Implementation of a Low-Cost Digital Short Wave Radar System for People Movers

Stefan Fuchs*, Bernhard Liesenkötter
FH Augsburg, University of Applied Sciences
Baumgartner Str. 16, 86161 Augsburg, Germany
*now with Robert Bosch GmbH, Diesel Systems, Stuttgart
E-mails: sfuchs@gmx.de, liese@rz.fh-augsburg.de

1. Introduction

As already proposed earlier (/1/) an obstruction detection system for trains or intelligent people movers operating on conventional railways can be realized using a microwave radar and in addition a short wave (HF) radar system, which gives an early warning capability even around curves for collision avoidance. The HF-radar is a vehicle based system using the rails and an elevated passive wire along the track as a transmission line for the radar pulses. The pulse signal attenuation along the track and also the reflectivity of different obstacles can be calculated, as well as the coupling between the vehicle and that transmission line.

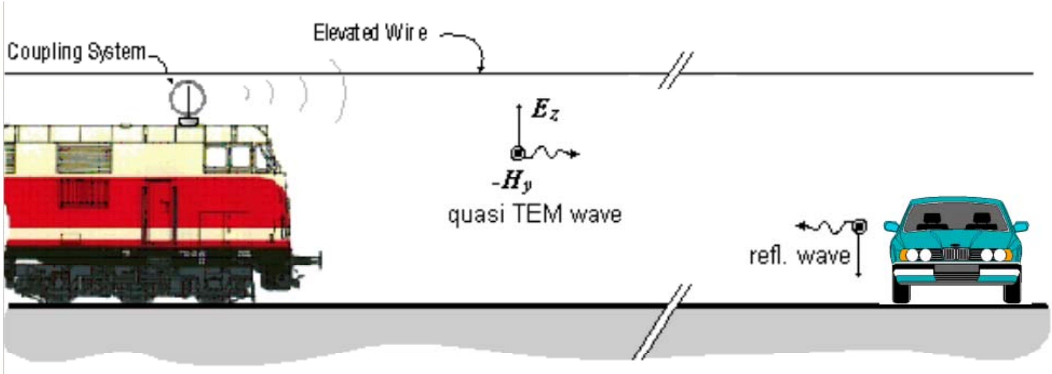


Fig.1: Basic principle of HF-radar along railway tracks

Because of the high attenuation of signals along the track and the noise in the HF band, signal processing is an important matter. But modern electronics render possible a completely digital solution from generating the HF-pulses up to the necessary signal processing and obstruction detection with low-cost components.

2. Calculation of radar signal attenuation and reflectivity of different objects

The actual reflection due to a certain obstructing object can be calculated using antenna calculation software in the following way: For calculation, the whole arrangement is assumed to be in steady state and the vehicle antenna transmits a continuous wave signal. The wave travels down the line (quasi-TEM wave because of losses in the ground) and the reflected portion travels back and will introduce a certain voltage standing wave ratio (VSWR) along the line between generator and object.
The calculation is performed with the well known software package ***Feko****, calculating the near field characteristics of the complete structure, which is composed of the long wire and rails including the transmitting vehicle and the obstructing object. In front of the obstruction the VSWR and the reflection attenuation a_r can be determined.
* Feko: Software from EMSS, www.emss.co.zaT

Calculations at 13 MHz and 27 MHz show attenuations in the range of 13 to 22 dB/km and an $a_r \approx 30$ dB (car); for a typical result see fig. 2.

The electric field distribution across the track at the place of the object (modern car, cabriolet, only metallic structure is modelled) is shown in fig. 3. There is a good concentration of the radar signal visible on the track.

