

Remote System for Reading Traffic Signs and Information

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Abstract—This paper presents an experimental system for remote communication between road users and traffic signs. Implemented solution consists of two modules: a transmitter (traffic sign), including novel system for remote *waking-up* by the passing vehicle with use of the quasi-passive (biased) diode detector circuit, and a receiver (vehicle), which is responsible for *wake-up* signaling and interpreting received messages. Both modules use *Wi-Fi* protocol operating in 2.4 GHz ISM band for sending data, and OOK signaling in 868 MHz ISM band for sending *wake-up* signals. The paper provides theoretical analysis, description of design challenges and chosen solutions, and finally, laboratory measurements as well as the results of tests conducted in the systems' target environment with a moving vehicle, confirming correct operation of the system.

Keywords—wireless systems, automotive electronics, telecommunications, traffic signs reading, Internet of Things

I. INTRODUCTION

SAFETY systems, both active and passive, have been among the most important things concerning traffic regulations as well as vehicle design since the beginning of the automotive industry. Road users' behaviour, based on traffic regulations, is conditioned mainly by traffic signs, which inform them about speed limits, crossroads ahead, change of traffic organization, etc. Situations in which drivers miss a sign (due to human error, poor visibility or weather conditions) might cause danger on the road. Some of the modern vehicles are equipped with the traffic signs recognition systems, which are based on the digital processing of the image obtained from the camera located in front of the vehicle. However, those systems do not solve the presented problem if a sign, for a variety of reasons, is invisible.

Nowadays, when virtually every car uses advanced on-board electronic systems and conception of *IoT* (*Internet of Things*) "accelerates" construction of more and more power saving (and even remotely powered [1, 2]) devices, it seems to be real to introduce system in which every traffic sign can wirelessly communicate with the road users. Nevertheless, this vision is still challenging to implement and this work focuses on potential problems and proposes solutions to them.

The main challenge is to deliver energy to supply the traffic sign module. The easiest case assumes nearby power grid installation (e.g. from street light), which is very common. However, in cases where power grid installation would be very expensive (e.g. most sections of highways), the traffic sign module would have to draw energy from another source. One

of possible solutions is to use solar energy harvesting system, in which one of the main implementation difficulties would be region and time dependent determinism in produced power [3]. Another idea is harvesting energy from electromagnetic waves, both "ambient" (especially from nearby high power transmitters used in cellular network or FM/AM broadcast) and from transmitters that could be installed in vehicles. Any type of energy harvesting requires highly efficient, ultra-low power devices [4], which is one of the main focuses in traffic sign module presented in this paper.

Implemented system, which is ideologically shown in Fig. 1, allows for communication between the transmitter module (which is intended to be placed in a traffic sign) and the receiver module (which is intended to be placed in a vehicle). Because power consumption of the wireless modules is largest during active periods (both transmitting and receiving [5]) and there is no need for a sign to transmit continuously, system is provided with the *wake-up* mechanism: a moving vehicle sends *wake-up* signals as it moves along a road, and when the sign is within the range, it changes its state from *deep-sleep* to *active* and transmits identification data. This data is then processed in the receiver (i.a. to reject data from signs directed to the opposite lane) and matched to a certain kind of information. A similar system was presented in [6]. The Authors used RFID technology, with the transmitter waking up continuously every 100 ms.

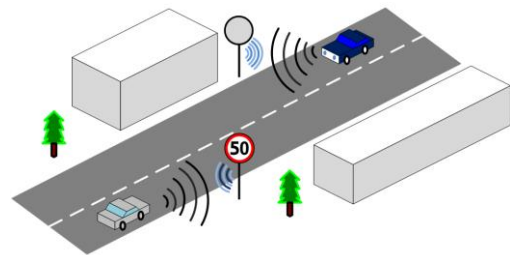


Fig. 1. Remote system for reading traffic signs and information basic idea

II. SYSTEM STRUCTURE

A block diagram of the system is presented in Fig. 2. In designing wireless systems, one of the first steps is to select appropriate communication protocol. In the presented system, protocol selected for data transmission is *Wi-Fi*, based on the IEEE 802.11 specification. Motivations for this choice are as follows:

- Operation in worldwide license-free 2.4 GHz band,
- Widespread use, which makes cost of a single module very low,
- Flexible power management,
- *MAC* (*Medium Access Control*) broadcast mechanism, known as *beacon frames*.

