EMC Analysis for Metropolitano Lisboa; an Overview

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***Abstract* — EMC Awareness is developing within Metropolitano Lisboa in the last few years. This has led to a number of projects where EM influences of the metro system to the outside world, on human beings and influences of the outside world on the metro system have been investigated. It can be concluded that in case a thorough EMC management from the start of projects is followed, compatibility can be reached in all cases, with a limited increase in project costs. An overview of three examples is given: Influence of a High-Voltage line on a signaling system; Influence of navigation RADAR on human beings; Determination of an EM fingerprint of the metro system.**

I. Introduction

Metropolitano Lisboa has been in operation since 1959. From a Y-shaped network of 6.5 km with 11 stations, it has developed into a 4 line network of 36.9 km and 48 stations, see Fig. 1, 180 million passengers year use the transport offer of 3300 million seats x km.

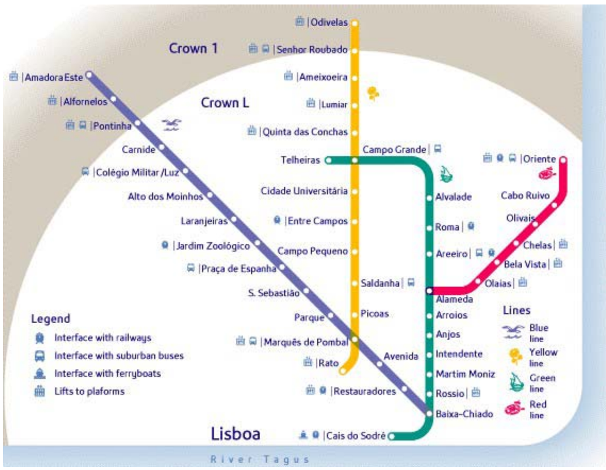

Fig. 1. Overview of the network of Lisbon Metro (status 2005)

Although EMC was recognized as being important in the past, the extension of Yellow line from Campo Grande towards Odivelas (realized in 2004) boosted EMC awareness within Metropolitano Lisboa. This led to a number of projects dedicated to EMC, for three projects an overview will be given:

- Influence of a parallel running High-Voltage Line on the metro system, in particular signaling equipment;
- EM fields of a navigation RADAR and compatibility with human beings;
- EM fingerprint of complete metro system, d.c. to 1 GHz, at various locations and distances.

II. High-Voltage Line

A. Overview

Between the stations Senhor Roubado and Odivelas the metro system is passing over a valley on a viaduct. For the construction of the metro extension a 220 kV High-Voltage line was relocated. After the relocation the High-Voltage line is running in parallel with the metro system (site 1) over several hundreds of meters at a distance of approximately 40 m and crossing directly over it with only a relative short distance between the lower phase bundles and the top of the metro line. (Site 2) An overview of the local situation can be found in Fig. 2.

Fig. 2. HV Line in parallel and crossing metro viaduct

B. Project Approach

Within the procurement specifications of the electro-technical equipment, it was assured that the equipment was in conformity with the European EMC directive, in this case in accordance with [1]. During the construction of the civil structural assets an earthing network was installed, realizing a connection towards earth of the reinforcement present in the viaduct [2]. Normally precautions are taken against vandalism when the metro is above the ground. In this case this provision has been realized as a full metal cage, with a relatively small mesh size. As this metal is coupled galvanically, a Faraday cage is constructed. This Faraday cage is an effective means of reducing Electro Magnetic Fields coupled into the system from the outside world, also a parallel ground conductor (the viaduct) as proposed in [3] is realized.

Metropolitano de Lisboa was mainly concerned with the following issues:

- Safety of human beings in stations;
- Safety of human beings in metro cars passing under the High-Voltage line;
- Safety of signaling equipment present on the viaduct;
- Possible interference at the train detection layer (track circuits);
- Safety of telecommunication equipment.

In the period between the finalization of the construction, but before the start of the test operations a large number of measurements and simulations were performed:

- Measurements of magnetic fields 10 Hz – 30 MHz;
- Measurements of electrical Fields 10 Hz – 1 GHz;
- Simulations 50 Hz magnetic fields;
- Simulations 50 Hz electrical fields;
- An inventory of equipment specifications was made;
- The functioning of safety critical systems was analyzed;
- The compatibility margin for telecommunication systems was determined;
- The safety of human beings was studied.

The measurements were a co-operation between Metropolitano Lisboa, REFER and Holland Railconsult.

