TOP-FACE

TOPOLOGICAL
Simulation of Railway
INTERFACES

by *CECUBE*

The easy route to Neighbouring Railway electrical compatibility

COUPLING PROBLEMS

SOLVED HERE

Problem Explanation

- Within the UK, Network Rail specify the recommended methodology of ensuring one Railway system does not interact with another railway (NR/GN/SIG/50018).
- No text book solution exists to calculate the interaction at rail network interfaces of varied complexity and uniqueness. Long parallel track sections, crossings at bridges and tunnels, stations, end on and adjacent railways are all affected.
- Two interacting coupling mechanisms are present (conductive and inductive) and conductor impedance paths are highly frequency dependent and non-linear.
- Rapid interface configuration is needed to add or remove features without rewriting the detailed mathematics upon which the simulation is derived

Theoretical Background

- The basic theory is borrowed from electricity industry work on overhead power lines dating back to 1926, which identified the need for a mathematical solution to return ground current dispersion effects.
- When the return current is shared by other earthed conductors (whether intentional or not) a distributed earth current results. Carson and Pollaczek independently formulated equations (using impedances based on Bessel functions) for calculation of the admittance of a power transmission line. The resulting infinite series converge slowly at high frequencies, requiring a numerical computer based iterative solution for practical application.
- The Carson-Pollaczek equations were shown by C Gary in 1976 to be equivalent to a return conductor buried in the earth at a depth given by a complex number. Subsequent verification proved Gary's approximation to be valid for all frequencies. This is now the preferred closed-form approximate solution, and is referred to as "the complex depth of earth return" method. It replaces the earth distribution with an equivalent earth conductor at a variable complex depth according to frequency and earth resistivity. The mutual impedance between a set of conductors (including the earth conductor) is calculated using formulae for induction.

Application to Railways

- The main body of published papers applying generalized coupling theory of long conductors to railways occurred between 1986 and 1994. These were principally due to Mellitt et al and Hill et al. However, at this time Gary's algebraic method using complex numbers was not broadly recognised, so railway authors adopted their own approximations to the Carson-Pollaczek improper integral.
- In railway infrastructure applications the ground depth of the imaginary earth conductor is much greater than the spacing of surface conductors. Hence, each set of supply conductors and running rails can utilise a single equivalent earth conductor with minimal error. For a network interface between two rail systems, then at least two independent equivalent earth conductors are required.
- The validity of coupling solutions has a limited frequency range if capacitative effects are omitted. At low frequencies the ground admittance is dominated by the conductive component. At radio frequencies the capacitative susceptance is significant. Measurement shows this becomes important above 50kHz.
- Leakage current between rails flow close to the surface, whereas the longitudinal complex depth conductor is at a deeper level. Therefore a single uniform, homogeneous, earth conductance is inappropriate. At least a two layer model is required to represent physical conditions.

TOP-FACE Approach - part 1

- Develop a generic track section with variable geometry between two neighbouring track systems including lineside cables, maintaining a consistent electrical substructure throughout.
- Construct interfaces from sequences of topologically connected track sections. This proposes that the importance of each section is weighed according to its geometric parameters and not by its electrical complexity, which remains the same section by section.
- Adjust geometric parameters of each section to match the physical layout of the interface.
- Specify earth layer resistivity appropriate to subsurface and deep ground conditions found at the location.
- Identify the specific conductor and running rail type, cross-section and position. Derive the conductor self impedance functions for all rail types.

