Design of Novel One Port SIW based Leaky Wave Antenna for Respiration Monitoring Applications

Manvinder Sharma (manvinder.sharma@gmail.com)
Punjabi University

Harjinder Singh
Punjabi University

Research Article

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Abstract

Proper and real-time monitoring of the respiratory activity of a patient is very important because failure of respiratory activity is difficult to predict in advance and this can become life critical in just few minutes. The conventional body mounted sensors can also infect sensor as the virus can stay on surface which limits the reuse of sensors for many days. In this paper, different methods which are used for monitoring respiratory activity have been studied. Electromagnetic waves based method is accurate and feasible. In this paper, the work has been carried out taking SIW and Leaky Wave Antenna. Modeling of SIW Leaky wave Antenna is done by making C shaped Slots. A range of frequency is applied as input ranges from 7 GHz to 11 GHz to analyse parameters like 2D far field pattern, VSWR, s-parameters and radiation efficiency of the proposed antenna. The results shows antenna is directional which can be focused on bed of patient. Antenna has directional pattern of 9.52 dB and 3dB angular width 37.5° and radiation efficiency of 96%. Proposed Antenna is compared with Horn, Helical, Patch and Yagi Uda Antenna previously used for respiration monitoring in terms of size, gain and HPBW.

1 Introduction

A patient’s monitoring of respiratory activity is very crucial because failure of respiratory activity is difficult to predict in advance and this can become life critical in just few minutes. For the current pandemic of COVID-19, as there is no vaccine or medicine available till date, WHO and CDC recommended some precautions to avoid COVID-19 which is basically avoiding close contact with affected patients. However the medical team is treating Corona affected patients and has to be in contact with them. This is increasing the threat of exposing to COVID 19. The current respiration monitoring devices include sensors to be placed on chest which means any medical staff has to touch the patient time to time and this exposes the staff also to COVID 19. More than 500 deaths of doctors have been reported in India alone who treated SARS-CoV-2 patents [1]. Also the sensors have to be sterilized before placing on other person’s chest or new sensors to be used. This increases the cost of system. Some existing methods are available in market for automatically measure the respiration rate. Existing contact based methods like electromyography, inductance plethysmography, fiber-optic plethys-mography and spirometry are having limitations of requiring physical contact (placement of sensor on skin, around abdomen/chest or inside oral region) with the patient. The contact based methods have certain limitation like it is difficult to place sensors for infants and burned patients also they can be taken out by patient unintentionally. The Respiratory activity is explained with parameters such as respiratory rate, respiratory depth level of gas exchange taking place during respiration. Figure 1 shows respiration system [2]. A non invasive (contactless) method is discussed to measure the respiratory activity of human in order to predetection of any respiratory failure.

The process of inhaling air into lungs is termed as inspiration, during this process the volume of chest is increased hence increase in size of chest. The process of exhaling air from lungs is termed as expiration, during this process the volume is decreased hence size of chest is decreased.
As respiration is a continuous process, the inspiration and expiration give periodic movement in the chest. This movement can be monitored and analyzed for any failure in respiration [3].

The respiration rate of any person is defined as the number of inhale and exhale activity (breathing) per minute. The respiration rate for an adult at rest, which is considered normal, is around 12 to 20 breaths per minute. While during rest conditions, if the respiration rate is under 12 or above 25 breaths per minute, that is considered abnormal [3]. Monitoring of respiration is necessary for critical cases which may have tendencies of abnormal breathing.

2 Contactless Method of Respiration Monitoring

Conventional methods of automatic respiration monitoring require direct contact with the patients, which can also get infected by COVID-19 virus. Also, the sensors can be taken off by the patients unconsciously. There is difficulty in placing these sensors on burned patients and newborn babies. Spirometry involves placement in the mouth, which is not comfortable for critically ill patients and newborns. Even in sleeping patients, try to rip off the sensors.

Non-invasive or contactless methods are also available for monitoring respiratory activity or respiration rate. In one study, Light Amplification by Stimulated Emission and Radiation (LASER) was used for contactless measurement. Signal peaks were monitored, and the difference between successive peaks was measured and gave proper results [4]. But for this skin was treated with zinc ointment and the subject (patient) was taken clothless. In another work, an acoustic wave (ultrasonic wave) was provided to the subject's head, and inhale and exhale activity from the nose reflected the wave and was analyzed. The exhaled airflow induced frequency shift [5]. But in this method, if the waves are directed to the subject's head, due to sleeping, the subject may change direction, which may cause the monitoring system to give false output.

