Modular Approach For Balise Crossing Simulations Based On Reaction Theorem

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Abstract

Balises are an essential part of pointwise train control systems ensuring the operational safety. Combined with a corresponding onboard unit, it represents an inductive transponder system (Fig. 1). During a crossing, the balise is activated by the 27 MHz magnetic field of the vehicle antenna and the activated balise sends the data signal back via the magnetic field in the 4 MHz band. At the European level, the Eurobalise is specified in [1]. The development of a balise channel requires the investigation which trackside or onboard conditions (metal, water etc.) influence the magnetic flux Φ at 27 MHz through the receiving antenna of the balise and consequently the 4 MHz current I in the balise transmitting antenna. This leads to a contact length for data transmission, which limits the maximum train velocity.

Fig. 1: Balise system overview [1]

Electromagnetic field simulation can play an important role for evaluation balise crossings. Following the straightforward approach, the 3D model includes the balise, vehicle antenna and relevant environmental conditions. The crossing is simulated by the antenna position change. Due to the small electrical system size, the COMSOL interface "magnetic fields" (AC/DC module) is applicable. The nonlinear balise IO-characteristic can be considered in the post-processing. This holistic approach has a high computational effort, since 3D meshing and simulation must be proceeded for each position. Even with the feature "moving mesh", no significant improvement can be achieved. This contribution presents a modular approach. Here, the transmission for the activation (27 MHz) and data signal (4 MHz band) can be reduced to the determination of a position-dependent coupling impedance Z_{12} (Fig. 2). This results from the reaction theorem assuming the quasi-magnetostatic approximation [2]:

$$Z_{12}=\frac{1}{I_1 I_2}\iiint_V E_1 J_2 \, dV \approx -\frac{j\omega}{I_1 I_2}\iiint_V A_1 J_2 \, dV, \quad \omega=2\pi f.$$

Fig. 2: Activation and data transmission as equivalent circuit

First for balise absence, the antennas magnetic vector potential A_1 needs to be calculated once for the current I_1. Second for antenna absence, the current density J_2 resulting from balise excitation with I_2 needs to be calculated. Finally, the crossing simulation only requires two 3D simulations for each frequency f and the reaction integral evaluation for Z_{12} regarding the relative position. This approach considerably shortens the entire simulation time. The validation example is the crossing of a reference balise centered above a metal plate (Fig. 3). The balise size and its minimal and maximum IO-characteristic is specified in [1]. A measurement at a 3D traversing unit serves as reference.

Fig. 3: Crossing a reference balise as validation example

Since the measurement involves a real onboard unit, this behavior needs to be considered by the corresponding circuit model. Based on the antenna reception level at 4 MHz, the simulation and measurement fit well. The 3D simulations on a standard-equipped computer are completed in 1-2 minutes. The coupling simulation between antenna and balise with nonlinear IO-characteristic is proceed within MATLAB in <1 min for 500 positions. This shows the improvement by the presented modular approach.

Reference

[1] – Agency for Railways (EU): SUBSET036 - FFIS for Eurobalise, online: www.era.europa.eu
[2] – Balanis, C.: Antenna Theory - Analysis and Design, Wiley & Sons Inc., 3rd edition, 2005

