EMI/EMC ASPECTS OF RAIL TRANSIT ELECTRICAL SYSTEM COMPATIBILITY

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Presentation Outline

- Electrical System Compatibility (ESC)
  - System Engineering Methodology
- Vehicle/ATC EMI/EMC
- European Union ESC TWG
- CBTC
  - RFI/EMC Design Issues

Electrical System Compatibility

- Designing for the Existing Rail Transit Electrical System Infrastructure
- Introduction of New System Elements
  - New AC Vehicle
  - Vehicle AC Rebuilds/Retrofits
  - New Communication Networks (car/wayside data networks, wireless LANs, wireless CCTV, etc)
  - New Signalling Technology (digital track circuits,CBTC)

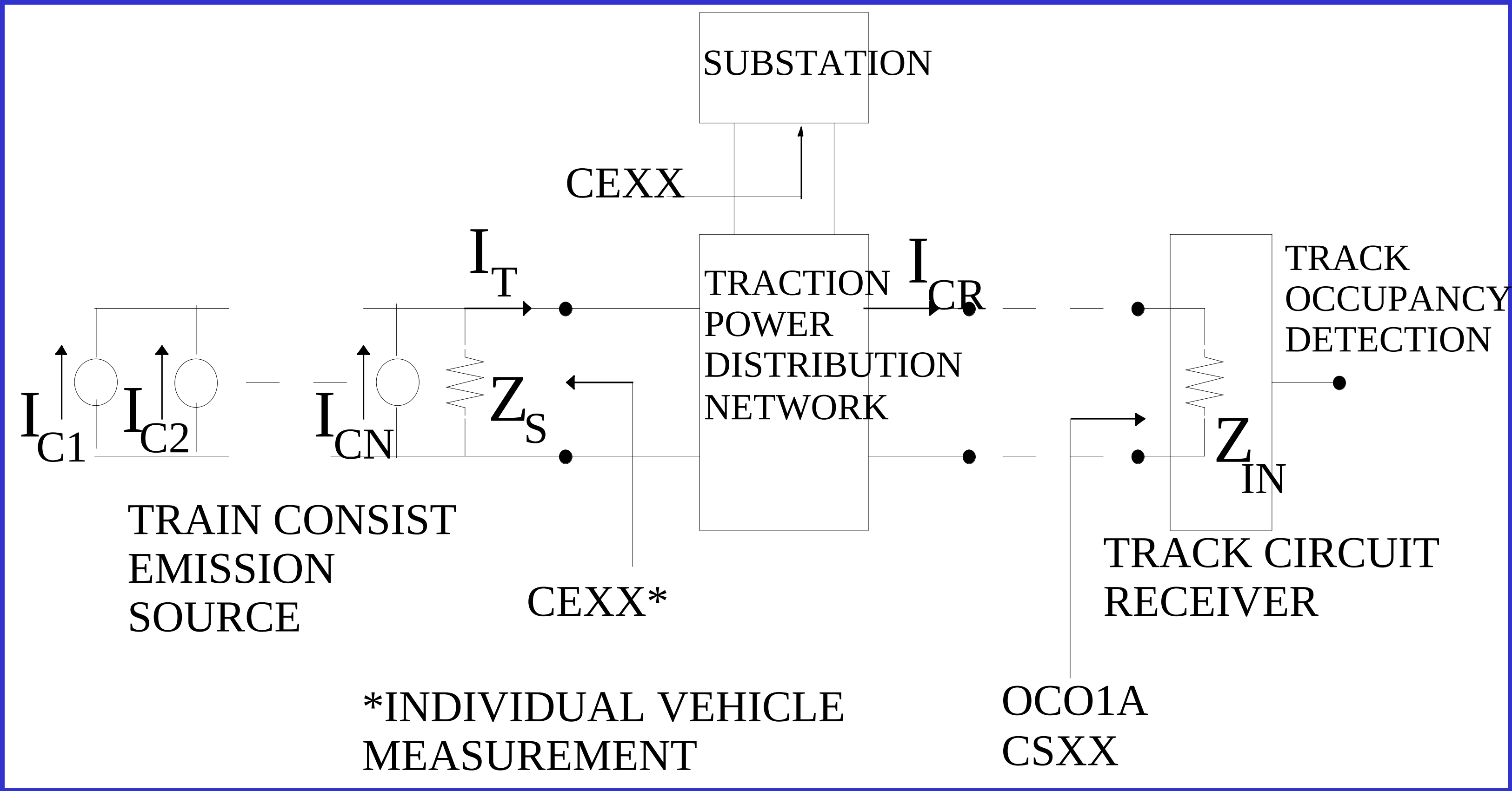
System Engineering Methodology

