Obstruction Detection for People Movers Operating on Conventional Small Branch Railways

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Abstract-- A combination of two different sensor systems using RF-waves is proposed: within the line-of-sight region a microwave radar module is used, and for the detection of more distant obstructions a radar using HF waves performs an early warning capability even around curves.

Index Terms-- Obstruction, people mover, radar, railway, intelligent vehicle, HF.

I. Introduction

In some regions of Central Europe traffic on small branch railways is decreasing considerably. Many track sections or whole branches in rural regions have already been closed due to unprofitable operation. The acceptance of railway service and also the profit can be increased with an improved mobility offer: automated intelligent vehicles can operate on demand as people movers on existing rails.

Especially, if the size of such vehicles is small enough (may be up to 10 persons) and basic principles of safety are valid as with cars (seat-belts, energy absorbing sections...) a fully automatic operation of a small fleet of vehicles (called „Schienentaxi“), linked together by radio, which is only monitored by one distant operator, should be possible.

One of the main problems of such a system is collision avoidance. With the assumption that only obstructions with a certain minimum dimension must be detected, and that this system should be somewhat more secure than conventional trains with respect to collision avoidance, a vehicle based obstruction detection system can be realized.

In this paper a combination of two different sensor systems using RF-waves is proposed: within the line-of-sight region a microwave radar is used, and for the detection of more distant obstructions, even around curves, a radar operating in the short wave range (around 10 - 30 MHz) performs the necessary long range warning capability.

II. Microwave Radar Module

Within the line-of-sight region a microwave radar module, as it is developed for use in cars for autonomous intelligent cruise control, see [1] for example, in principle could be used, were it not for the large amount of clutter resulting from the structure of the rails (screws, ties, ballast). In this case even large obstructions possibly could remain undetected, especially if they are not moving or exhibit a low radar cross-section in the direction to the vehicle.

A. *Proposed principle for microwave radar*

To overcome the problem of too small obstruction related signals compared to the clutter of the rail structure, along the rails of this branch line small radar reflectors would be installed in optimal distance to each other, see Fig.1.
The echo pattern of those reflectors, measured during calibration rides, is stored in the vehicle’s computer, and if there is a defined amount of deviation between the actual reflection and the corresponding stored signal, an obstruction must be assumed.

B. *Influence of obstructions*

The necessary number of reflectors along the railway depends on the frequency and on the minimum dimensions of the objects to be detected. First calculations of radar cross-sections of a typical installed

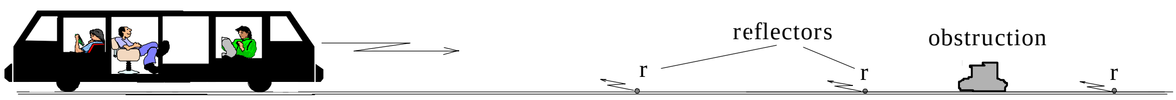

Fig. 1. Proposed arrangement of reflectors along a railway for obstruction detection within the line-of-sight region using microwave radar

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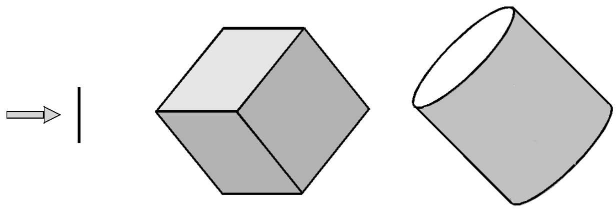
reflector and of possible obstructing objects are shown in Fig. 2. The calculations were performed at the frequency 24 GHz, the dimensions of the objects are in mm.

planar reflector	metallic cube	metallic cylinder
70 mm · 70 mm	150 mm · 150 mm	170 mm · 170 mm



in main direction	in worst direction	in direction 45°
± 2°: $\sigma \geq 1$ m²	± 2°: $\sigma \approx 10^{-5}$ m²	± 2°: $\sigma \approx 2{\cdot}10^{-4}$ m²

Fig. 2. Monostatic radar cross-section σ of metallic objects in adverse directions compared to a planar reflector (at 24 GHz)

Even large metallic objects may have a very low radar cross-section if they are positioned in an adverse attitude. Compared to the noise and clutter produced by the rails, those radar cross-sections would be too small for direct detection of the objects. Instead, those objects influence the signal, which is reflected from a reflector behind the object, within a cross-section larger than the geometrical dimensions due to well-known diffraction effects.