Figures used in the abstract

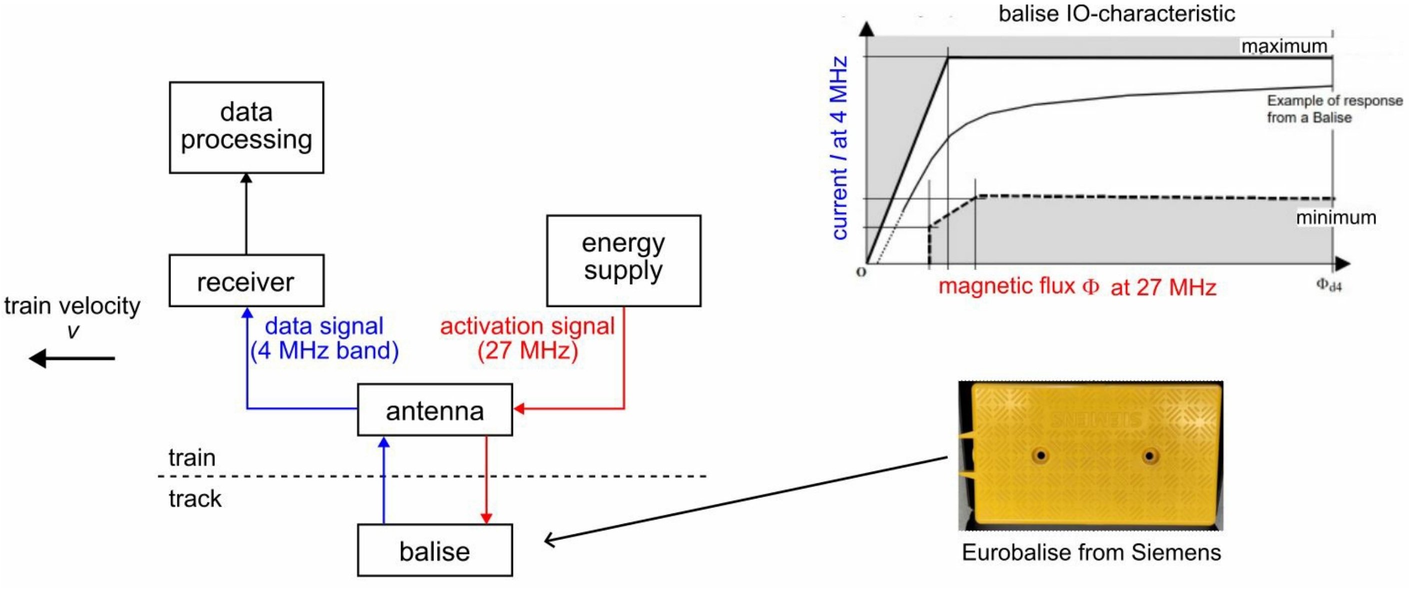

Figure 1 : Balise system overview [1]