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For the purpose of *wake-up* signaling, European 868 MHz ISM band was selected. The *wake-up* signal is a single harmonic switched on and off with period dependent on the speed of the vehicle, obtained from the GPS system.

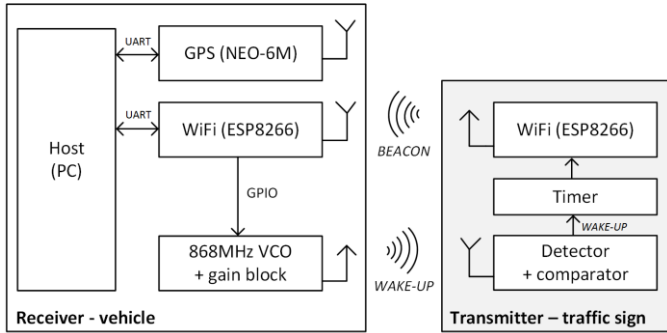


Fig. 2. System block diagram

To meet the requirements of the system, two modules were designed and built. One of them is the receiver, consisting of *Wi-Fi* module, *GPS* module, 868 MHz Voltage-controlled oscillator with amplifier and host, which for the tests purposes was a Personal Computer with dedicated software. The transmitter device consists of the *Wi-Fi* module, the quasi-passive (biased) detector circuit with comparator and the timer module.

III. TRANSMITTER CIRCUIT

The key element of the transmitter device is *ESP8266* Integrated Circuit, which is low-cost *Wi-Fi* module with MCU (Microcontroller Unit) and full TCP/IP stack handling. For the test purposes, *ESP8266* was set to the Access Point mode, in which the device sends *beacon* frames containing traffic sign's identification data as *SSID (Service Set Identifier)* every 100 ms. To conserve energy, the *Wi-Fi* module's power is switched on only when nearby vehicle triggers the *wake-up* circuit.

The *wake-up* circuit reacts on incident power received by an antenna at 868 MHz frequency. Fig. 3 shows the transmitter device electrical diagram, consisting of the diode detector

with the impedance matching and the bias circuit, the ultra-low power comparator, the hardware timer and the *Wi-Fi* module.

A. Diode detector

A basic diode detector circuit (shown in Fig. 4) is the series-diode half-wave rectifier.

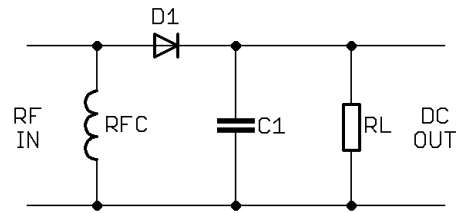


Fig. 4. Basic diode detector circuit

A simplified principle of operation of this circuit is that the input RF signal alternately reverse biases and forward biases the D1 diode. When the diode is forward biased, capacitor C1 is charged to the approximately peak value of the input voltage (for the large signal operation, $P_{in} \gg -20\text{dBm}$, depending on diode type). Most of the diode detectors use Schottky barrier diodes because of their speed (operation with majority carriers only) and significantly lower forward voltage in comparison to p-n junction diodes [7]. For small-signal operation ($P_{in} \ll -20\text{dBm}$), where the operation point of the diode is near zero on the forward current vs. forward voltage curve, detected voltage is proportional to the input power, not to the input voltage as it is in linear (large-signal) region, and this kind of operation is called *square-law* [7]. For the most of applications, an RF choke (RFC in Fig. 4) must be placed at the input of the detector, which appears as a high-impedance for RF signal, and a low-impedance path to ground for DC signal.