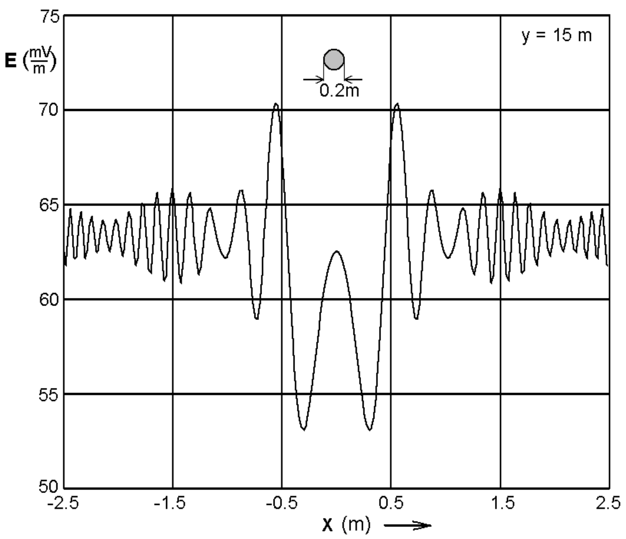


Fig. 3. Electrical field intensity along the lateral dimension x, 15 m behind a metal cylinder with 0.2·0.2 m² cross-section. Distance between transmitter and object: 100 m.

Some calculations (using the program of [3]) of that diffraction effect were performed analysing the diffracted field behind metal objects. Fig. 3 shows the field intensity along a horizontal line 15 m behind a 0.2-m cylinder. It can be seen, that the object shows clearly a shadowing effect up to a width of roughly about 0.8 m.
Even a dielectric sphere with a diameter of 0.25 m and an ε_r = 4 exhibits a similar effect.

At a first glance it can be estimated, that radar reflectors positioned along the railway with about 1 m horizontal distance and about 20 - 30 m distance along the line could enable the sensor system to detect obstructions with dimensions down to about 0.5 m cross-section.
Taking into account the movement of the vehicle along the rails, and the possibility of having a broad antenna aperture with some beam switching capability, it can be assumed that modern signal processing will reduce the necessary number of reflectors considerably.

III. Long range obstruction detection for large objects with HF-waves

Because of the limited range of the microwave radar (line-of-sight-range) there must be a supplementary module for ‘seeing around the curve’ to increase the possible speed of an automated vehicle. This can be performed by a quasi-TEM-wave radar operating between about 10 and 50 MHz . The wave will be coupled from the vehicle into the line formed by the existing rails and an additional elevated wire.

Some time ago in [1] the possible use of HF signals between the rails or between one rail and one additional parallel wire (with low height) for ground based train detection came into question. It was not considered to be useful, because of several disadvantages, as for instance high attenuation and influence of the ground.
In contrast to that, in this paper, a vehicle based obstruction detection is proposed, and this needs to function only over a limited, predetermined distance in front of the vehicle.
For that reason the possibility of a guided radar along the rails should be again thought about in more detail.

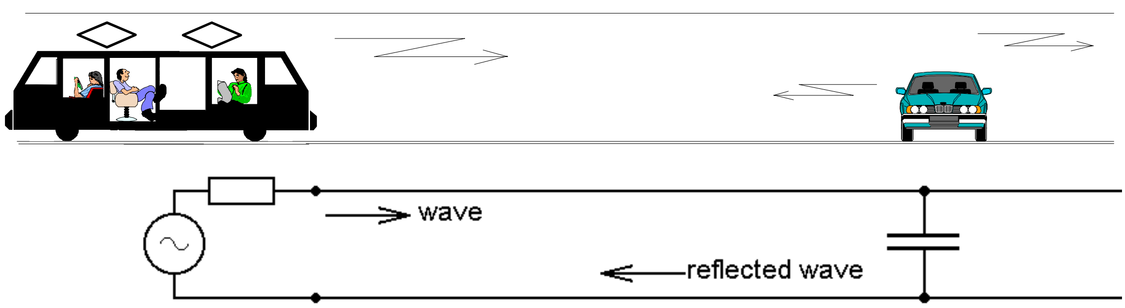


Fig. 4. Principle of the HF-radar

Fig. 4 shows the method, together with an equivalent circuit of the arrangement. The HF-radar in the vehicle couples short impulses into the line. The impulses travel down the line, which is lossy due to a certain amount of radiation and, especially, due to the real ground around the rails (the signal attenuation is about 13 dB/km).

If within a certain distance a large object is positioned in the region between the rails and the elevated wire, it acts as a capacitive load. This is a disturbance in the line which results in a noticeable reflection of the impulses.