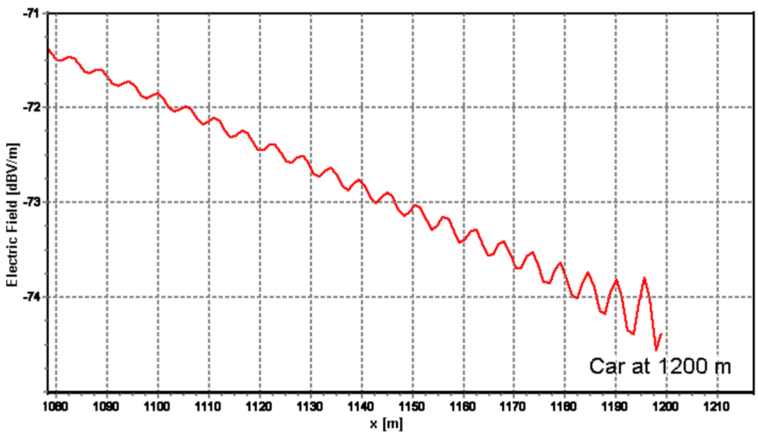


Fig. 2: Calculation of line attenuation and a_r of the obstruction

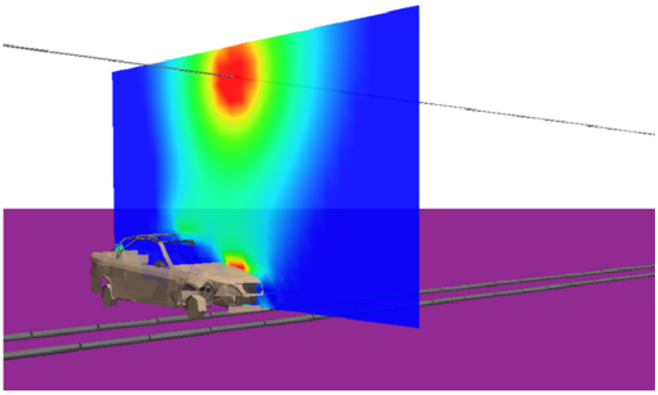


Fig. 3: Field distribution across the track, dynamic range 20 dB

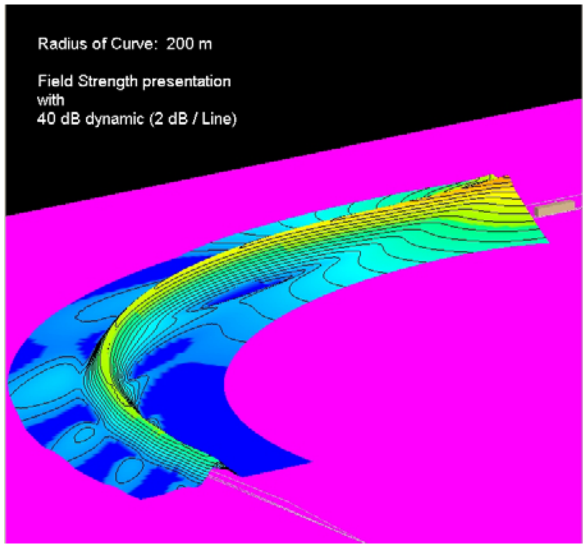


Fig. 4: Radar signal around the curve

The radar signal is following the line, therefore the vehicle is able to detect obstructing objects along curves, as shown in fig. 4. This curve only has a radius of 200 m.

For the development of the signal processing part, the following realistic assumptions were made: Use of one common antenna for transmitting and receiving on the vehicle; attenuation due to coupling into the line, line attenuation (1,000 m) and an a_r of 40 dB (small obstruction) results in a total attenuation between transmitter power and received power of about 131 dB.

3. Digital signal processing methods and hardware for the Short Wave Radar System

Taking into account the given numbers for attenuation of the signal, and in addition the low efficiency of the broadband transmitting/receiving antenna on the vehicle, a fully digital realization of the radar system is described. The system is a low pulse repetition frequency pulse radar with a pulse repetition frequency of 67,5 kHz. Despite the fact of higher range attenuation, the higher frequency of 27 MHz was used because of the increasing “man made” noise at lower frequencies.

Due to high noise and high attenuation, the echo signal from a relatively small and far obstruction exhibits a signal-to-noise ratio (SNR) of only about -10 to 5 dB at the receiver. To gain this signal to noise ratio, a transmitting power of 750 W is needed. An SNR of 15 dB is required to safely detect an obstruction. Processing and filtering the signal digitally can increase the SNR to the required level.

