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Research Article

DESIGN AND IMPLEMENTATION OF DOPPLER MICROWAVE MOTION SENSOR FOR INDOOR APPLICATION

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ABSTRACT

This paper presents a systematic integration and circuits design scheme of ISM-band Doppler radar for short-range applications. The authors designed a complete CW Doppler radar transceiver and made a test for verification. Firstly, we establish a system model by conventional radar equation. Secondly, design the schematics of main modules including an oscillator, a mixer, and antennas. Finally, perform system integration using the designed circuits diagrams and parameters. The performance is found fairly satisfactory by test verification.
Keywords: Doppler radar, motion sensor, microwave radar, ISM band.

1. INTRODUCTION

Doppler radars play an important part in many industrial, scientific, and medical areas. Recently, more and more Doppler radar products are especially found in some commercial short/long-range use circumstances such as automotive speed measurement & law-enforcement, liquid flow control, hospital patient surveillance and intruder detection in security system for decades and played a particularly important role in Intelligence Transportation Systems (ITS). As ITS applications intend to serve a mass–market, cost of the sensor systems should be as low as possible, check on work attendance system, family guard against theft and alarm system, and human body's vital sign detection system, etc. The features of these Doppler radar products are with high sensitivity of target detection; low power radiation to reduce harm for human body; low cost to facilitate wide applications; easy of circuits alignment to fit the batch production; and small circuit size [1-3].

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Microwave motion sensors have become an integral part of the security industry, be it home safety or industrial. These sensors measure presence of objects in an area and their motions therein. They work by gauging the motion, direction of movement, velocity, and the range of motion. A major plus point of these useful tools is that they can operate on very low power. Also, as they have no moving part s, there is not much that can go wrong with the sensors. They can also function in all kinds of environments, even unfavourable ones such as an explosive situation, and that too with no adverse impact on those operating them.

Microwave technology can be listed under five categories: presence sensing, velocity sensing, motion sensing, range sensing, and direction of motion sensing. Microwave sensors make use of existing electromagnetic fields and devices with frequencies that can range from ~300 MHz to many terahertz. The devices can be of many kinds such as Doppler Effect radars, pulsed radars, FM-CW (frequency-modulated continuous-wave) radars, passive detectors (radiometers), modulated targets, transmitter receiver systems, UWB (ultra-wideband) systems, impedance meters, resonator sensors, and noise-using devices. With the exception of radiometers in the list mentioned, other sensors employ a signal generator or transmitter and a detector or receiver. The sensors may differ from each other based on their system design and the signal modulation they employ. For instance, some of these sensors function when away from the object whereas others may have to be mechanically conjoined with the object for operation.

In the present study, the Doppler Effect radar is employed for motion sensor architecture. Doppler Effect, is the change in the frequency of a wave for an observer moving relative to the source of the wave. With the source of the wave moving closer, the time taken by each wave crest to be emitted and reach the observer is lesser than the previous one. Thus, it takes less time, frequency is increased and is more than the previous ones.

The aim of the team was to create a Doppler Microwave Motion Sensor (DMMS) design in ISM band for employment in indoor applications. Fig. 1 displays the basic design model chosen; this design was preferred for lowering the cost in manufacturing the model. Fig 1a shows the design for the short-range sensor application that can operate within a range of less than 5 metres while Fig. 1b is the model for the long-range sensor application for a range of more than 10 metres.

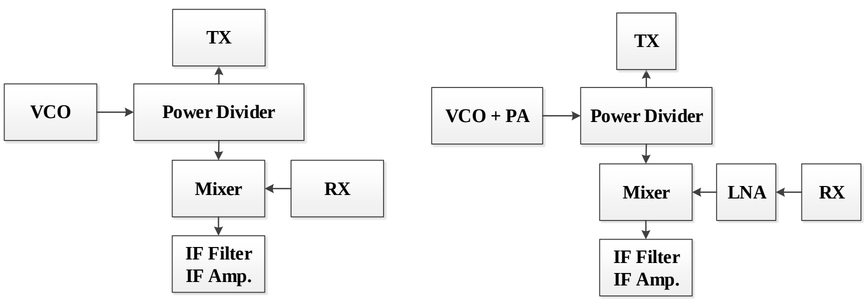


Figure 1. Schematic of DMMS for (a) short-range detections (b) long-range detections

Both of the designs in Fig. 1 is based on Doppler Effect. The signal created from the first stage will be divided with half power divider. Half of the signal will be sent to the environment via TX and other half is taken as local oscillator input of the Mixer stage. If there is a moving object in the environment, the frequency of signal propagated from TX will shifted according to Eq. (1).

$$f = \left(\frac{C + v_r}{C + v_s} \right) f_0 \tag{1}$$

where c is the speed of electromagnetic waves in the medium; v_r is the speed of the receiver relative to the medium; vs is the speed of the source relative to the medium.