A. Calculation principle for analyzing the influence of obstructing objects

The actual reflection due to a certain obstructing object can be calculated with high accuracy using antenna calculation programs in the following way:
For calculation, the whole arrangement is assumed to be in a steady state and the vehicle antenna transmits a continuous wave signal; then the wave travels down the line and the reflected portion travels back and will introduce a certain voltage standing wave ratio (VSWR) along the line between generator and object.

The calculations are performed with programs based on the method of moments (e.g. the well-known NEC2), calculating the nearfield characteristics of the complete structure, which is composed of the long wire and rails including the transmitting vehicle antenna and the obstructing object. Because of a necessary limitation of the structure due to limited computer capacity, appropriate loads have to be added on both ends of the line.
Fig. 5 shows a typical pattern of the electrical field intensity in a certain height along the rails, the vehicle antenna is positioned at x = 7 m, at x = 200 m there is an object on the rails.

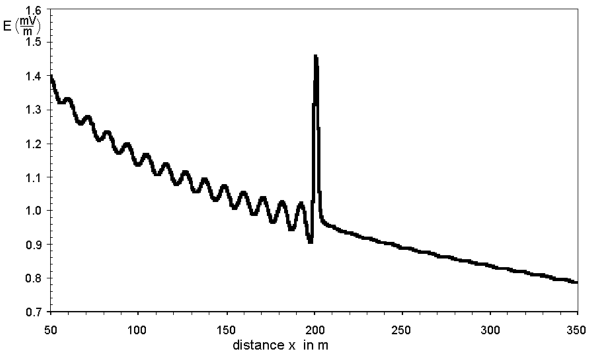


Fig. 5. Electrical field strength along the line in a constant height above the rails. Metallic object at x = 200 m.

The calculated curves clearly exhibit the behaviour of a lossy line; the reflected wave is attenuated as well as the transmitted wave. Actual calculations were performed assuming rails from steel, an elevated copper wire and ground parameters for dry and wet ground. The mean value of attenuation was found to be about 13 dB/km at a frequency of 13.5 MHz [2].

Analysing the VSWR in the region a few meters before the object and taking into account the wave attenuation along the line, an exact reflectivity level of objects at different distances can be stated.

B. Calculated reflectivity levels for metallic objects

Using NEC2, the reflectivity levels of metallic objects with different height were calculated. Fig. 6 shows the arrangement of the elevated wire (radius 10 mm, height 5 m), the two rails (modelled as wires with 100 mm diameter, center 150 mm above ground) and a wire-grid-modeled metal box at a height of 0.5 m above ground with different height dimensions h.

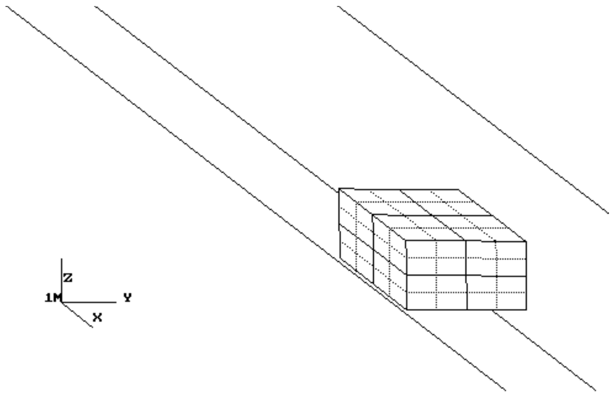


Fig. 6. Configuration for the calculation of reflectivity vs. height of the objects using the program NEC2

The ground parameters were assumed to be between $\varepsilon_r = 5$, $\sigma = 1$ mS/m and $\varepsilon_r = 10$, $\sigma = 10$ mS/m.

The calculations resulted in the following values of reflection attenuation a_r vs. height h, measured at about 50 m in front of the obstructing object:

height h	a_r / dB
0.5 m	45 - 50
1.0 m	42 - 45
1.5 m	38 - 39
2.0 m	34 - 35
2.5 m	30 - 31

Assuming a lower elevated wire, the reflectivity levels increase accordingly.

For comparison a surface patch model of a car (compact class; without plastics, doors and wheels) was built, which was good enough for calculations at 13.5 MHz with the program of [3] assuming ideal ground.
This car, see Fig. 7, was positioned in longitudinal direction above the rails. It showed roughly the same reflection attenuation as the 1.5-m-box: 40 dB.

