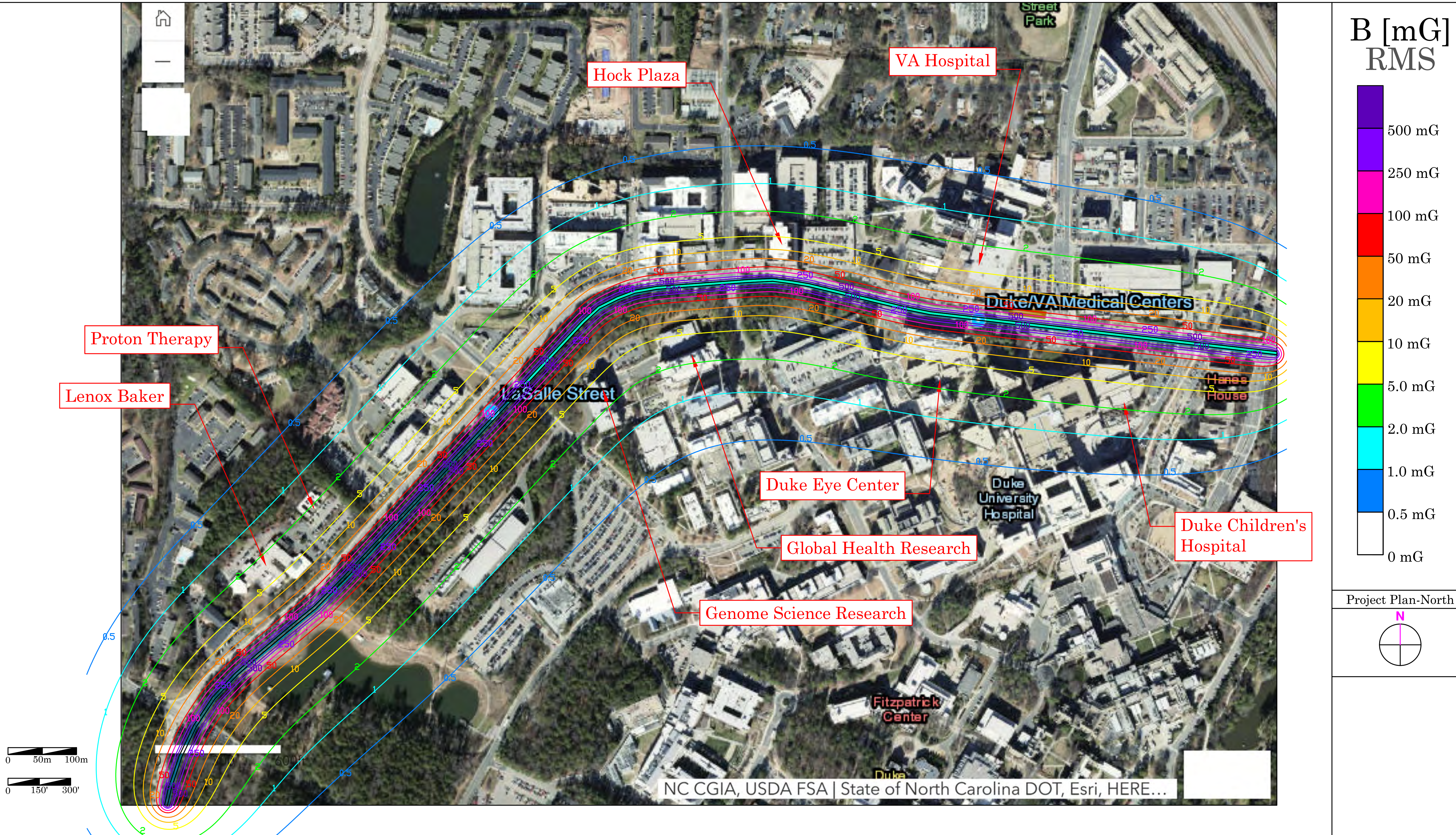
VITATECH ELECTROMAGNETICS

Figure #1	Durham-Orange	ELEVATION	ELEMENTS SHOWN		Note
Issue: 1.0	DC Light Rail EMI Study	Section View	East Bound Line	West Bound Line	
VTE-0000	Section View Simulation Profile Predicted Magnetic Flux Density Levels	FREQUENCY: DC ELECTRICAL LOAD: Worst Case	Combined Messenger & Contact Wire (200 A) Rails (210 A)	Combined Messenger & Contact Wire (1512 A) Rails (1498 A)	Due to limited information and time, constant current flow is assumed throughout the track for this simulation. More detailed simulation will be performed when more information about the train and electricalsystem is available.
PREPARED BY: PZ DATE: 03-01-2019					



VITATECH ELECTROMAGNETICS

Figure #2

Issue: 1.0

VTE-0000

PREPARED BY	DATE
PZ	03-01-2019

Durham-Orange

DC Light Rail EMI Study

Zone 3 Simulation Profile
Predicted Magnetic Flux Density Levels

ELEVATION	
2.0 m Above Rail Elevation (2.0 m total elevation)	
FREQUENCY	ELECTRICAL LOAD
DC	Worst Case

ELEMENTS SHOWN	
East Bound Line	West Bound Line
Combined Messenger & Contact Wire (200 A) Rails (210 A)	Combined Messenger & Contact Wire (1512 A) Rails (1498 A)

Note

Due to limited information and time, constant current flow is assumed throughout the track for this simulation. More detailed simulation will be performed when more information about the train and electricalsystem is available.