Then the shifted signal is taken to the RF input of the Mixer via RX. Thus in IF output of the mixer there will be a low level signal which can be easily sensed after IF filtering and amplifying stage. In next section s, the design and measurement result of each stage for DMMS in Fig. 1b is presented. The designed circuits had been used in order to make a study case for detection of a moving person for indoor applications. And finally the paper end with conclusion and acknowledgment section.

2. CIRCUIT DESIGN

2.1. Transmitter

First stage of our DMMS design is the signal generator stage. For Voltage Control Oscillator stage we had used MAX2750 module [4]. In Fig. 2. The printed module had been given with its measurement results in Fig. 3.

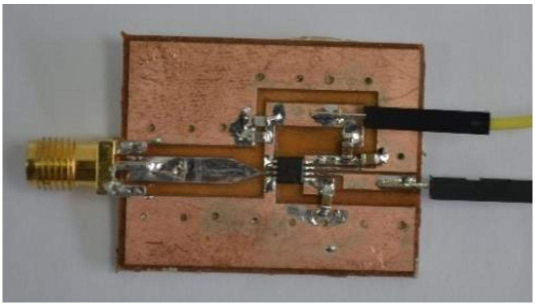


Figure 2. Printed MAX2750 VCO

Figure 3. Measurement results of MAX2750

For Amplifier stage, we had used BFP650 transistor and printed it on FR4 substrate. We had aimed to have a Mid Power Amplifier MPA design with at least 10 dB measured gain @ 2.4 GHz frequency with 1 dB compression point @ 5 dBm input signal level. In Figs. 4-5 the simulation results of the MPA design are given. @ 2.4 GHz almost 13dB gain had been obtained with a return loss value less than – 15 dB. The simulated compression point of the design is simulated at 7dBm input signal level where the gain drops to 12 dB. In Fig. 6 the fabricated circuit on FR4 is presented with its measurement results in Fig. 7. As it seen from the measurement result, the 10dB Gain target @ 2.4 GHz had been achieved with a return loss less than -10dB.