C. Results

The effect of the Faraday cage for 50 Hz could be determined from the measurement results: the damping is approximately a factor 2 for the magnetic field, and approximately a factor 300 – 1000 (depending on measurement site) for the electrical field. This is in accordance with the expectations found in general EMC literature [4]. The E-field strength inside the Faraday cage(site 1) is 0.15 V/m, outside 5 V/m, H-field: 0.55 A/m inside and 1.1A/m outside, site 2 values: 2 V/m inside, 2 kV/m outside & 2.2 A/m inside, 2.8 A/m outside (all values at 50 Hz). Using the measurement techniques as described in [5], a fingerprint of the high frequency behavior of the High-Voltage Line and the EM environment of the Metro system was made. The effectiveness of the Faraday cage could not be determined directly, but a comparison between different measurement sites shows that the damping is in the range of 3 – 10 dB. The emission of the High-Voltage line is mainly in the range 9 – 150 kHz, whereas the EM environment at higher frequencies is mainly determined by intentional transmitters, such as FM radio communication and GSM.

Using specially developed Rogowski Coils and integrators [6], the induced currents in the rail were measured. An example of one of the results can be found in Fig. 3. The influence of the High-Voltage line can be seen quite clearly, note the peaks at 50 Hz, 150 Hz, 250 Hz and 350 Hz. At 5 kHz the current from the train detection system itself (including side lobes) can be seen, the peak at 2 kHz is caused by a track circuit in the adjoining track.

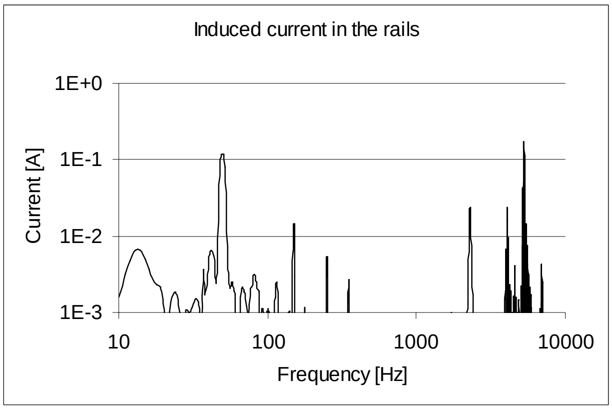

Fig. 3. Current in the running rails, at HV crossing location.

D. Discussion

When comparing the measured emission levels with the known immunity levels a sufficient compatibility margin was found for systems. For the signaling system the difference between 50 Hz and the working frequency in combination with the amplitude of the disturbance is sufficient to ensure a safe functioning. A similar conclusion can be drawn for human beings based on [7]. An example for H-fields can be found in Fig. 4.

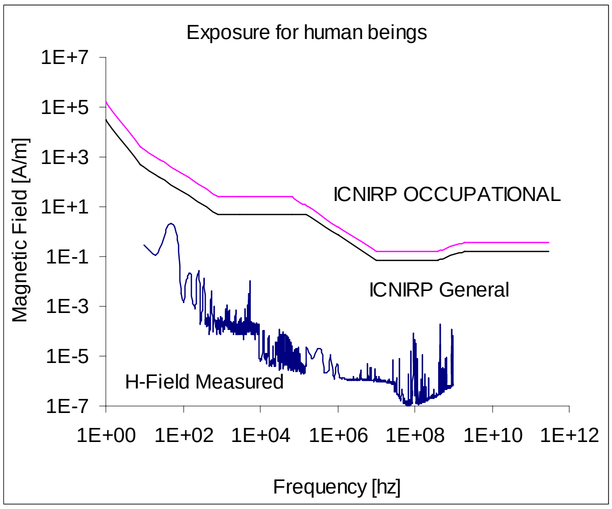

Fig. 4. H-fields in metro system compared with ICNIRP limits

A successful combination of infra structural elements such as a Metro system and a High-Voltage line is possible, but actions are needed to ensure compatibility: a careful selection of equipment, and a thorough design of the earthing system. The decision to combine the functions of anti-vandalism precautions and Faraday Cage proved to be useful. A detailed analysis of the as built situation is needed, as a basis of the safety case for the mass transport system. The combination of simulations and measurements on a number of locations over a large frequency bandwidth were a very powerful tool in proving compatibility.

III. NAVIGATION RADAR

A. Overview

For navigational purposes Metro Lisboa is using a radar system mounted under the rolling stock (Fig. 5), operating at 9.9 GHz. The possible health effect was causing concern amongst personnel, in order to assess this situation an analysis was performed consisting of both simulations as well as a measurement campaign.