- Define/quantify vehicle and wayside subsystem interfaces
  - Operational functionality (normal, degraded, failed)
  - Electrical input/output characterization (operating range and thresholds, input/output impedance, etc)
- Apply standard methods of modeling, analysis, and testing to support both design and final commissioning phases.

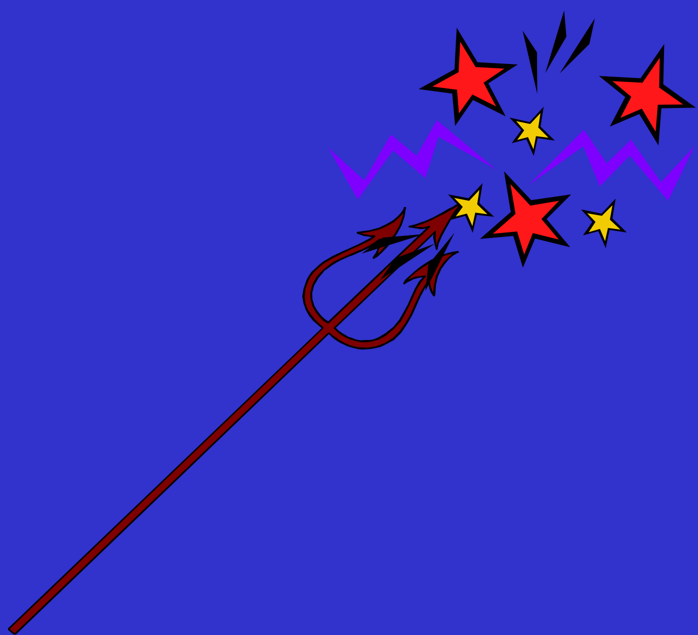
Rail Transit EMI/EMC Vehicle/ATC Interface

- Approach successfully applied over two decades ago to resolve major vehicle/ATC compatibility problems discovered during final pre-revenue commissioning.
- Technical working group of propulsion and signaling supplier design engineers developed a methodology and tools to address this and future vehicle/ATC EMC issues.