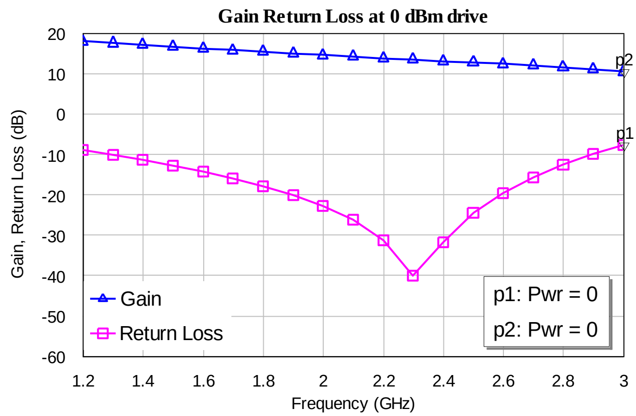


Figure 4. Gain and return loss simulation of MPA

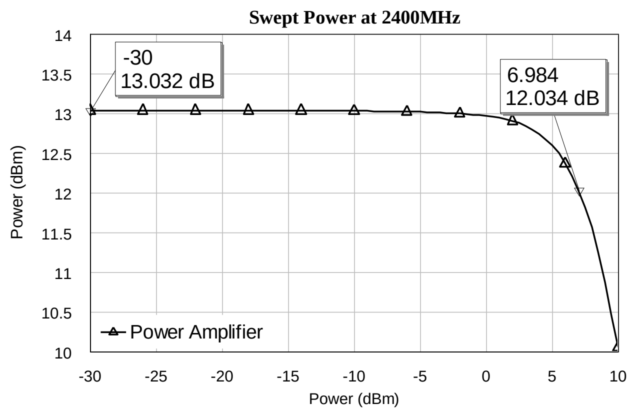


Figure 5. Simulation result for 1 dB compression point

Figure 6. Fabricated MPA circuit

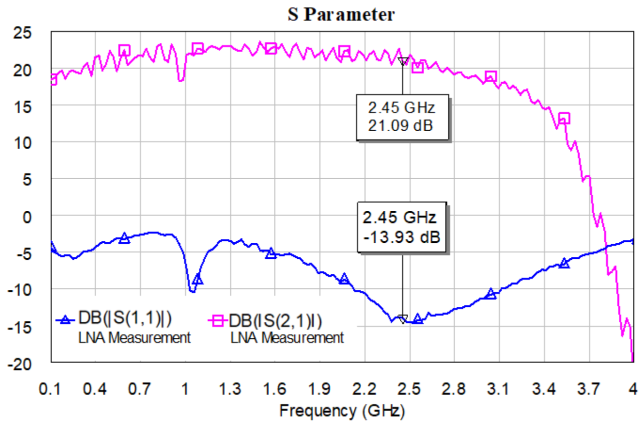


Figure 7. S_{11} and S_{21} measurement results of the MPA.

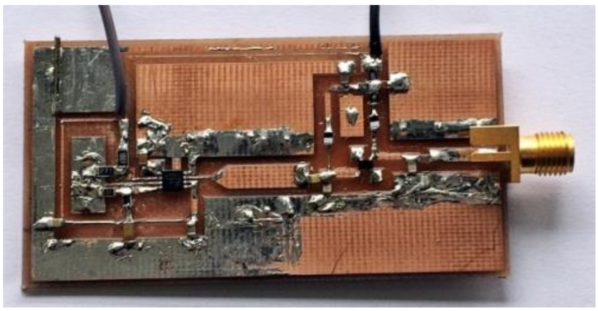


Figure 8. Fabricated Transmitter circuit

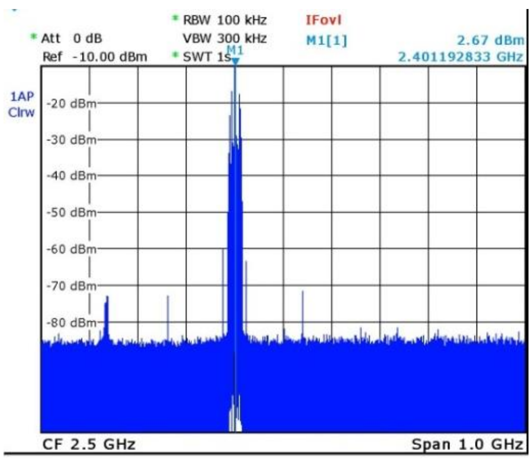


Figure 9. Measurement result of transmitter

For complete the transmitter design, the VCO module and MPA designs are cascade connected and printed on the same FR4 board. In Fig. 8, the printed transmitter circuit had been presented with its measurement result in Fig. 9. Since there are no ports between VCO and MPA the measurement signal at output port had been increased to 1~2 dBm.

2.2. Power Divider

For power divider stage we had used power divider with defected ground structure in [5]. The power divider in Figs 10 is a simple and low cost design with good performances values obtained in both simulation (Fig. 11) and measurement (Fig. 12) results.

(a) (b) (c)

