Wearable Antennas for Medical Applications

Albert Sabban, IEEE Senior Member
Electrical Engineering Ort Braude College, Karmiel, P.O. Box 78, Karmiel 21982,Israel
Tel: 972-4-8759111, Fax: 972-4-8759111, sabban@netvision.net.il

ABSTRACT

Biomedical industry is in continuous growth in the last few years. Low profile compact antennas are crucial in the development of wearable human biomedical systems. The polarization of the proposed antenna may be linear or dual polarized. Design considerations, computational results and measured results on the human body of several compact wideband microstrip antennas with high efficiency at 434MHz±5% are presented in this paper. The compact dual polarized antenna dimensions are 5x5x0.05cm. The antenna beam width is around 100º. The antennas gain is around 0 to 2dBi. The proposed antenna may be used in Medicare RF systems. The antennas S11 results for different belt thickness, shirt thickness and air spacing between the antennas and human body are presented in this paper. If the air spacing between the new antenna and the human body is increased from 0mm to 5mm the antenna resonant frequency is shifted by 5%. Tunable antennas may be used to compensate variations in the antenna resonant frequency at different locations on the human body.

Keywords

Wearable Antennas, Tunable antennas, medical applications

1. INTRODUCTION

Printed antennas are widely employed in communication system and seekers. Microstrip antennas posse's attractive features such as low profile, flexible, light weight, small volume and low production cost. In addition, the benefit of a compact low cost feed network is attained by integrating the RF frontend with the radiating elements on the same substrate. Microstrip antennas are widely presented in books and papers in the last decade as referred in [1-7]. The effect of human body on the electrical performance of wearable antennas at microwave frequencies is not presented in [8-13]. RF transmission properties of human tissues have been investigated in several papers such as [8-9]. Several wearable antennas have been presented in papers in the last decade as referred in [10-17]. A review of wearable and body mounted antennas designed and developed for various applications at different frequency bands over the last decade are presented in [10]. In [11] meander wearable antennas in close proximity of a human body are presented in the frequency range between 800MHz and 2700MHz. In [12] a textile antenna performance in the vicinity of the human body is presented at 2.4GHz. Numerical results with and without the presence of the human body are discussed in this paper.

In [13] the effect of human body on wearable 100 MHz portable radio antennas is studied. In [13] the authors concluded that wearable antennas need to be shorter by 15% to 25% from the antenna length in free-space. Measurement of the antenna gain in [13] shows that a wide dipole (116x10cm) has -13dBi gain. The antennas presented in [10-13] were developed mostly for cellular applications. Requirements and the frequency range of medical systems are not the same as in cellular industry. A new class of wideband compact wearable microstrip antennas for medical applications is presented in this paper. The antennas VSWR is better than 2:1at 434MHz±5%. The antenna beam width is around 100º. The antennas gain is around 0 to 4dBi. The antenna resonant frequency is shifted by 5% if the air spacing between the antenna and the human body is increased from 0mm to 5mm.

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2. DUAL POLARIZED PRINTED ANTENNA

A new compact microstrip loaded dipole antennas has been designed to provide horizontal polarization. The antenna dimensions have been optimized to operate on the human body by employing ADS software. The printed slot antenna provides a vertical polarization. In several medical systems the required polarization may be vertical or horizontal polarization. The proposed antenna is dual polarized. The printed dipole and the slot antenna provide dual orthogonal polarizations. The antenna consists of two layers. The first layer consists of RO3035 0.8mm dielectric substrate. The second layer consists of RT-Duroid 5880 0.8mm dielectric substrate. The substrate thickness determines the antenna band width. However, thinner antennas are flexible. Thicker antennas with wider bandwidth have been designed. The dimensions of the dual polarized antenna shown in Fig 1 are 26x6x0.16cm. The antenna may be used as a wearable antenna on human body. The antenna may be attached to the patient shirt in the patient stomach or back zone. The antenna has been analyzed by using Agilent ADS software. The matching stubs width and length has been optimized to get the best VSWR results at the antenna input ports. The length of the stub L is 10mm. The number and location of the coupling stubs control the axial ratio value. The axial ratio value may vary from 0dB to 20dB due to different location and number of the coupling stubs. The length and width of the coupling stubs in Figure 1 are 12mm by 10mm.The number of coupling stubs may be minimized to around four. The antenna cross polarized field strength may be adjusted by varying the slot feed location. There is a good agreement between measured and computed results. The antenna bandwidth is around 10% for VSWR better than

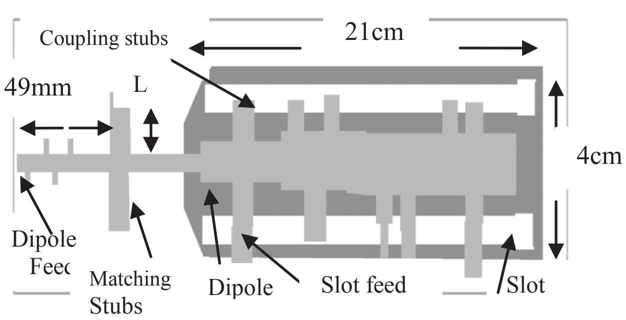

Figure 1: Printed dual polarized antenna, 26x6x0.16 cm.