Conducted Interference Equivalent Network

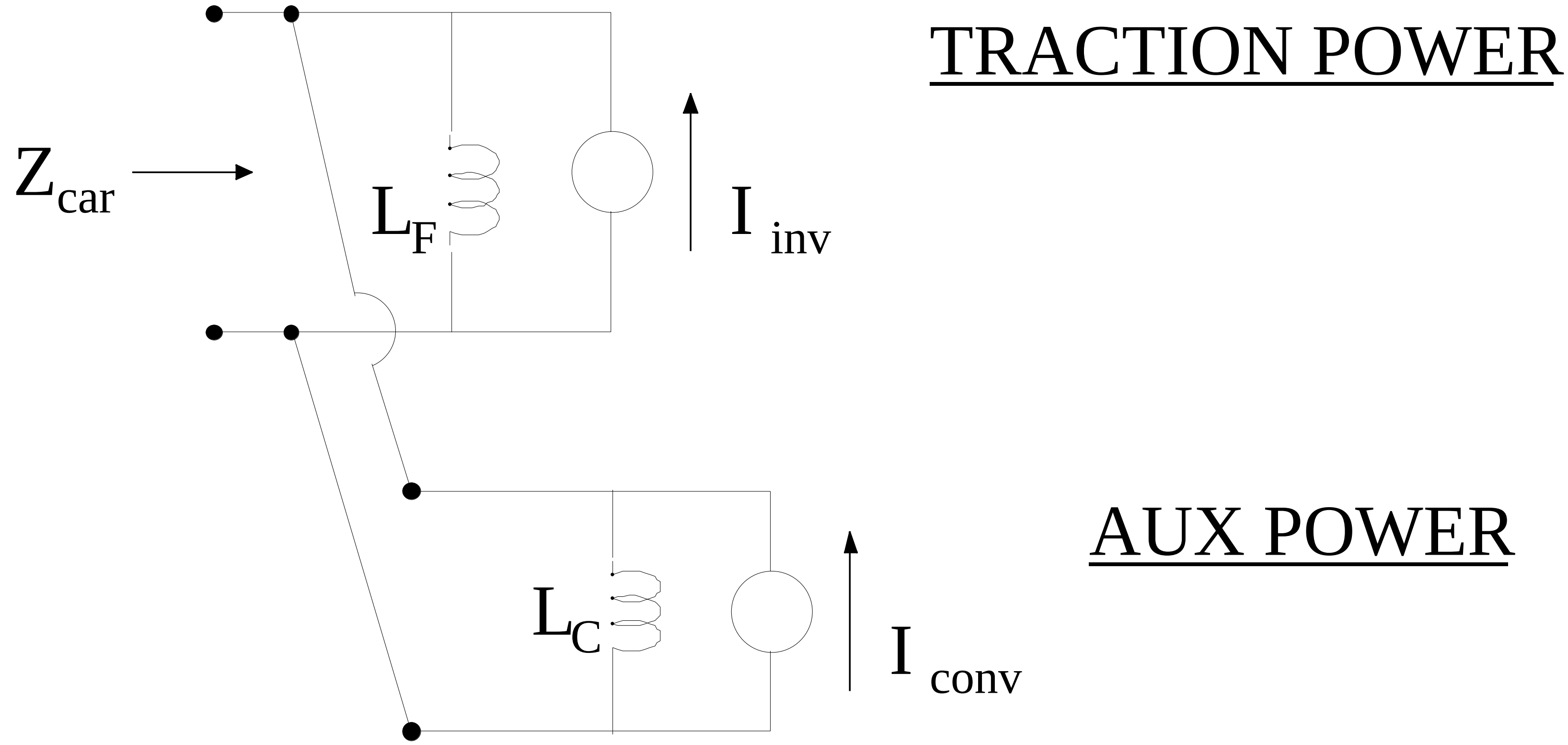