Figure 10. (a) Layout, (b) Frontal (b) Back view of the design

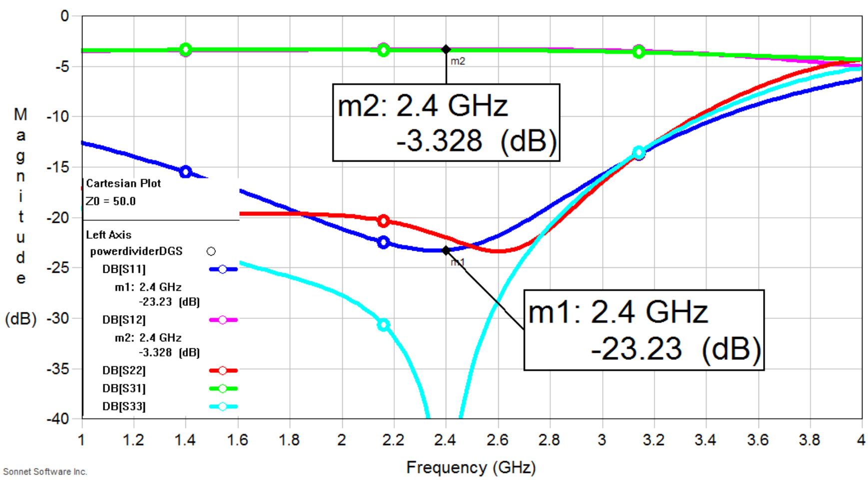


Figure 11. Simulation result of power divider design

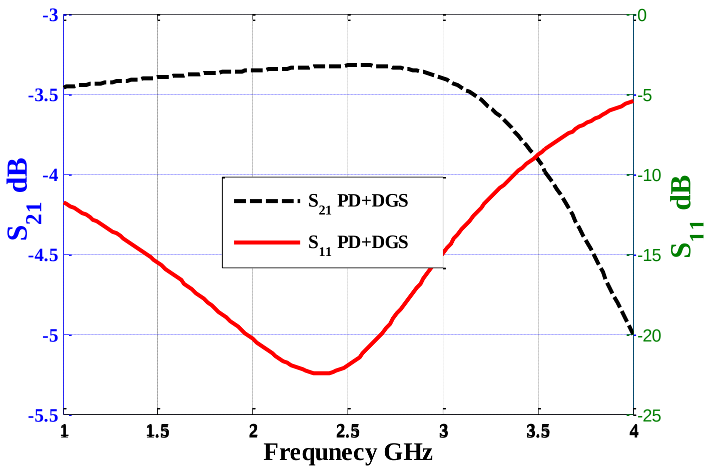


Figure 12. Measurement results of both design

2.3. LNA Design

For low noise amplifier design we had used two BFP640 transistors to design a two stage LNA given in Fig. 13 with its measurement results in Fig. 14.

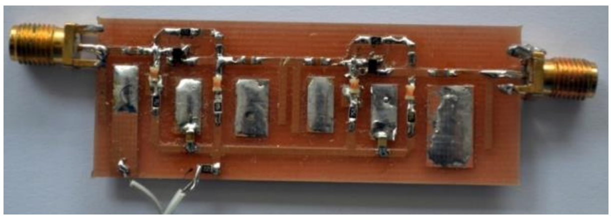


Figure 13. Fabricated two stage LNA circuit

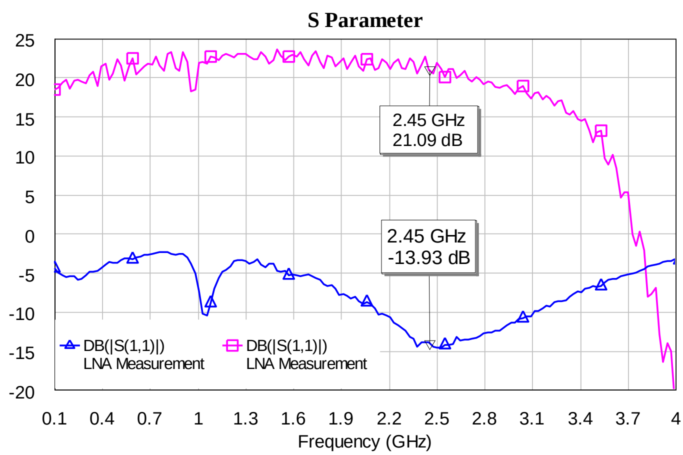
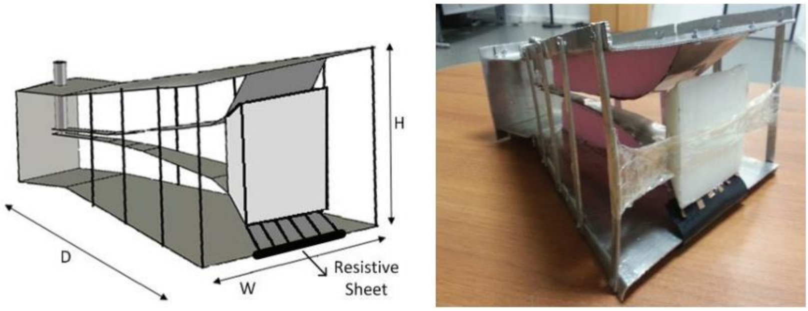


Figure 14. Measurement result of the LNA design

2.4. Antenna Design

For TX & RX stage of the DMMS, Two identical antenna Fig. 15 (a) had been used for these stages [6]. Aperture width (W) = 24.4 cm, aperture height (H) = 15.9 cm, outer depth (D) = 27.9 cm



(a) (b)

Figure 15. Manufactured horn antenna for TX/RX; (a) The 3D view of the PDTEM-RHA geometry (b) Photo

The partial dielectric-loading configuration is proposed to enhance the antenna gain and input reflection performances over the wideband. The dielectric profile material is Teflon. The grating wires are used near the antenna aperture to prevent the filtering of high-frequency waveguide modes' radiation of the ridged horn structure (see Figure 15 (b)). The antenna design in [6] has a measured ultra-wide operation band within 0.4-15GHz in which it almost has 8 dB directed gain characteristic at 2.4 GHz frequency with VSWR characteristic of 1.5.