In another study, a temperature-based system is proposed which measured the difference between the temperature while respiratory processes. The difference between temperatures is converted into a digital signal and was used for monitoring. [6] Again, this system needs to focus on the head of the subject, and this was affected by nearby disturbances like changes in temperature. In another study, EM (Electromagnetic) based methods are used, which have advantages of minimum attenuation while signal propagates in air. Unlike ultrasonic waves, electromagnetic waves can penetrate through heavy clothes, and electromagnetic waves based respiration monitoring can easily be used in a completely non-invasive mode. Figure 3 shows non-invasive or contactless respiration monitoring.

3 Literature Review

In a work, preliminary experiments of an apnoea detector that used radar to monitor respiratory movement. A study has been carried out for low-cost respiration monitoring which measured the difference in temperature between inhalation and exhalation cycles of respiratory activity. Then the difference monitored in temperature was converted into a digital signal. Conversion is done by using ATMEGA 328 (8 bit microcontroller). The abnormalities like apnoea, tachypnea were detected by analyzing the digital...
signal. A buzzer was incorporated with device to which is triggered if there is any sudden or unusual change in respiratory rate [6].

In a study, helical antenna is used [7], size of antenna is not mentioned, and the setup was able to detect respiration activity. Gain of antenna was 6dB. Helical antenna used is shown in Fig. 4.

In another study, horn antenna was used with dimensions 284x184x252 mm and is shown in Fig. 5, the gain of antenna is 10dB [8]. The antenna is bulky in size.

Yagi uda and Patch Antenna is used for same application [9]. Yagi uda antenna has length of 90 mm and width of 50 mm. Yagi uda antenna used is shown in Fig. 6 and radiation pattern of antenna is shown in Fig. 7. The half power beamwidth of antenna is more than 120° and gain is 8.69 dBi.

Patch Antenna with 2x1 patch is used. Width of antenna is 137.4 mm and length of antenna is 82.7 mm with half power beamwidth of 120° and gain of 6.38 dBi [9]. Patch antenna is shown in Fig. 8 and radiation pattern is shown in Fig. 9.

**4 Substrate Integrated Waveguide Based Leaky Wave Antenna & Design Equations**

Several designs involving EM waves has been studied, most of the studies used horn antenna which is large and non-compact in size. Thus, it's not appropriate to be utilized in a commercial respiratory monitoring. To decrease size patch antenna was used in studies but problem for the patch antennas includes that it is tough to attain wide bandwidth which can be a problem if it is desired to work at multiple frequencies. An antenna particularly designed and made for EM wave non contact respiratory sensing is not found. Also with the shorter wavelength, the high frequency waves, they suffer from various attenuations like atmospheric attenuation and absorption by gases in environment. These are also affected by rain and humidity, which reduces its signal strength and range [10]. For transmission of high frequency waves, metal or micro-strip devices are not efficient as their manufacturing requires very tight tolerance [11–13]. The transmission lines if used for higher frequencies results in copper loss, skin effect, and radiation loss. For high frequencies a waveguide is preferred [14].

For guidance of high frequency signals a transmission line is used. Most commonly used transmission lines for higher frequency are rectangular waveguide and microstrip. Rectangular waveguide (RWG) structure is known for low losses and high power handling abilitiy, but size is bulky also cost is high and it is difficult to integrate with other structures. Microstrip line has advantage of easy integration and low cost production but power handling ability and quality factor is less [15].

Substrate Integrated Waveguide (SIW) is transition from RWG. SIW is structure having two planes which are separated by pillars of two rows known as vias. Structure of SIW is shown in Fig. 10.

**4.1 Cutoff Frequency of SIW**
The cut off frequency is given as [16]

\[ f_c = \frac{c}{2\pi} \sqrt{\left( \frac{m\pi}{a} \right)^2 + \left( \frac{n\pi}{b} \right)^2} \]

Where \( m \) and \( n \) are the modes, \( c \) is speed of light \( 3\times10^8 \) m/sec, from the shown Fig. 11, \( a \) is width and \( b \) is height of the waveguide. Design equation for SIW can be expressed as

\[ a_s = a_d + \frac{d^2}{0.95p} \]

where \( d \) is via diameter, \( p \) is distance of vias, \( a_d \) is width

### 4.2 Leaky Wave Antenna

The slot length is given by

\[ \frac{\lambda_0}{\sqrt{2(\varepsilon_r + 1)}} \]

\( \lambda_0 \) is wavelength at mid frequency.

The radiation beam is

\[ \theta = \sin^{-1}\left( \frac{\beta}{k_o} \right) \]

The mode of propagation should be \( \beta < k_o \) for radiation in structure, Where \( \beta \) is the phase constant [17]

### 5 Proposed Methodology

Figure 12 shows the method for monitoring respiratory activity as discussed in section 3. Figure 13 shows the proposed setup for respiration monitoring of subject. EM waves have the ability to penetrate heavy clothes as well. For the setup pair of antennas will be used one for transmission and another for reception. The antenna will be mounted above 1 meter height of patient bed so that the whole bed can be covered.