Various combinations of detector diodes can be implemented to passively increase detector output voltage. The most common multiplier is the voltage doubler consisting of two detector diodes (Fig. 5) [8]. For the output circuit, the diodes are connected in series, effectively doubling the detected

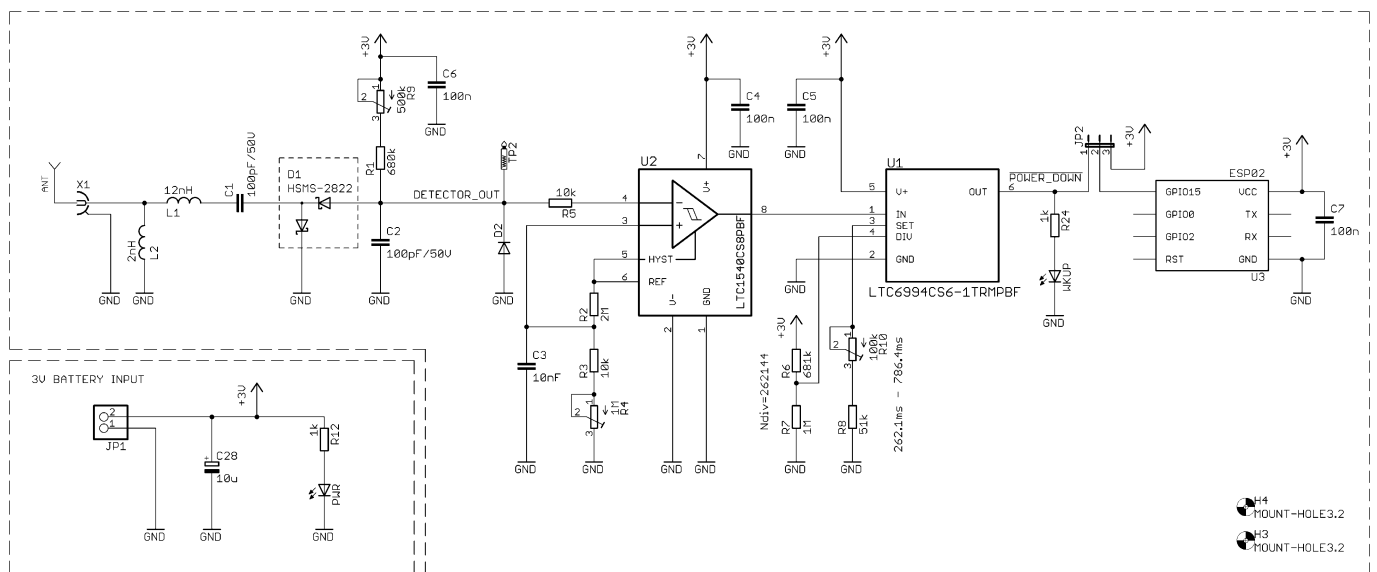


Fig. 3. Transmitter circuit schematic diagram

voltage (at least nominally [9]). For the input (RF) signal, the diodes are connected in parallel, which lowers the input impedance and simplifies the design of the matching network [10]. In case of the voltage doubler, a shunt diode (D1 in Fig. 5) provides DC signal return, which eliminates the need of an RF choke at the detector input.

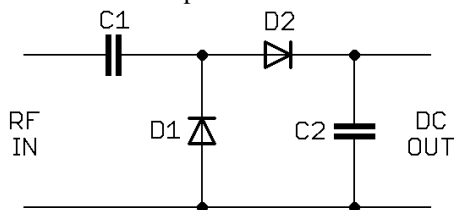


Fig. 5. Voltage doubler detector circuit

For the described application, the voltage doubler detector circuit was chosen and built with the use of HSMS-2822: series connected, single packaged pair of diodes, for its compact size and best matching between diodes (that were diced from the adjacent sites of a wafer). A small (3μA) bias current was applied to lower diodes' junction resistance [11].

Because the role of the detector circuit in the system is to detect energy radiated only on the one frequency (868 MHz), narrow-band, high Q-factor matching network at the input was introduced, which also acts as the input filter. Matching network consists of two inductors: shunt connected and series connected.