2.5. Mixer

For Mixer stage HMC422MS8E had been used. The manufactured circuit is shown in Fig. 16.

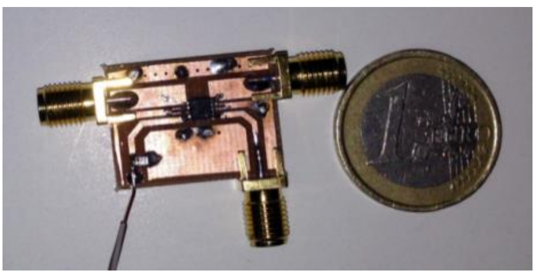


Figure 16. Manufactured mixer circuit

2.6. IF Amplifier

The IF amplifier is consisted of cascaded first order high pass filter for Filtering DC signals and a fourth order low pass filter with cut-off frequency of 32 KHz. The gain of the amplifier stage is approximately 40 dB (100 V/V). In Figs. 17-19 the designed 60dB IF amplifier @15-500 Hz bandwidth is presented.

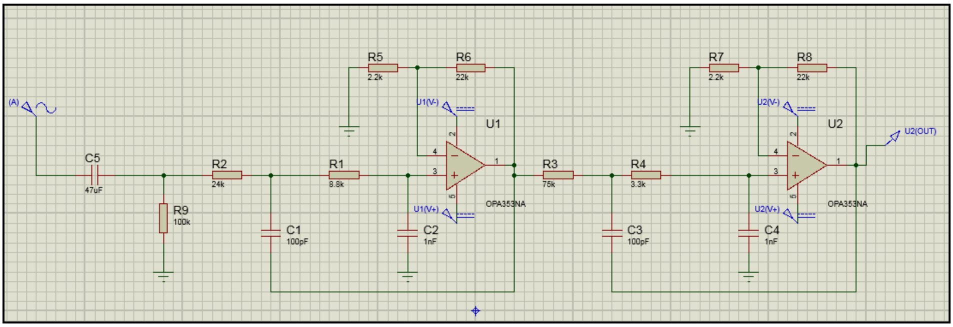


Figure 17. Schematic of the 60dB IF amplifier at 15-500 Hz

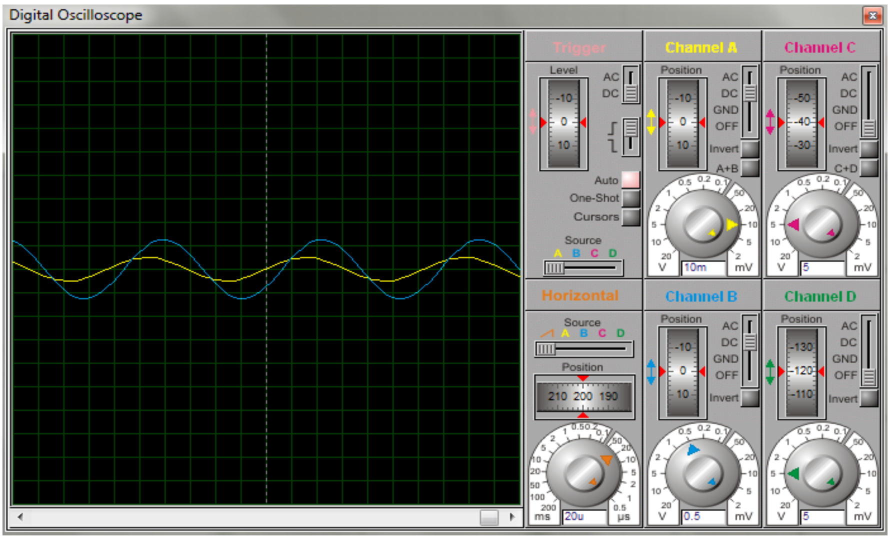
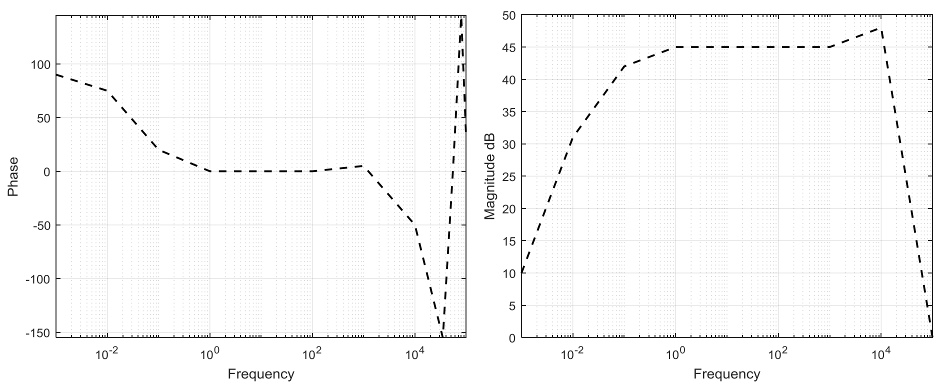