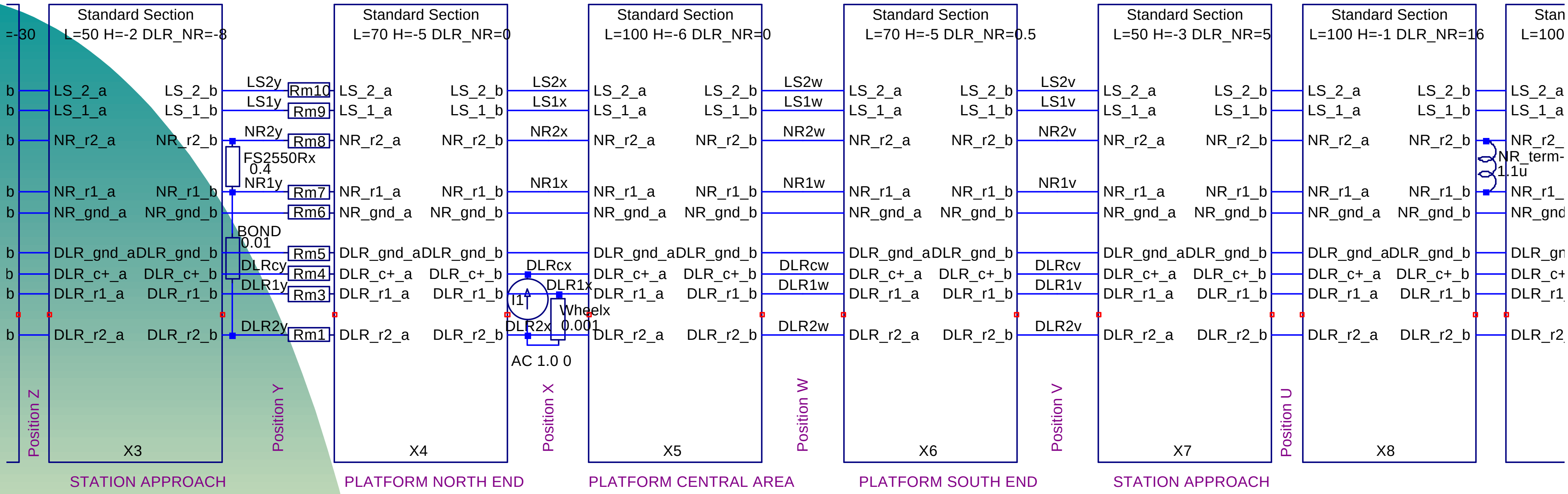
TOP-FACE Approach - part 2

- Use a proprietary and proven simulation tool in preference to bespoke software modelling for support to safety related work.
- Incorporate the capacity for continuous model expansion in a logical and hierarchical manner.
- The ability to automate frequency sweeping using step by step, steady state analysis.
- Requires a platform that efficiently solves high order, non-linear equations and includes behavioral modelling. This is provided by SPICE 3f5 (http://bwrc.eecs.berkeley.edu/Classes/IcBook/SPICE/).
- To find an adequate approximation to the complex depth calculation for the equivalent ground conductors.
- To permit connections, bonding and terminations to be added without restrictions, and additionally models of track circuit transmitters and receivers.
- To easily investigate the effect of multiple fault modes at different locations.

Topological Interface Construction

SAMPLE INTERFACE   Each section is topographically controlled by the setting of 3 parameters

L = Section length   H = height of NR track wrt DLR track   DLR_NR = Spacing between nearest running rails of DLR and NR tracks



.param dlr=1.50 dnrr=1.50 dcp_r1=0.57 dnr2_ls1=0.6 dls=0.1

.param r_dlrc=0.107 r_dlrr=0.084 r_nr=0.088 r_ls=0.005

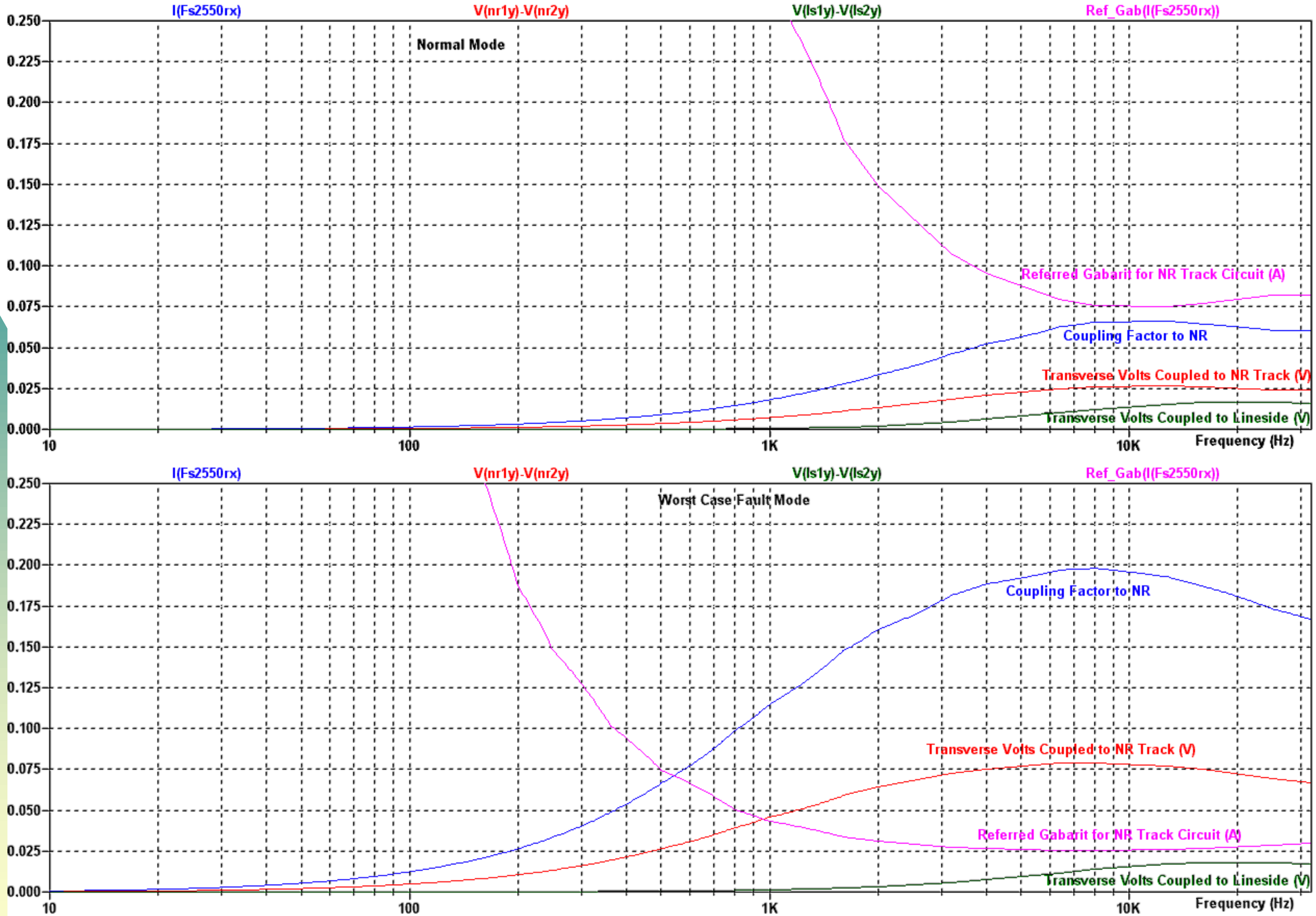
.param rho_dlr=6000 rho_nr = 6000 rho_top=1500 rho_bot=250