The detector circuit was simulated using ADS (Advanced Design System) software. To determine matching network inductors' values, the input impedance of an unmatched detector was calculated. As the input impedance of the detector circuit varies with input power, the optimization of the matching network was carried out with -35 dBm single-tone stimulus (this value was chosen experimentally in simulation as the target sensitivity of the detector circuit, in which the detected voltage can be larger than the overdrive voltage of the comparator with respect to reference). In these conditions, the input impedance of an unmatched circuit was 2,688-j55,65 Ω at 868 MHz (simulation was carried out using LSSP - Large-Signal S-Parameter simulator). The impedance matching is shown schematically in Fig. 6.

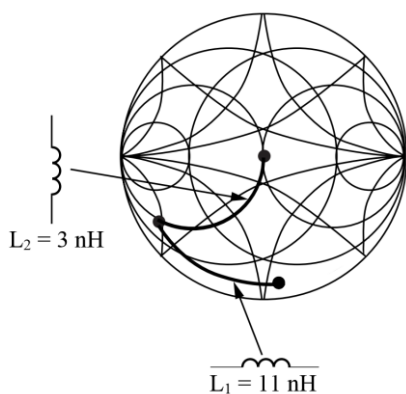


Fig. 6. Impedance matching circuit shown on Smith chart [12]

Calculated input impedance with matching circuit was 56,03+j6,434 Ω, giving |S₁₁| = -21,62 dB. In practical realization, the best impedance match was obtained with

values L₁ = 12 nH and L₂ = 2 nH. Used inductors: Coilcraft 0402HP-12NXJLU (12nH/5%, Q=66, SRF=4,4GHz, Irms=1200mA) and Johanson Technology L-07W2N0CV4T (2nH/±0,2nH, Q=51, SRF=6GHz, I_{max}=1040mA). Fig. 7 shows the measured reflection coefficient of the assembled detector circuit with -35 dBm stimulus.

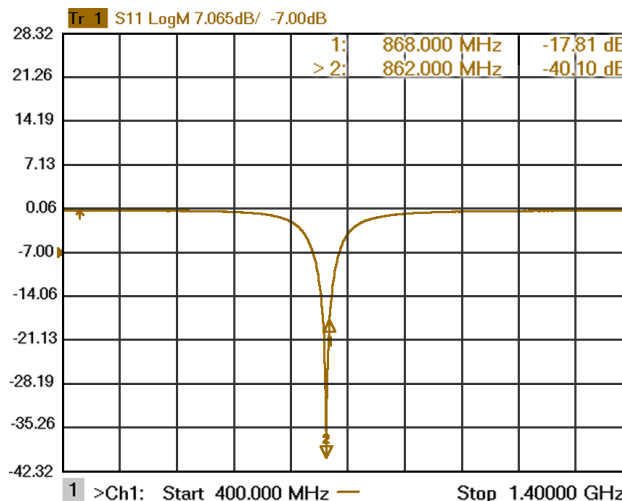


Fig. 7. Reflection coefficient of the assembled detector circuit, Pin = -35dBm

The measurements of the input impedance (reflection coefficient) depending on the input power are presented in Table I and as Smith chart in Fig. 8.

TABLE I.
DETECTOR'S INPUT IMPEDANCE VERSUS INPUT POWER

Pin [dBm]	S ₁₁ [dB]	Z _{in} [Ω]
-35	-18.05	38,66 + j0,83
-30	-24.98	50,9 - j5,62
-25	-10.04	95,4 - j6,08
-20	-4.8	136,12 + j77,9
-15	-2.8	68,44 + j121,52
-10	-4.08	53,26 + j82,38