Figure 18. (a)Fabricated IF Amplifier input 5 mV 8 kHz (Yellow) output 500 mV 8 kHz (Blue)



(a) (b)

Figure 19. (a) Frequency- Phase (b) Frequency- Magnitude

3. CASE STUDY

In this section, the fabricated circuits designs had been used to create a prototype DMMS shown in Fig. 20, for detection of a person's movement in a room detection. In Fig. 21a the IF signal read by the oscilloscope is given when the person is standing still, after that when the person starts to make a movement the shifted signal can be clearly seen in Fig. 21b. Also in [7] a short video of the setup and its detection range is given.

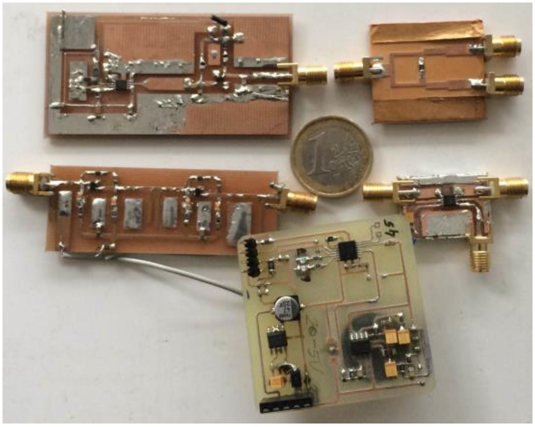


Figure 20. Circuit elements of the prototyped DMMS

(a) (b)

Figure 21. IF output when there is (a) no motion (b) small motion in the environment

4. CONCLUSION

As it seen from previous sections, it is possible to detect motions in an indoor environment by using DMMS setup. Our proposed setup can detect slow movement in a radius of 10 meters as it seen in [7]. The designed DMMS is capable of sensing the slowest motions from the objects in the environment such as opening or closing of doors, person's steps and hand gestures. In future work, it is aimed to decrease the noise of the design, using a smaller antenna such as monopoles or patch antennas.

Acknowledgment

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REFERENCES

[1] H. Meinel, “Automotive millimeter wave radar: History and present status,” in Proc. 28th Eur. Microwave Conf., Amsterdam, The Netherlands, 1998, pp. 619–629.

[2] P. Heide, “24 GHz short-range microwave sensors for industrial and vehicular applications,” presented at the Short-Range RadarWorkshop, Ilmenau, Germany, July 15–16, 1999.

[3] B. C. Li, J. Cummings, J. Lam, E. Graves, and W. Wu, “Radar Remote Monitoring of Vital Signs,” in February 200 IEEE Microwave Magazine, pp. 47-56.

[4] http://www.maximintegrated.com/en/products/comms/wireless-rf/ MAX2750.html

[5] P. Mahouti, M. A. Belen, H. P. Partal, S. Demirel and F. Güneş, “Miniaturization with Dumbbell Shaped Defected Ground Structure for Power Divider Designs Using Sonnet”. Applied computational electromagnetics society 2015.

[6] A. S. Türk, A. K. Keskin, M. D. Şentürk, “Dielectric Loaded TEM Horn Fed Ridged Horn Antenna Design for Ultra-wide Band Ground Penetrating Impulse Radar”. Turkish Journal of Electrical Engineering & Computer Sciences.DOI: 10.3906/elk-1303-48.

[7] Design and Implementation of Doppler Microwave Motion Sensor for Indoor Application, https://www.youtube.com/watch?v=pvl26qnbYFs& feature=youtu.be, (available 26.05.2018).