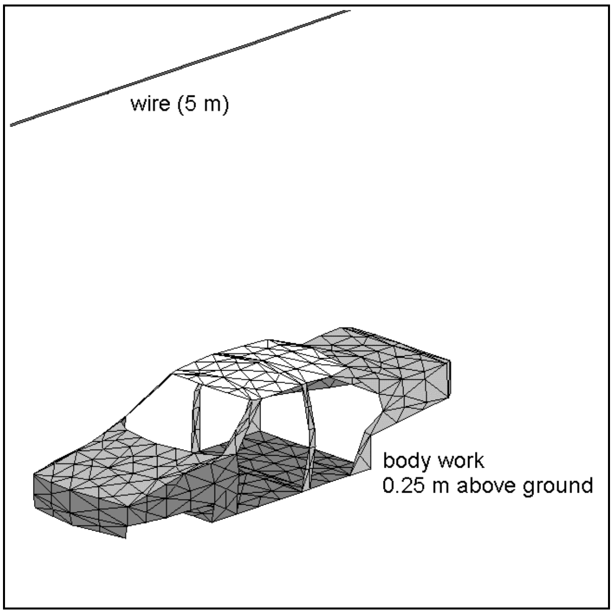


Fig. 7. Rough model of a car, calculation with FEKO [3].

C. Detectability of nonmetallic objects

Not only waggons or large cars could be dangerous obstructions on the railway but also large animals, e.g. cows or similar. Because the reflection effects of non-metallic objects cannot be calculated using the NEC program, first rough estimations were made by calculating the characteristic impedance of the line including the cross-section of such dielectric obstructions, under the assumption of a sufficiently large length of the object. The results of such calculations with [4], showed a rather good congruence with the following more exact computations. With FEKO the influence of dielectric objects can be calculated more efficiently. The assumption of a body with the dimensions 1 m · 1.5 m · 2 m and with the complex permittivity of $\underline{\varepsilon}_r$ = 50 -j50 possibly can characterise a cow. This object exhibits nearly the same reflection effect as the above mentioned car.

D. Discrimination between objects with different lateral distances to the guiding structure

Because of the possibly widespread field distribution between the high elevated wire and the ground the discrimination capability of the proposed HF-sensor has to be examined. The field distribution of the above mentioned configuration with steel rails and lossy ground including a car as obstruction can be seen in Fig. 8. There the electrical field distribution over a horizontal plane in a constant height above the rails is shown. The reflections from the object are to be seen as well as the relatively narrow region with high signal intensity.

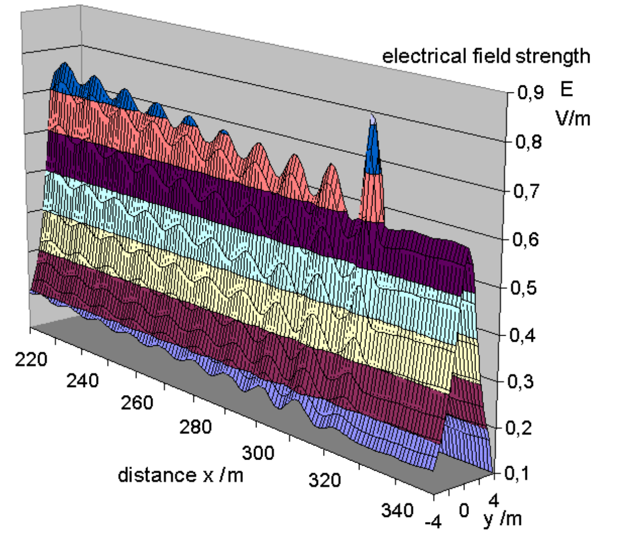


Fig. 8. Field distribution in a plane parallel to the ground; y-dimension expanded; car at x = 320 - 324 m, wire height 4 m.

A presentation of the field distribution in the lateral plane of the guiding structure shows a rather high concentration around the metallic components of the line. A metallic object with some lateral distance will have no large influence on the wave, as can be ascertained from Figs. 9 and 10. There a wire-grid-model of the car is positioned in the region of the line. In a cross-sectional-plane of the guiding structure the electrical field strength is plottet with lines of constant values. In this example the elevated wire is at a height of 4 m, the model of the car is in a center position in Fig. 9 and with a lateral displacement of 5 m in Fig.10.

