Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 47 (2012) 178 – 183

Procedia Engineering

www.elsevier.com/locate/procedia

Proc. Eurosensors XXVI, September 9-12, 2012, Kraków, Poland

Development of an Antenna Sensor for Occupant Detection in Passenger Transportation

Hermann Sterner[a]*, Wolfgang Aichholzer[a], Matthias Haselberger[a]

[a]*Carinthia University of Applied Sciences*

Abstract

We investigate a novel sensor system for occupancy detection in automobiles or mass transportation. The sensor system is developed on the basis of electromagnetic coupling between a transmitter and a receiver patch antenna. Based on the relation of the transmitted and received electromagnetic wave the occupancy of a seat can be reliable detected with minimum transmitting power. The antenna sensor is analyzed by applying finite element method (FEM) simulation for which different antenna performance parameters, e.g. *S*-parameter, Z-parameter, gain and directivity have been extracted and furthermore verified by measurements. It is shown that at 868MHz with a relatively low radiated power level of 3dBm to 6dBm (2mW to 4mW), a reasonable and reliable occupancy detection could be achieved. A stand-alone sensor application including the evaluation hardware for signal processing has been manufactured to verify simulation data.

Keywords: Occupancy detection; Seat occupancy; Patch Antenna; Human Body Model;

1. Introduction

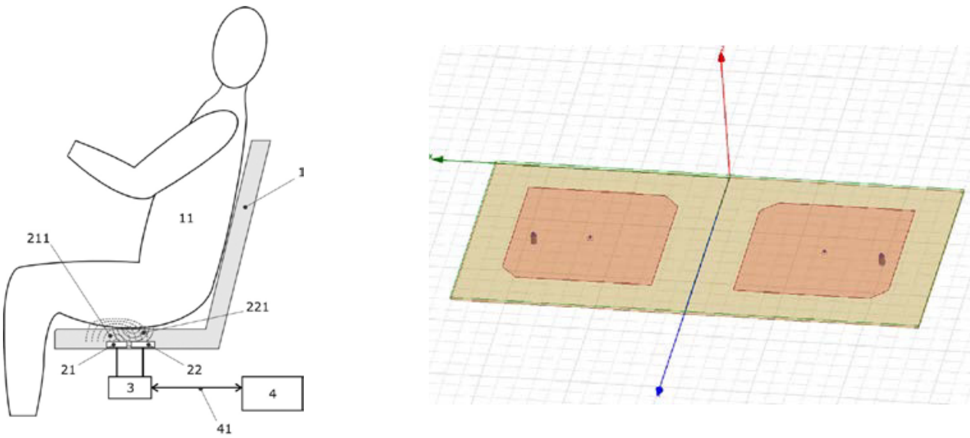
The ability to recognize if a seat is occupied by a person or not via a sensor-supported automated system is rapidly gaining importance. Typical applications for such systems can be found for example in automotive safety technologies to control passenger-side airbags, safety belts, warning devices and most

* Hermann Sterner. Tel.: +43-5-90500-2175; fax: .: +43-5-90500-2110.
E-mail address: h.sterner@cuas.at.

doi:10.1016/j.proeng.2012.09.113

recently commuter transport logistics. Examples of commuter transport applications are determining the number as well as the location of free seats in mass transit systems such as busses, subways, trams and railways. The most commonly used technical solutions usually utilize force and/or pressure sensors in various operating modes and configurations. The disadvantages of such systems in addition to substantial overhead costs for the installation and the wiring is that the detection of seat occupation is performed exclusively through weight. Similar limitations also apply to a variety of optical and/or acoustic sensors, which detect the presence of objects on a seat via reflective measurements (or transmission measurements). In addition to high complexity and the respective costs of such systems and moreover the possible side-effects of ultrasound on animals (i. e., pets), these sensors are not reliable when trying to distinguish between humans and objects.