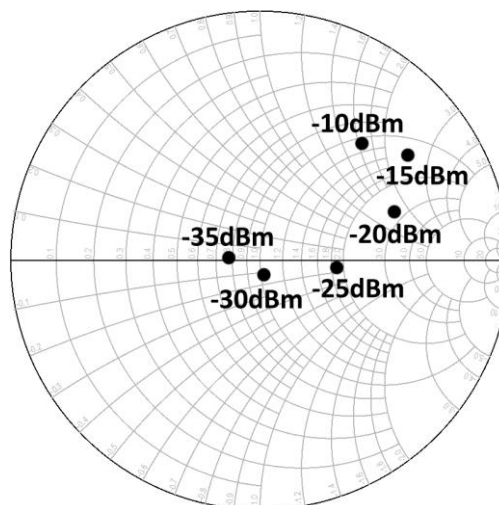


Fig. 8. Measured input reflection coefficient versus input power

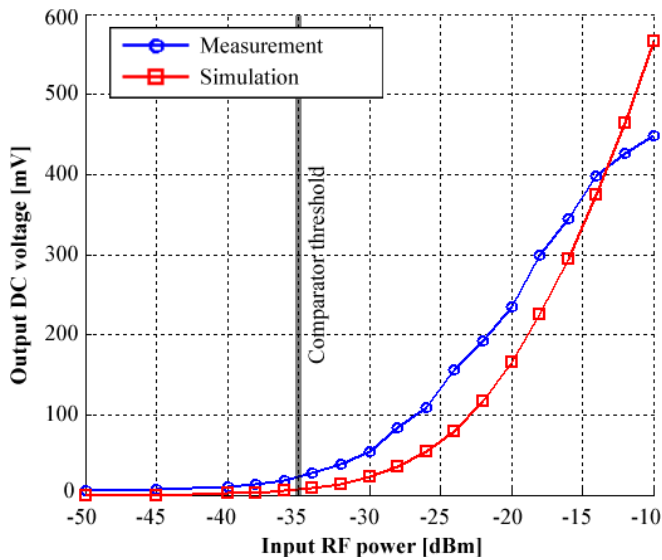


Fig. 9. Transfer characteristic of the diode detector

Transfer characteristic of the diode detector was also simulated (using transient analysis) and measured.

Fig. 9 shows both simulation and measurement results. The output voltage of the used detector is subtraction of biased diodes forward voltage and detected voltage, however, for clarity, the characteristic shows detected voltage as a positive number. The input power point described as the comparator threshold is empirically determined value for system sensitivity (-35 dBm). Above -15 dBm in the measured characteristic, clamping diode (D2 in the Fig. 3) begins to conduct, which was not included in the simulation model.

B. Comparator and timer circuits

The output signal of the diode detector (*DETECTOR_OUT* node in the Fig. 3) is fed into the input of an ultra-low power comparator LTC1540, which has power consumption less than 0.6 μ A, integrated reference voltage source and 10 mV overdrive parameter. Reference voltage was resistively divided to give 280 mV at the non-inverting comparator input (biased diodes forward voltage with no input RF power is 295 mV), which resulted in assumed -35 dBm sensitivity. The comparator drives the input of the LTC6994 delay block, which was programmed to give 500 ms falling edge delay (*beacon* frame interval is 100 ms). The output of the delay block switches power supply for the ESP8266 module.

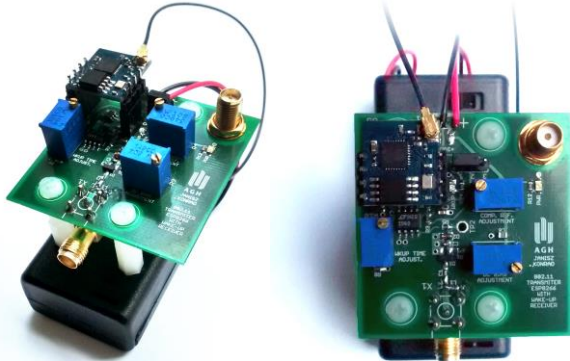


Fig. 10. Assembled transmitter circuit photographs, PCB dimensions are 45 mm x 47 mm

Fig. 10 shows a photograph of an assembled circuit. A Printed Circuit Board was designed using Eagle CAD software

and manufactured using 0.8 mm thick FR4 laminate. Board is supplied by two series-connected 1.5 V AA batteries placed in a container.