.param p=687*SQRT(rho_bot/(f*SQRT(f)))

.param Lterm=0.5m Rterm=0.015 Z0=120 Zgnd=20

- This model is part of a fictitious interface comprising 11 sections in total, representing a station where two separate network lines are vertically separated by 5m, and then diverge apart beyond the station approaches. This has both parallel and crossing aspects to the interface.
- Close examination of the length, height and horizontal separation parameters (L, H & DLR_NR at top of each section box) shows they change value from section to section. Also, the section lengths vary to prevent a build up of approximation errors. NR/GN/SIG/50018 recommends this approach to crossing interfaces.
- The worst position for the source is at the edge of a the station (at Y) with an unintentional bonding fault between track running rails. The worst site for the train source is in the station and close to the track circuit (at X).
- Permutation of possible failure mode locations is undertaken to discover where the worst coupling occurs.

Station Interface Results



Station Interface: **TOP** - Normal **Bottom** - With Infrastructure Faults

Simulation Results

- Graphical results are generally of the form coupled voltage per unit current source (V/A) versus frequency. Potential victim devices attached to the coupled circuit may also be investigated, determining the direct coupled current from the 1A train interference source.
- The trend for gradual coupling increase with frequency agrees with other published sources. Correct coupling levels have been verified against a comparable measurement from document BR13442.
- Under fault conditions the voltage coupled to both the neighbouring railway (NR) track and the lineside system generally increases. However, the voltage coupled to the lineside cables is normally small in crossing interfaces. The NR track coupling increases locally to a fault, and may be comparable to the track voltage from the interference source.
- The proportion of earth current is used as a simulation diagnostic. In an idealised model scenario its value is 0.3, or 30%, according to the recommended (NR/GN/SIG/50018) approximation to the complex depth of earth return equations. Since topological interfaces include modelled non-ideal features (bonds and terminations) and fault modes, the earth current proportion varies slightly from the 0.3 ideal. However, data errors *(such as entering a wrong parameter by a factor of 10)* are quickly revealed by an uncharacteristic deviation in the ground current proportion.

TOP-FACE Conclusions

- A method for evaluating coupling between neighbouring rail systems is described. The simulation is topological, flexible, easily reconfigured, and uses parameterised physical dimensions for the interface.
- Different interface types can be built without reference to the complex underlying mathematics, reducing the possibility of error. Individual section lengths from 4m to 1000m are possible.
- Calculates quickly and efficiently the voltages and currents of conductor systems with ground returns in close proximity. Sample results have been verified.
- A new interfaces changes the topology of the model but not the electrical substructure, therefore new verification is not required.
- Can provide tabular results for spreadsheet post-processing, in addition to standard graphical output.
- Support for worst case infrastructure failure modes which generally increase the track coupling factor. Determines leakage currents and paths.
- Lineside coupling increases with frequency but is usually only significant in long parallel interfaces.