Basic approaches to integrate artificial intelligence may be able to mitigate this problem, but this in turn increases the complexity as well as the costs of the necessary sensor systems (compare [1], [2], [3], [4], [5]).



(a) (b)

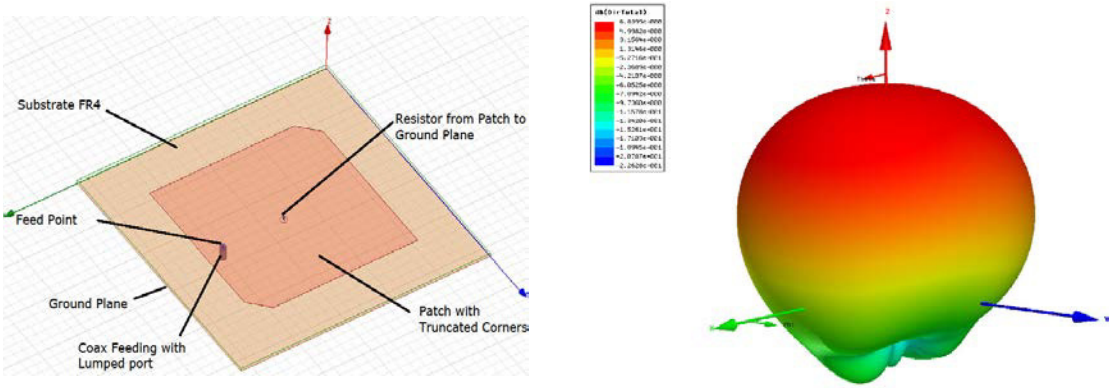
Fig. 1: (a) Configuration and position of antennas (21, 22) on seat (1); (b) Geometry of the transmitting antenna (21) and receiving antenna (22)

Alternatively, RF-transmission systems have also been proposed. The working principle here is the measurement of the attenuation of high frequency radio waves typically in the GHz range [6] or fields [7] which is caused by the presence of a person between the respective antennas.

2. Alternative Concept – Functional Principle

An oscillator supplies a transmitting antenna (21). Depending upon if a person (a commuter) (11) is present or not, the amplitude and the phase signals which are received by the second antenna (22) will change. In comparison to other detection procedures mentioned previously, the radio waves (211) do not penetrate the human body; instead the waves (211) are reflected by the body surface.

The distance of the antennas from the object to be recognized amounts to approximately 3cm to 10cm dependent upon the seat construction (1). The object to be measured is thus located in the near field range of the antennas. This does indeed influence the transmitting antenna; however, this effect is not exploited in the procedure applied here. Moreover, occupancy detection is also possible over greater distances with corresponding higher power emissions.



(a) (b)

Fig. 2. (a) Configuration of a patch antenna, transmitter antenna and a receiver antenna; (b) Polar plot of the emission characteristics

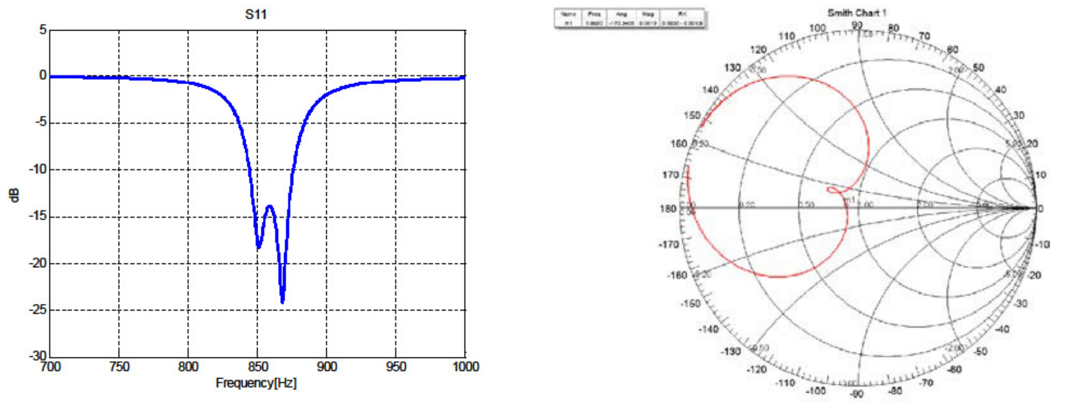
Through the applied conditionally and extremely low distances, a transmission power of typically 0dBm (1mW) for a sure positive recognition is sufficient. The measurement itself takes only a few milliseconds. Thus, the EM exposure order of magnitude lies beneath the allowed specific absorption rate (SAR) [8].