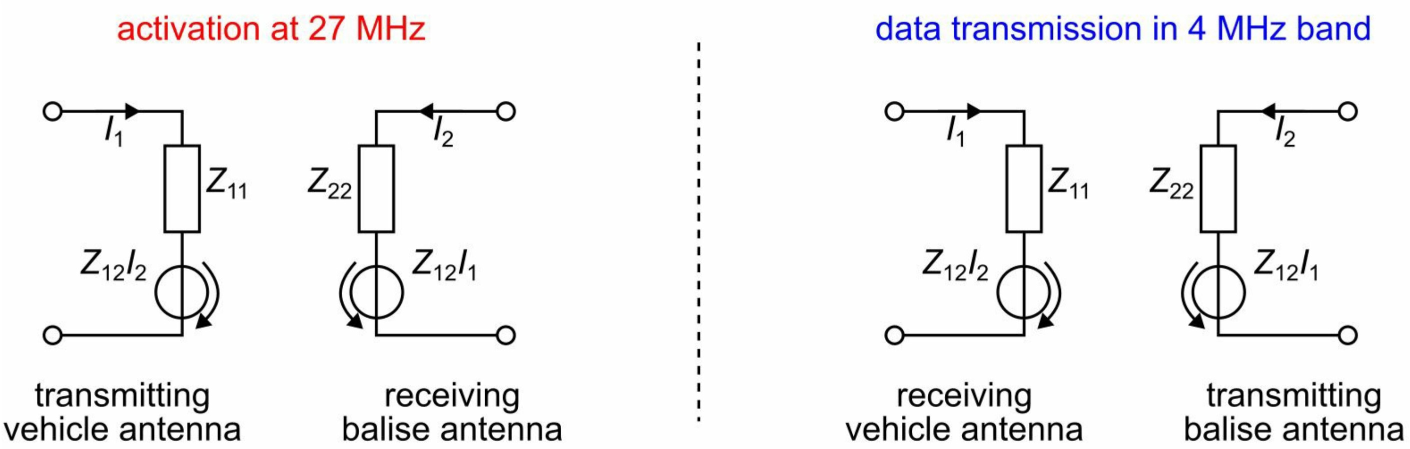

Figure 2 : Activation and data transmission as equivalent circuit

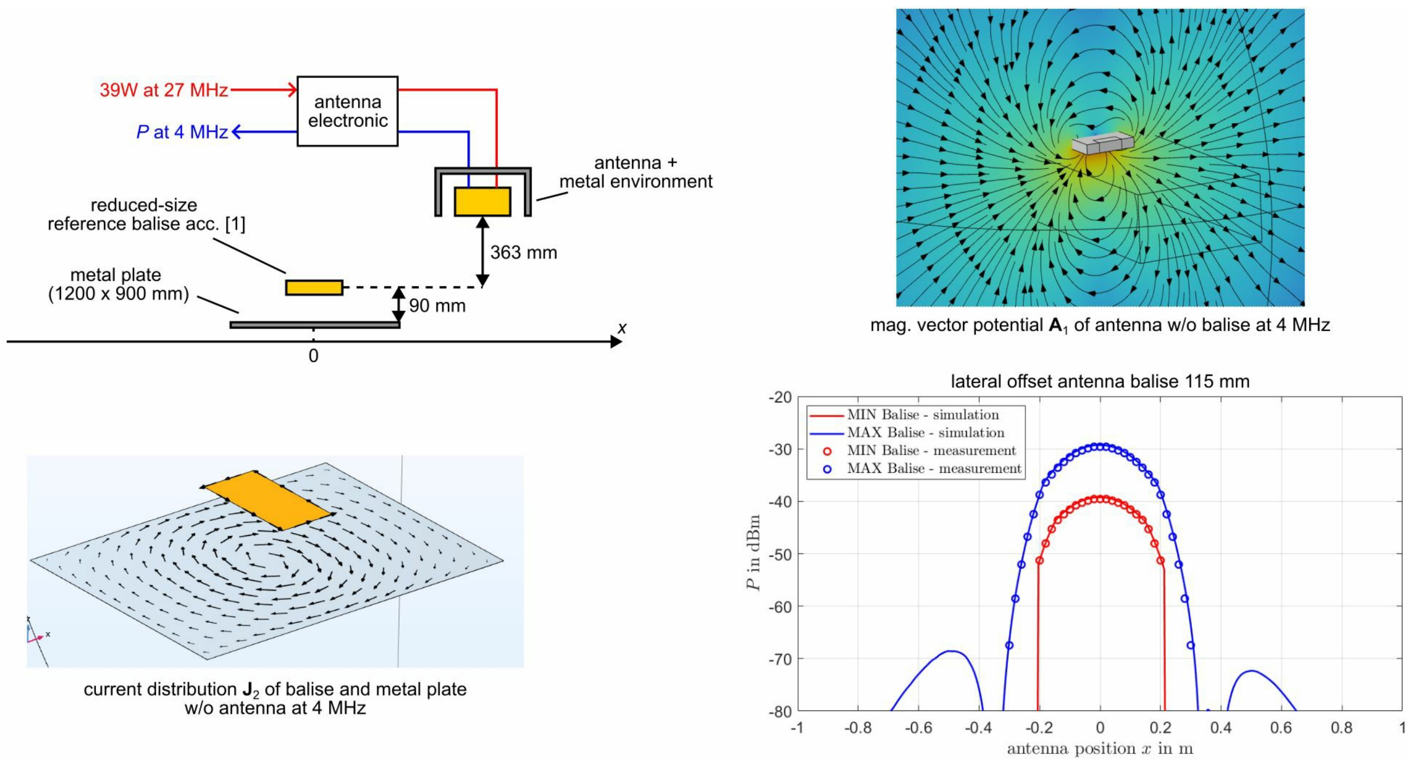

Figure 3 : Crossing a reference balise as validation example