IV. RECEIVER CIRCUIT

The receiver module (presented in Fig. 11 as the block diagram and in Fig. 12 as the assembled module photograph), which is intended to be placed in the vehicle, consists of:

- *Wi-Fi* module - ESP8266, the same as in the transmitter, but configured in Station mode to receive *beacon* frames,
- 868 MHz generator, a PCB with a Voltage-controlled oscillator and a gain block (output power 15.5 dBm), which is turned on and off periodically, with period value dependent on the vehicle speed,
- GPS module – NEO-6M, which gives information about the speed and the direction of movement of the moving vehicle,
- Two USB-UART converters based on CH340G ICs, first for communication with the *Wi-Fi* module, second for communication with the GPS module,
- Host, which for the test purposes was a Personal Computer.

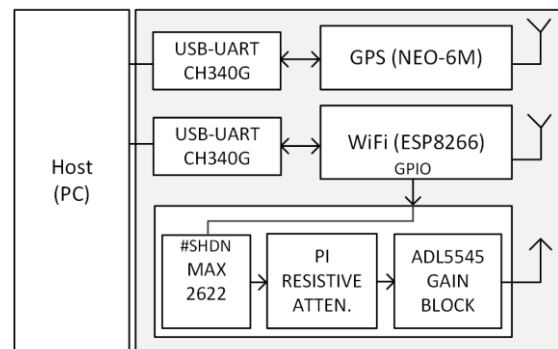


Fig. 11. Receiver module block diagram

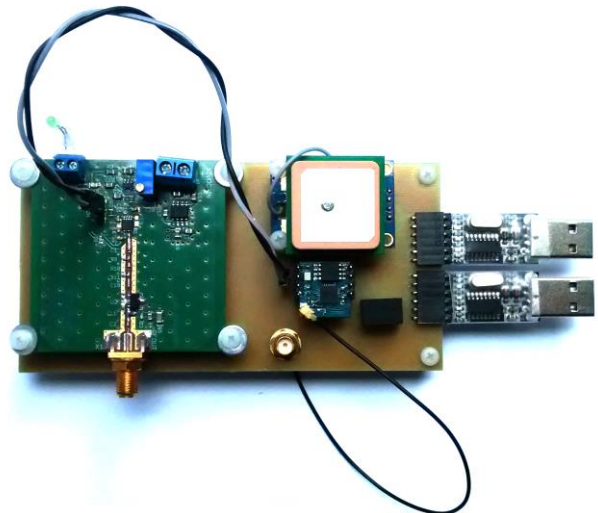


Fig. 12. Assembled receiver module photograph, bottom PCB dimensions are 128 mm x 65 mm

The host software was written in the *Python* language. The algorithm works in the infinite loop, continuously communicating with the *Wi-Fi* and the GPS modules through

COM ports and periodically sending the *wake-up* signal. When the *Wi-Fi* module receives *beacon* frame containing SSID field in the form of ASCII string “<sg>type, <parameter1>, <parameter2>, ...”, the script parses its content for the type of a traffic sign and parameters, which can be an azimuth in which the sign is directed, a geographic coordinates, etc. For the test purposes, SSID contained the type of the sign and the azimuth. RSSI (*Received Signal Strength Indicator*) of the beacon frame was also saved for debug purposes. The data parsed from the *beacon* frame is compared against the data from the GPS module (GPRMC frame in NMEA standard containing minimum recommended GPS data) to discard frames directed to the opposite lane. Fig. 13 shows a simplified block diagram of the described algorithm.