Application of Methodology



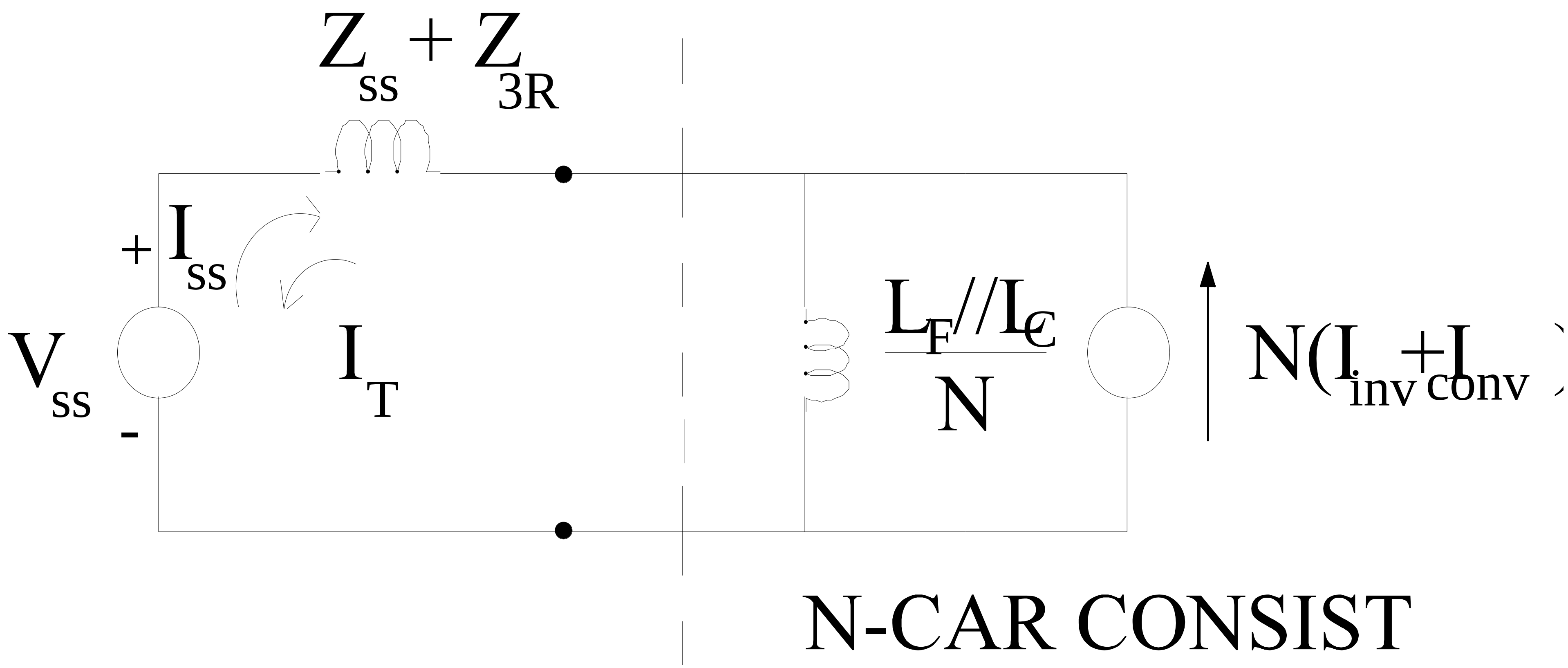
"The Devil is in the Details!"