Some well-known principles of radar signal processing (/2/) are discussed and are used gainfully with the digital implementation of the 27 MHz short wave radar.
First to mention, and most powerful, is coherent pulse integration. Radar bursts of e.g. 20 pulses are sent to the target. The echoes are added in the receiver. Because of the slow speed of the people mover, up to 20 and more pulses can be integrated without the need of correcting the phase of the echo signal.
Pulse compression is used to achieve a narrower peak for an obstruction in the envelope signal at the output of the receiver. This makes it easier to determine the obstacle's exact distance. Therefore, the sender's signal is biphase-modulated with a Barker code. In the receiver this modulated signal is compressed using a pulse compression filter. A side effect of the biphase-modulation is a higher bandwidth of the signal, which effects in lower electromagnetic disturbance in the railway's surroundings.
The compressed pulse is filtered with a matched filter, implemented using a digital FIR filter, whose frequency response is tailored to the compressed pulse's frequency spectrum.
After a complete simulation using a Simulink model, the hardware for the radar system was put into reality using a high-speed digital-to-analog (DAC) and analog-to-digital converter (ADC), an FPGA and a low-cost digital signal processor (DSP). Fig. 1 shows the whole system.

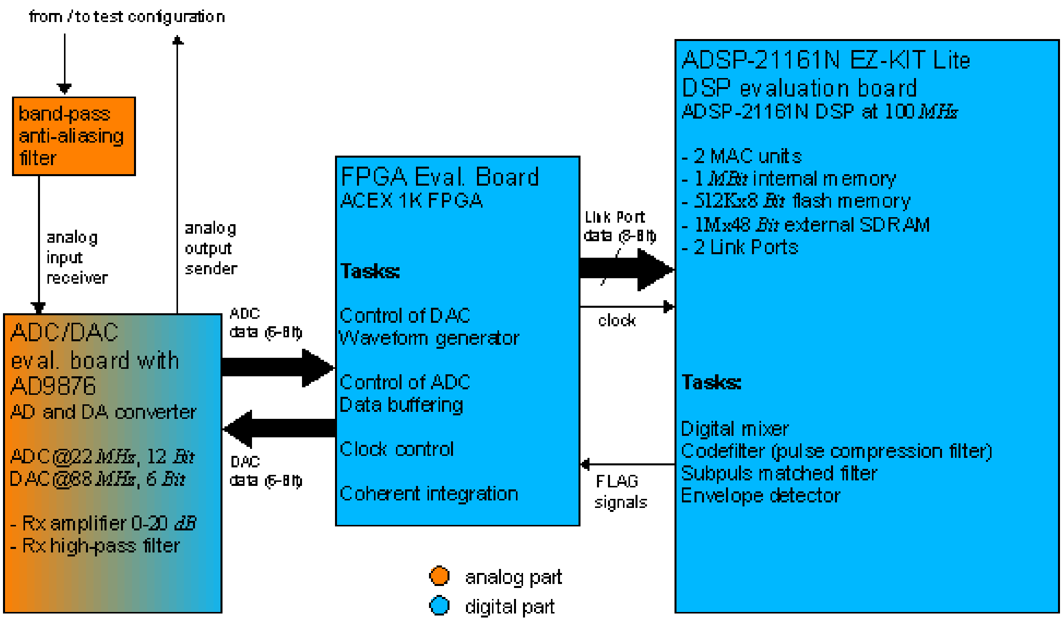
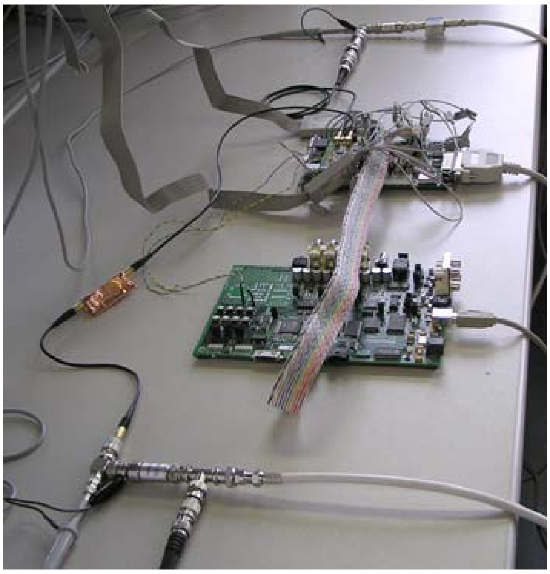