The frequency chosen is as 10 GHz which comes in non-ionizing spectrum and SAR value to body will be in made in limit as regulated by Federal Communications Commission (FCC) and National Council on Radiation Protection and measurement (NCRP). The maximum Permissible Exposure (MPE) is regulated by these bodies are SAR 4W/kg.

### 6 Modeling And Design
The top view geometry of proposed model for substrate integrated wave leaky wave antenna is shown in Fig. 14. The perpendicular current is spread on the walls of SIW through the array of vias. The mode TE10 is open in SIW structure. In modeling, longitudinal slots are made on the upper metal plane.

The dimensions of width of slots do not effect but it should be less than half of length of slot. The gap between the slots decides beam tilt angle. The gap between the slots is taken as \( \lambda/2 \) to steer the beam towards center. The slots are not taken parallel otherwise they will merge to create a larger slot. The longitudinal slots Jx cut transverse current. Figure 15 shows design in 3D. Table 1 shows the various parameters taken for design.

| Description               | Value         |
|---------------------------|---------------|
| Thickness of Substrate    | 1.55 mm       |
| Dielectric Constant       | 2.2           |
| Width of waveguide        | 14.44 mm      |
| Via Diameter              | 1.2 mm        |
| SIW effective width       | 13.94 mm      |
| Length of SIW             | 89.99         |
| Slot Width                | 1 mm          |
| Slot length               | 18 mm         |
| Slot Gap                  | 5.5 mm        |
| Copper Thickness          | 0.035         |
| Microstrip Width          | 4.8 mm        |
| Minimum frequency in sweep| 7 GHz         |
| Maximum frequency in sweep| 11 GHz        |

7 Results And Discussions

The design has been simulated and modeled on 4x2.60 GHz processor speed on CST Studio. The increase in frequency exerts force on charges and charge particles hence increases electric field intensity. The electric field filled the volume inside the waveguide structure and surface current propagates on large cross sectional area of waveguide walls. The electric field is radiated through the slots. Dielectric used for design is RT-5880 relative permittivity is taken as 2.2. Figure 16 shows electric field norm plot.
The $S$ parameter is can be observed by Fig. 17 in which, near frequency 10 GHz $S_{11}$ reaches about $-16$ dB. For an good antenna for far field this should be below $-10$dB.

The far field radiation pattern can be observed from Fig. 18. The main lobe is tilted towards 9° and farfield directivity is 9.52 dBi. The 3dB angular width (HPBW) is 37.5°. The beam is directive as needed for the design so that it can be focused on chest.

The VSWR plot is shown in Fig. 19. It can be observed from the plot the VSWR value of proposed antenna at 10 GHz is about 1.5, which shows only 4% power is reflected back. The efficiency of proposed design is 96%. The radiation efficiency plot is shown in Fig. 20.

The comparison of antennas used for respiration monitoring previously is shown in Table 2. It can be observed from the table, the proposed design is smaller in size with good gain of antenna. The important factor for this particular application of respiration monitoring is beam width. The proposed design has Half power beamwidth of 37.5° which shows this is highly direction antenna. Thus beam can be directed towards chest without interfering with other nearby human or any electronic/electrical equipment.

| Parameters                   | Helical | Horn      | Yagi Uda     | Patch         | Proposed SIW based LWA |
|------------------------------|---------|-----------|--------------|---------------|------------------------|
| Size                         | Not Mentioned But Bulky | 284x184x252 mm | 90 x50 mm | 137.4 x 82.7 mm | 89.99x14.44mm |
| Gain                         | 6 dB    | 10dB      | 8.68 dB      | 6.38 dB       | 9.31 dB               |
| Half Power Beam Width        | Not mentioned | Not Mentioned | More than 120° | 120°          | 37.5°                 |

### 8 Conclusion

The failure of respiratory activity due to any disease or drug may take the life of patient within small amount of time. Traditional methods involve contact based systems for monitoring. In which some sort of sensor is to be placed on the body of patient which may be taken off by patient during sleep or unintentionally. Also for burned patient or new born babies it is difficult to place the sensor on body. Contactless respiration monitoring methods have been studied but antenna used for this is not proper which can be used commercially. In this paper, SIW based Leaky Wave Antenna for contactless respiration monitoring was designed and simulated. The design uses combination of longitudinal slots. The radiation pattern for far field, efficiency, VSWR was also calculated for given frequency range to be used for respiration monitoring. The antenna has directive radiation pattern so it can be focused on bed only and it will not interfere in nearby devices. The proposed antenna has better parameters as compared to various antennas used for same application. A methodology is proposed for monitoring the respiration activity in contactless manner.
Declarations

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