Sample Vehicle/Electrical Network Model



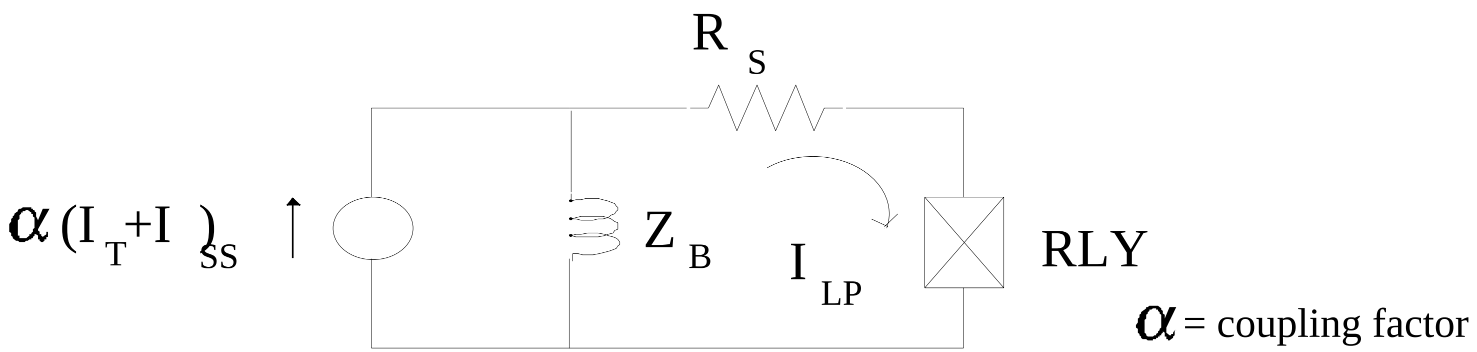
a) Single Car Model

Sample Vehicle/Electrical Network Model

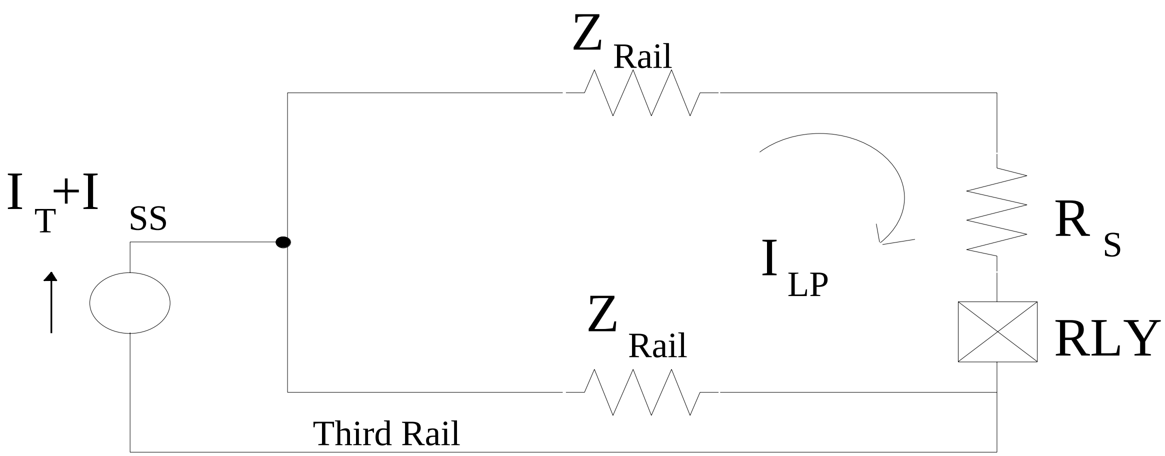


b) Train Model

Sample Signalling Models



a) Double-Rail Circuit (Occupied)



b) Single-Rail Circuit (Occupied)

I_{LP} = Relay Interference Current

Rail Transit EMI/EMC Vehicle/ATC Interface (Cont'd)

- Recommended practice was developed, EMI test procedures were soon published by U.S. DOT, and are now routinely referenced in vehicle EMI/EMC specifications.*

* Ref: Frasco, L.A., "EMC Commissioning & Safety Certification of AC Rail Transit Vehicles – U.S. Experience", IEEE International Conference on Developments in Mass Transit Systems, 20-23 April 98, London

Rail Transit Vehicle EMC Commissioning Experience

Experience has shown:

- EMI test procedures alone are not sufficient for an EMC evaluation.
- If proven modeling & analysis techniques of recommended practice methodology are not applied by system engineers and subsystem designers early and throughout the design and commissioning process, significant EMC problems can result.

Rail Transit Vehicle EMC Commissioning Experience (Cont'd)

- New test procedures, modeling & analysis tools are needed at subsystem interfaces where new EMC problems have been identified.

What Exactly Can Go Wrong?

- High conducted emission levels discovered late in traction inverter prototype testing.
  - Five fold increase in dc link filter capacitance required
  - Inverter repackaging issues
  - Problems with distributed capacitance, parasitic cable inductance affecting filter performance

What Exactly Can Go Wrong? (Cont'd)

- Early prediction/measurement of low conducted emissions by traction inverter supplier based on previous designs.
  - Electrical characteristics of new motor design increased emissions over a factor of two.
  - Significant line filter redesign/inverter repackaging late in program.
  - Parasitic inductance and distributed capacitance effects line filter performance

What Exactly Can Go Wrong? (Cont'd)

- Incorrect application of EMI test procedures
  - Procedures mandate the use of real-time spectrum analyzer(RTSA)
  - Use of RTSA peak-hold & waterfall modes allows comprehensive characterization of swept harmonic frequency bands and emission levels, transient behavior, etc.
  - <u>In addition to RTSA</u>, narrow-band filters can also be used to assess levels/time response at critical frequencies

What Exactly Can Go Wrong? (Cont'd)