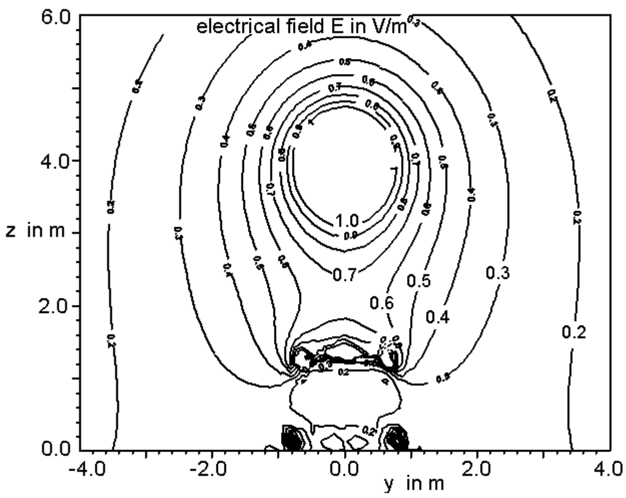


Fig. 9. Electrical field distribution across the guiding structure including a metallic object (wire-grid-model of a car) above the rails (field strength values around the wire omitted)

The comparison of the different resulting VSWR values in the line system depending on the lateral displacement of the object exhibits a steep decrease of the influence within a few meters.

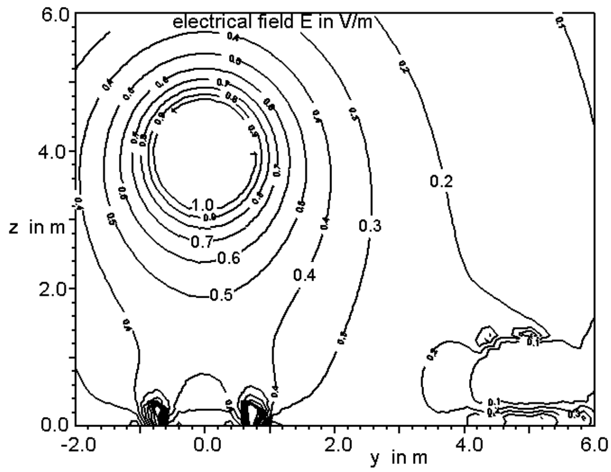


Fig. 10. Electrical field distribution across the guiding structure with the car-model at 5 m lateral displacement.

Some calculated values of additional attenuation **a** versus the lateral displacement of the car model are shown in the following table (valid for 4 to 5 m wire height):

lateral displacement	additional attenuation **a**
1 m	6 dB
2 m	9 dB
3 m	10 - 11 dB
5 m	≈ 11 - 12 dB

The results with higher lateral displacement are not very accurate, because of modelling inaccuracy: due to limited computer capacity the guiding structure had to be limited using loads at both ends. The modeled loads exhibited a remainder of VSWR in a similar order of magnitude compared to the results of the lateral displaced objects.

The steep fall-off of the reflections with increasing lateral displacement of objects causes an excellent discrimination capability between obstructions on the rails and objects beside the railway. A vehicle based guided radar system will measure the distance to the objects by the time delay of the impulses and, depending on that longitudinal resolution of the radar, it therefore can clearly discriminate between large nearby-objects beside the rails and even smaller more distant objects on the rails, because a lateral displacement of about 2 m corresponds to an attenuation of more than 0.5 km distance.

E. Comments to the applicability of the analysed guiding structure for use as an HF-radar system

Using field solving computer programs as often used for antenna analysis, the characteristics of the guiding structure, composed of existing rails and one (or more) additional elevated wires, can be calculated very well including the effect of obstructing objects. But at the same time it turns out, that small irregularities within the rail construction and the wire suspension will have a large influence on the reflection pattern. In addition the variation of ground conditions due to weather influence has to be taken into account.

That means, that the proposed HF-radar principle should be realisable for branch lines with limited length, because within this limited length all discontinuities of the guiding structure - due to mechanical or other systematical reasons - can be measured during calibration rides and stored in the vehicle’s computer. In addition the tolerances due to weather influence can be evaluated and also be taken into account.

IV. Conclusion

A vehicle based obstruction detection system for people movers operating on conventional small branch railways is proposed and analyzed. It consists of a microwave radar system for the line-of-sight-region and an HF-radar system with guided waves for an early warning around the curves.

Using computer programs for antenna analysis, the amount of reflections of some obstructions are analysed. As an important prerequisite for the application of the proposed system it is necessary to have calibration data of both radars from the complete branch line stored in the vehicle’s computer for comparison with actual measured data, because variations in the ground conditions and other systematical errors have a considerable influence on the received reflections.

This stored-data-condition results in a certain fail-safe operation characteristic of the system.

V. References

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