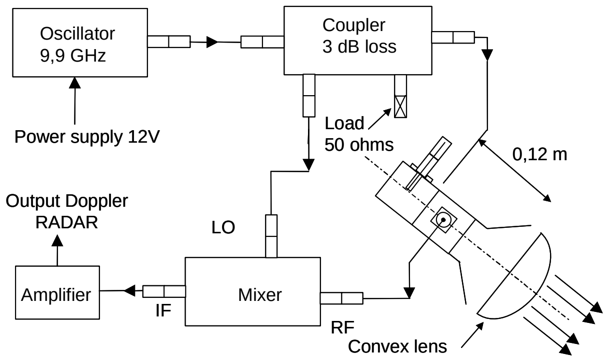

Fig. 5. Overview of RADAR system

B. Measurements

Normally measurements for this kind of equipment are carried out in an anechoic chamber. Given the size of a metro car this was not a viable option, but a dead end tunnel was available. Due to the depth of the tunnel, ambient noise is limited to 450 MHz, telecom, see Fig. 6.

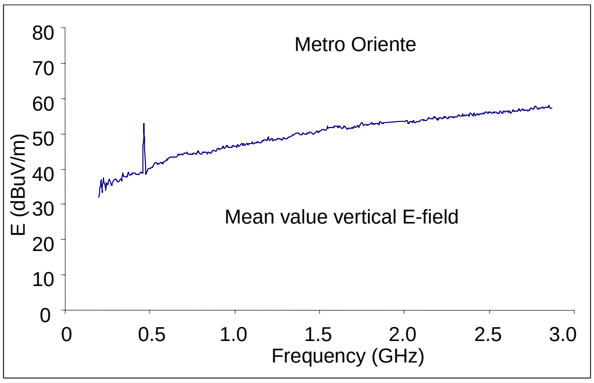

Fig. 6. Ambient noise present at measurement location

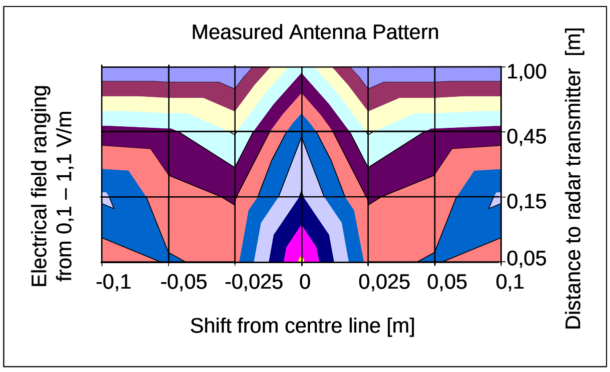

Fig. 7. E-field, measured antenna pattern, 1V/m @ (0 cm, 5 cm)

The measurements were carried out in front of the radar transmitter at different locations in order to determine an antenna pattern, see Fig. 7.

C. Simulations

Unfortunately the data available on the antenna was limited, therefore extensive modeling was not possible. Based on the opening angle, power and geometry of the set-up, basic formulas from [8], were used for the model. An example of the results can be founding Fig. 8. The simulations fit with the measurements within ± 6 dB, given the uncertainties in the modeling and the measurements this can be considered a good result.

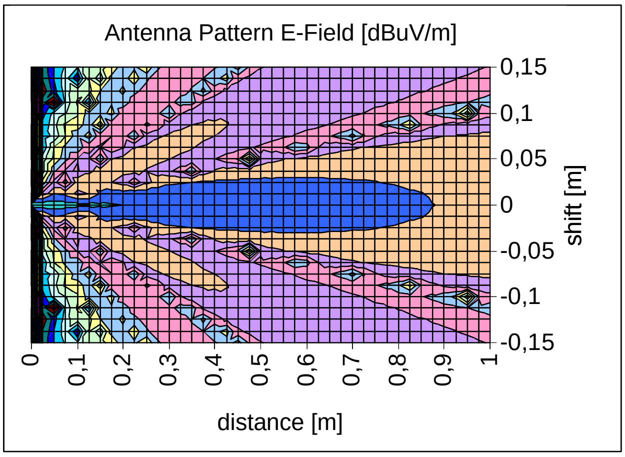

Fig. 8. Simulated antenna pattern, main lobe (blue) = 120 dBuV/m

D. Discussion

Close to the antenna, the field strength is 1.2 V/m (after statistical treatment of the data). With all electrical equipment functioning in the cabin, at the position of the waist and head this value is 56 V/m, resp. 51 V/m. These values were not influenced considerably by the operation of the RADAR. As these values are below the limits of ICNIRP [7] in the frequency region 10 MHz – 300 GHz for occupational, compliance is reached.