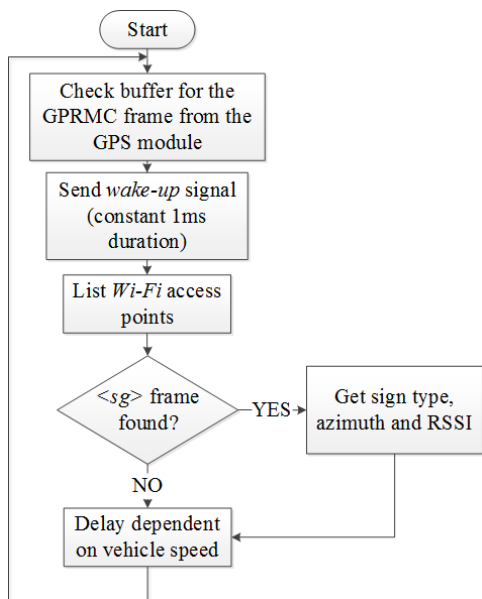


Fig. 13. Simplified receiver module algorithm block diagram

V. SYSTEM TESTS

The functional tests of the built system were conducted in real environment with a moving vehicle. The *Wi-Fi* modules were equipped with popular 3 dBi gain antennas, giving reach of approximately 100 meters. In the 868 MHz system, the generator output was fed into a 3 dBi gain antenna. At the detector input, a 11 dBi gain, directional antenna was mounted. This configuration gave approximately 15 meters reach, which could be improved by the use of dedicated antennas.

In the test, the transmitter module was mounted at the side of the road, 1 meter above the ground. The vehicle was equipped with the receiver module, which was placed at the dashboard. Several trials were performed (with speeds of 24 km/h, 35 km/h, 54 km/h and 74 km/h), in every case the traffic sign was correctly recognized. Table II contains host console record of the test performed with maximum tested speed – 74 km/h.

The data in column “Host console record” was printed every 230 ms (script loop duration), which means that the vehicle stayed in the transmission reach for at least 460 ms. The tests for a greater vehicle speeds were not conducted.

TABLE II

. RECEIVED DATA DURING THE TEST AT 74 KM/H VEHICLE SPEED

Host console record	Comment
Wake-up signal Speed: 40.180 knots, Angle: 149.83°	State in front of the sign, no <sg> framed detected yet, speed from GPS: 74,4 km/h.
Wake-up signal <sg>83, 290, RSSI: -57 dBm Parsed sign type: 83 Angle: 290°	First <sg> frame discovered, parsed correct data.
Wake-up signal <sg>83, 290, RSSI: -85 dBm Parsed sign type: 83 Angle: 290°	Second <sg> frame discovered, parsed correct data, RSSI decreased.
Wake-up signal	No further data received.

Fig. 14 shows a frame from the video captured during the test, in the moment of the transmitter waking-up.



Fig. 14. Frame from a video of the test with vehicle moving with 74 km/h speed. Red LED is indicating that transmitter is woken-up

VI. CONCLUSIONS

The article presents the motivation, theoretical analysis, design process and test results of the system in which the traffic signs are equipped with the wireless transmitters, being able to communicate with the traffic users (vehicles).

The proposed solution takes into account potential challenges for this kind of system, including necessity for low-power consumption in the transmitter and determination of the traffic sign azimuth. The *wake-up* signaling was introduced. The traffic sign transmitter stays in the non-active, ultra-low power mode until its quasi-passive (biased) diode detector circuit detects power in the ISM 868 MHz band. The transmitter, 2.4 GHz *Wi-Fi* module, is woken up by the hardware and then sends several MAC layer broadcast *beacon* frames consisting of the sign identification

data. The module placed in the vehicle sends *wake-up* single-tone signals with a variable period, dependent on the speed of the vehicle. The *Wi-Fi* channel is continuously scanned for the traffic sign identification frame, and when the specified data is received, the type and the azimuth of the traffic sign are parsed. Based on the comparison between the vehicle azimuth (obtained from the GPS) and the traffic sign azimuth, the data from the opposite lane traffic signs can be rejected.

The detector circuit was tested and optimized in the laboratory, obtaining -35 dBm sensitivity. The whole system was tested in the real environment with the moving vehicle and during every test run worked in the correct way. A maximum vehicle speed during test was 74 km/h.

Further development of the system assumes quantitative parameters improvement, especially *wake-up* system reach, with the use of dedicated antennas, and transmitter power consumption reduction.

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