The measurement is carried out under normal circumstances intermittently in predetermined, application-dependent, freely choosable time intervals; typically in the region of a few seconds up to more minutes. In comparison, the typical measurement times lie in the scale of a few milliseconds, from which the relative duty cycles of normally ≤ 1 % result.

Taking into account the frequency dependent behavior of bio-organic tissue as well as legal standards, the preferred frequencies used in the applied processes presented here are in the ITU Region 1 (Europe, etc.) in the region of SRD 868 MHz-band and in the ITU Region 2 (North and South America) the especially preferred frequencies are in the region of ISM 915 MHz-band.

2.1. Modeling and Simulation of the Antennas

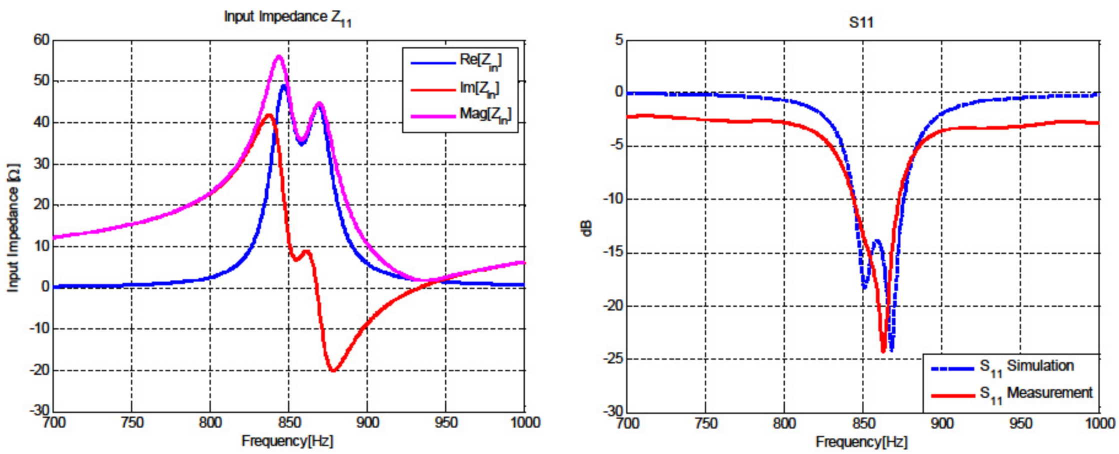
The interior compartments of public transport vehicles (bus, subway trains, etc.) are generally very stable and well built (security against vandalism).Thus, there are in the immediate vicinity of the seats numerous massive metal frameworks available. In order to mitigate the effects of metal frameworks on the antennas as affectively as possible, a patch antenna has been chosen as the preferred antenna type. Patch antennas are constructed to be flat and thus have a distinct, highly developed directional characteristic, see Fig. 2(b). The antenna was developed using a 3D-field simulator HFSS from ANSYS and optimized for the frequency regions listed above. Fig. 2(a) illustrates the geometry of the implemented antenna. Material used is the standard circuit board material FR4 ($4.2 \leq \varepsilon_r \leq 4.4$; tan $\delta \approx 0.02$), substrate thickness of 1.5mm, double-sided 30µm copper lamination) in order to keep material costs at a minimum. Moreover, the evaluation electronics of the sensors can be additionally placed on the same substrate next to the antenna. This allows for a cost-efficient production of the sensor configuration; however, this geometry only allows a realization of 0dBi antenna/aerial gain.