IV. EM FINGERPRINT OF METRO SYSTEM

A. Overview

The new extension of Red Line from Alameda to Saldanha and S.Sebastião will pass under the buildings of the Technical University. Because sensitive equipment will be present here, it was decided to determine an EM finger print of the part already in operation, using measurements and simulations. Six measurement locations were chosen:

- Alameda branch line
- Bela Vista
- Surface section Olivais - Bela Vista
- Cabo Ruivo platform
- Cabo Ruivo Atrium
- Surface above Cabo Ruivo

B. Measurements

Using five different measurement systems magnetic fields were measured d.c. to 30 MHz, and electrical fields 10 Hz – 2 kHz and 30 MHz – 1 GHz. The HF measurements were in accordance with [5].For an example of a LF magnetic field measurement see Fig. 9.

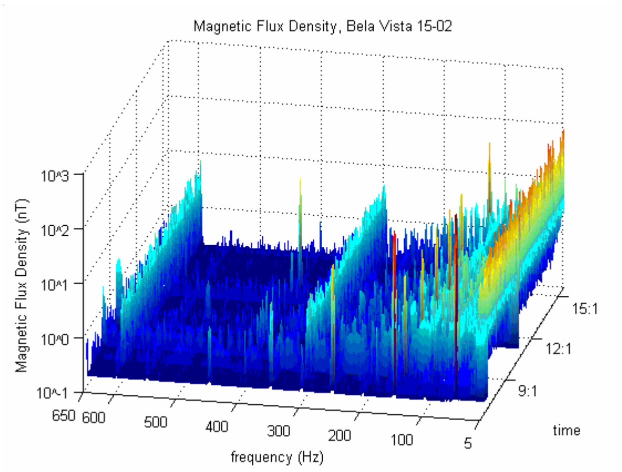

Fig. 9. Magnetic flux, Bela Vista, 7.2 m from the track

C. Discussion

From the HF measurements it can be concluded that the system behavior is compliant with [5]. The d.c. magnetic field measurements fit well with the simulations. The soil between the metro system and the surface provides a considerable damping for HF fields. At the surface (Olivais), apart from distance effects, d.c. H-fields are not attenuated while traction harmonic frequencies show some attenuation, see Fig. 10, where a comparison is made between positions along the track (2.4 m from centre of rail) outside on top of the metro system.

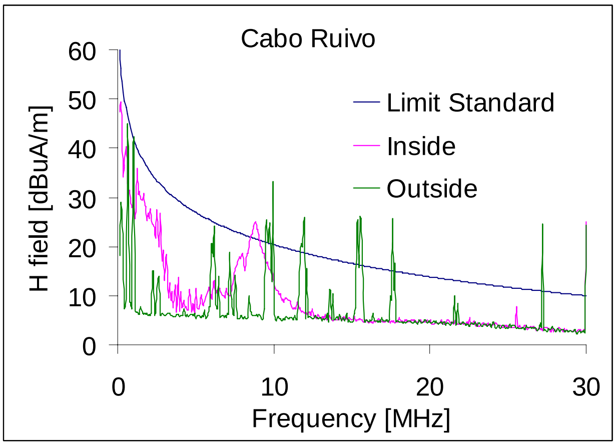

Fig. 10. 80/80 value of H-field, inside and outside @ Cabo Ruivo

In combination with possible victim systems such as electron microscopes, this indicates that d.c. H-fields are the main concern. It was suggested to create a Faraday cage using a 30 mm thick iron tunnel lining. Using Oersted BEM software two situations were studied, a closed cylinder and a 250° cylinder with an opening at the bottom, see Fig. 11. The effect is low for the closed structure for realistical values of the permeability The open structure in some cases leads to locally stronger fields. It should be noted that in case a homopolair current is present (stray currents) these fields are not attenuated at all by the lining, therefore other solutions (for instance like Helmholtz cages around the sensitive equipment might be more economical.

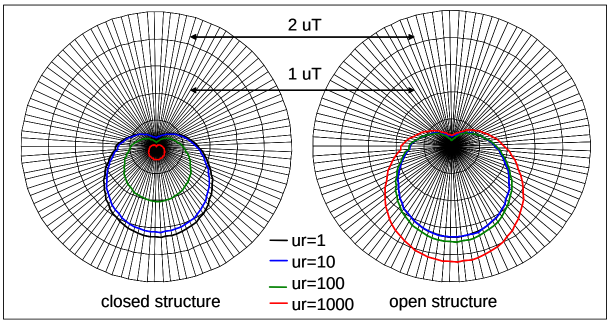

Fig. 11. Magnetic flux on 18 m radius, as function of permeability.

V. Conclusion

Awareness for EMC is developing within Metropolitano Lisboa. Reaching EM Compatibility system internally and externally (both metro system as victim and source) at acceptable costs has proven to be possible, provided that EMC management is incorporated in the project at an early start. Especially the HV-Line and Red Line extension projects prove this.

Acknowledgement

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