- Vehicle input impedance problems
  - Line filter resonant pole too close to 25 Hz traction supply harmonic and signalling frequency – filter "gain"
  - High emission levels, instability, increased traction supply harmonic currents, potential high harmonic currents "circulating" between vehicles in train

What Exactly Can Go Wrong? (Cont'd)

- Cab signal interference (CSI) from inverter swept harmonics induced from AC motor and cabling into ATC antenna coils remains a common problem.
  - Test procedures for CSI emissions and ATC susceptibility exist but remain to be standardized
  - No early power lab measurements or performed improperly
  - …

What Exactly Can Go Wrong? (Cont'd)

- CSI(Cont'd)
  - Lack of coordination or configuration control of undercar/truck cabling
  - CSI EMC design guidelines not followed
  - Traction motor operated with saturated flux to meet required performance (CSI emissions <u>ten times</u> acceptable levels!!)

What Happens When EMC Problems Are Found Late?

- Project Delays
- "Band Aid" Fixes
- Pressure To Compromise Safety

Conclusions

- As performance requirements increase and new technology is introduced on both the vehicle and ATC side, a continued assessment of the EMI/EMC impact is necessary.
- Vehicle EMC Commissioning has been very successful – but we have been very lucky!

Conclusions (Cont'd)

- We have had several "near misses" – with resolution only days, hours before planned revenue start.
- System integrators and subsystem designers must be able to accurately predict EMI emission & susceptibility levels for their new designs.

European Union ESC Technical Working Group

- Interoperability objective among European passenger & freight railways
- Building a computer database of electrical characteristics (power, signals, communication, etc.) of all European railways
- Also to include modeling & analysis tools and design criteria used by individual railways

European Union ESC Technical Working Group (Cont'd)

- Will also allow railway suppliers access to characteristics of existing railway electrical system infrastructures, helping ensure design of compatible equipment
- Pilot completed, EU funding for next phase

Communication-Based Train Control (CBTC) RFI/EMC Design Issues

- Use of wireless data communication layered network protocol allows for possibility of a flexible physical layer, loosely coupled to train control application and network management layers. (Note: Systems using RF ranging for position location may require special consideration)

Communication-Based Train Control (CBTC) RFI/EMC Design Issues (Cont'd)

- In this case, the performance of the physical layer, which includes the choice of RF communication scheme, can be independently characterized to provide the required quality of network service (e.g., bit error rate, burst error distribution vs. packet error rate, packet retransmission and throughput)

Examples of CBTC Datacom Networks

- European ETCS using GSM-R
  - GSM-R is based on GSM public cellular phone network with dedicated railroad frequencies and a number of network software enhancements for improved latency and message delivery to support ETCS application and RFI environment (Note: GSM-R is presently based on digital TDMA. Third Generation GSM will be CDMA Spread Spectrum)

Examples of CBTC Datacom Networks (Cont’d)

- U.S. CBTC using unlicensed 2.4 GHz Spread Spectrum (S^2) Band
  - Based on proprietary network designed especially for this application
  - Operates on an open unlicensed channel using S^2 communication techniques for RFI immunity against other S^2 and licensed narrowband users.
  - If layered network protocol is used with loosely coupled physical layer, frequency migration is possible if RFI problems occur.

RFI Characterization of 2.4 GHz S^2 Channel

- Self-Interference
- Interference from other S^2 users (802.11 LANs, etc.)
- Interference from narrowband signals (licensed users, CW jammers)
- Impulse noise (third-rail gaps/arcing, pantograph bounce/phase breaks/dead sections, snow/ice, etc.)

RFI Characterization of 2.4 GHz S^2 Channel (Cont'd)

- Broadband Incoherent Noise (AWGN)
- Dispersive channel effects (multipath time spreading, frequency selective fading)

References

- Frasco, L.A., “EMC Commissioning & Safety Certification of AC Rail Transit Vehicles – U.S. Experience”, IEEE International Conference on Developments in Mass Transit Systems, 20-23 April 98, London.

Note: This presentation and paper referenced above are available at www.frascoassoc.com