(a) (b)

Fig. 3. (a) Scattering parameter S_{11}; (b) Smith chart of the scattering parameter S_{11}

The impedance of the antenna in this region lies, as illustrated in Fig. 4(a), in the area of 50Ω and thus can be powered with a 50Ω coaxial transmission line. The position of the feed point was likewise optimized.



(a) (b)

Fig. 4. (a) Impedance Z_{11} of the Antenna; (b) Comparison of measured values S_{11} versus simulated values S_{11}

The antenna was manufactured after the simulation process was completed and then measured using a Vector Network Analyzer ZVB8 from Rhode and Schwarz. The simulated data and the measured data correspond and match quite well which can be seen in Fig. 5(b). In order to provide a better overview, the most important values are compared with each other in Table 1.

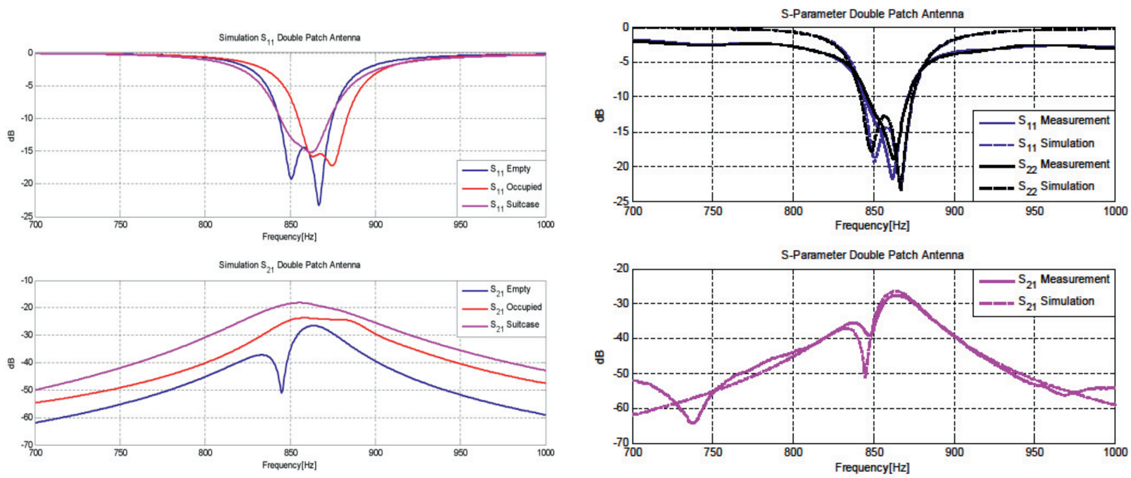
Table 1. Comparison of Simulation and Measurement Results of Single Patch Antenna

	Simulation data	Measurement data
Resonance frequency f_r	868MHz	863.5MHz
S_{11} at $_r$	-24dB	-24dB
S_{11} at 868MHz	-24dB	-15.8dB
Bandwidth B	32MHz	30MHz
Z_{11} at $_r$	(45-j0.06)Ω	(56-j4.4)Ω
Z_{11} at 868MHz	(45-j0.06)Ω	(56-j7.6)Ω

2.2. Frequency dependent Coupling of the Antennas

The propagation of electromagnetic waves into the human body is very dependent on the frequency [10]. In this case however the differences between the biophysical tissue dispersion must not be considered because the penetration of these tissues in the frequency range of 800MHz to 1GHz is still in the region of β-Dispersion1 and the excited waves will almost completely be reflected. This changes at frequencies above 1GHz. Here the behavior on the skin surface changes from reflection to absorption, γ-Dispersion [11].