Fig.5: Block diagram of hardware prototype of the radar system

A DAC with a sampling rate of 88 MHz generates the modulated 27 MHz signal for transmission. The ADC in the receiver can run at a lower sampling rate for cost saving reasons. This so called undersampling transforms the signal from a center frequency of 27 MHz to a center frequency of 5 MHz without loss of information. To make this method work a bandpass filter must be installed at the receiver analog input.
The FPGA controls the analog to digital and digital to analog converter and stores the sampled data values from the ADC. It is capable of sending whole bursts and pre-processing the received data. The FPGA device also does the coherent integration.
The signal processor is connected to the FPGA via a fast parallel interface (Analog Devices Link Port) running at a clock rate of 22 MHz. The DSP first mixes down the receiver signal to the low pass area. Then the signal is filtered with a combined pulse compression and subpulse matched filter. At last the envelope of the filtered signal is generated and compared to an adjustable threshold value.

In a rough estimate, the prototype system can send and receive 350 radar bursts per second. One main advantage of the designed hardware is its flexibility. The number of pulses per burst, the rate of the pulses and the modulation can be modified easily.

4. Laboratory test results



→ to coaxial cable

from coaxial cable ←

↑noise

Fig.6: Hardware prototype of the radar system

Transmitter and receiver hardware has been tested under laboratory conditions. Fig. 6 shows the hardware.
The values for attenuation and noise have been adapted according to the assumed real-world values. The sender signal has been fed into a coaxial cable of 1,000 m length which simulates the delay of an obstruction at a distance of 500 m. The attenuation has been set according to an obstruction at a distance of 550, 1,000 and 1,200 m.

Fig. 7 shows an example output signal of the receiver.
The signal processing system achieves an improvement in signal-to-noise ratio of at most 25 dB depending on pulse length, number of pulses per burst and modulation.
This radar system can typically achieve a working range of up to 1,200 m (assuming a_r = 40 dB, false-alarm probability $P_{fa} = 10^{-6}$, probability of detection P_d = 99 %).

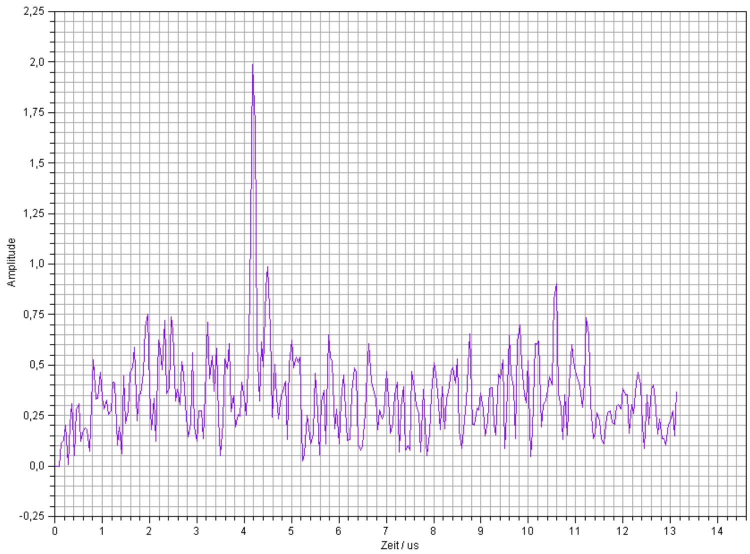


Fig.7: Envelope of the receiver signal of an obstruction in a distance of 1,000 m

5. Conclusion

A concept and prototype hardware for a vehicle based obstruction detection radar system at 27 MHz for people movers is proposed and analysed. The calculations using antenna calculation software, the simulations with Matlab and the laboratory tests of the hardware prototype show that the radar system at 27 MHz can be realized using low-cost hardware and is capable of detecting obstructions along the railway up to a distance of over 1,000 m.

/1/ Liesenkötter, B. *Obstruction Detection for People Movers Operating on Conventional Small Branch Railways,* IEE Intern. Conf. on Intelligent Vehicles 1998, Vol.1, pp 280-284

/2/ Ludloff, A. *Praxiswissen Radar und Radarsignalverarbeitung,* Vieweg 1998