This behavior was also simulated with the software program HFSS. In order to simulate human tissue, the Human Body Model (HBM) from the company ANSYS was used. The simulated antenna configuration is illustrated in Fig. 1(b). The transmitted electromagnetic waves penetrate all types of clothing (even wet clothes) nearly completely unmuted in this region of the applied frequencies (and thus the wave lengths). Thus, the reflection of the waves takes place mainly in subcutaneous fibrous connective tissues. This in turn should lead to the expectations that the receiving transmitter antenna will always receive similar values when detecting humans. Material goods such as luggage and bags will generate significantly higher (or lower) side lobes.



(a) (b)

Fig. 5. (a) S_{11} and S_{21} parameters of the different seat occupation scenarios; (b) Simulated vs. measured S-Parameters; upper chart: comparison of the transmitting antenna S_{11} to the receiving antenna S_{22}; lower chart: transfer function S_{21}

During the simulation three cases/scenarios were evaluated:

- unoccupied seat
- occupied seat by a person
- a metal suitcase on the seat.

The basic model for the simulation setup is a two-port network, where the transmitting antenna represents Port 1 and the receiving antenna Port 2. The simulation results of the three scenarios are shown in Fig. 5(a). It is clearly evident that the differences between 'unoccupied', 'occupied' and 'suitcase' can be easily identified.

To verify these results the system was metrologically evaluated. The simulated and measured data were compared and it can be seen that there is a definite conformity between the two sets, see Fig. 5(b).

3. Results and Discussion

This paper proposes the utilization of a sensor that makes it possible to detect if a seat is unoccupied or occupied by a human body via an antenna configured system. The antennas were simulated and measured individually as well as pairwise (transmitting and receiving antennas). The Human Body Model (HBM) from ANSYS was utilized to simulate human tissues. The comparison of simulated and measured data show for this situation that the modeling offers a very positive opportunity to successfully optimize the antenna system to fulfill the practical application of open seat detection.

Acknowledgements

The concept of this sensor system was developed in the Austrian Research Agency (FFG) project '*FreeSEAT2*', reference number 825241 and has been registered by the Austrian Patent Office, reference number A796/2011.)

References

[1] Aisin Seiki K.K., Aichi J.: Patent DE10045689: Sitzbelegungssensor.

[2] Breed, D.,; Johnson, W.; Duvall, W.E.; Morin, J.L.; Xu, Kunhong; Varga, A.J.: Patent US6397136 B1: System for Determining the Occupancy of a Seat in a Vehicle.

[3] Hofbeck, K.; Mosel B.; Stielow, A.: Patent DE102004050884 B3: Vorrichtung zum Erkennen der Sitzbelegung eines Sitzes

[4] Robert Bosch GmbH: Patent DE10124915 A1: Anordnung zur Erfassung des Belegungszustandes eines Sitzes.

[5] Satoshi, B.; Takashi, S.; Shiko, O.: Patent JP 3413479: Occupant Detection System.

[6] Boby, G.; Zangl, H.; Bretterklieber, T., Brasseur, G.: A Combined Inductive-Capacitive Proximity Sensor for Seat Occupancy Detection, IEEE Transactions on Instrumentation and Measurement, 2010.

[7] Tumpold, D.; Satz,A.: Contactless Seat Occupation Detection System Based on Electric Field Sensing. IEEE Industrial Electronics, IECON'09, 2009.

[8] Ruddle, A.R.: Computed SAR Levels in Vehicle Occupants Due to On-Board Transmissions at 900 MHz, IEEE Loughborough Antennas \& Propagation Conference, 2009.

[9] Stutzman, W.L.; Thiele, G.A.: Antenna Theory and Design, 2nd Edition. Wiley. 1997. ISBN 9-7804-71025-900.

[10] Poutanen, J., Villanen, J., Icheln, C., Vainikainen,P.:Behavior of Mobile Terminal Antennas near Human Tissue at a Wide Frequency Range, IEEE Proceedincs of iWAT2008.

[11] Tritthart, H.A.: Medizinische Physik und Biophysik, Schattauer, 2001.