2:1.The antenna beam width is around 100º. The antenna gain is around 2dBi. The computed S11 and S22 parameters are presented in Figure 2. Figure 3 presents the antenna measured S11 parameters. The computed radiation pattern is shown in Figure 4.
The dimensions of the folded dual polarized antenna presented in Figure 5 are 7x5x0.16cm. . The length and width of the coupling stubs in Figure 5 are 12mm by 9mm. Small tuning bars are located along the feed line to tune the antenna to the desired resonant frequency. Figure 6 presents the computed S11 and S22 parameters.

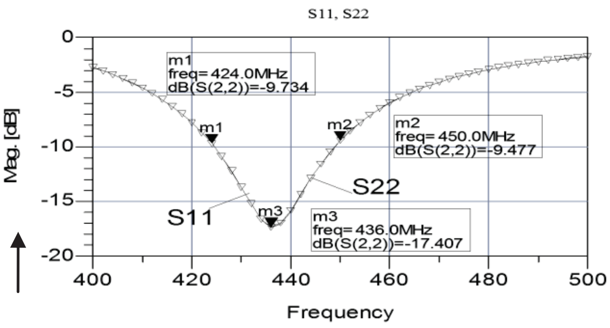

Figure 2: Computed S11 and S22 results

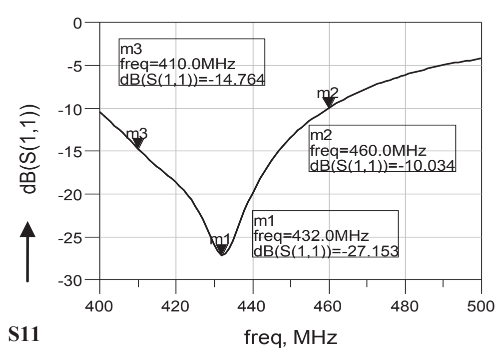

Figure 3: Measured S11 on human body

The computed radiation pattern of the folded dipole is shown in Figure 7. The antennas radiation characteristics on human body have been measured by using a phantom. The phantom electrical characteristics represent the human body electrical characteristics. The phantom has a cylindrical shape with a 40cm diameter and a length of 1.5m. The phantom contains a mix of 55% water 44% sugar and 1% salt. The antenna under test was placed on the phantom during the measurements of the antennas radiation characteristics. S11 and S12 parameters were measured directly on human body by using a network analyzer. In all measurements the measured results was compared to a known reference antenna.

3. LOOP ANTENNA WITH GROUND PLANE

A new loop antenna with ground plane has been designed on Kapton substrates with thickness of 0.25mm and 0.4mm. The antenna without ground plane is shown in Figure 8. The loop antenna VSWR without the tuning capacitor was 4:1. This loop antenna may be tuned by adding a capacitor or varactor as shown in Figure 8. Matching stubs are employed to tune the antenna to the resonant frequency. Tuning the antenna allows us to work in a wider bandwidth. Figure 9 presents the loop antenna computed S11 parameter on human body. There is good agreement between measured and computed S11. The computed radiation pattern is shown in Fig 10. Table I compares the electrical performance of a loop antenna with ground plane with a loop antenna without ground plane. There is a good agreement between measured and computed results of antenna parameters on human body. The results presented in Table I indicates that the loop antenna with ground plane is matched to the human body, without the tuning capacitor, better than the loop antenna without ground plane. The computed 3D radiation pattern is shown in Fig 11.

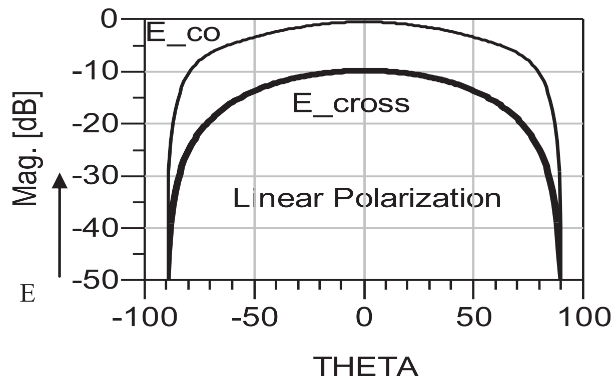

Figure 4: Antenna Radiation pattern

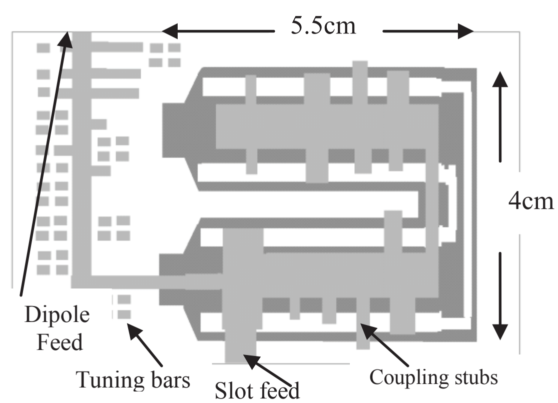

Figure 5: Folded dual polarized antenna, 7x5x0.16cm.

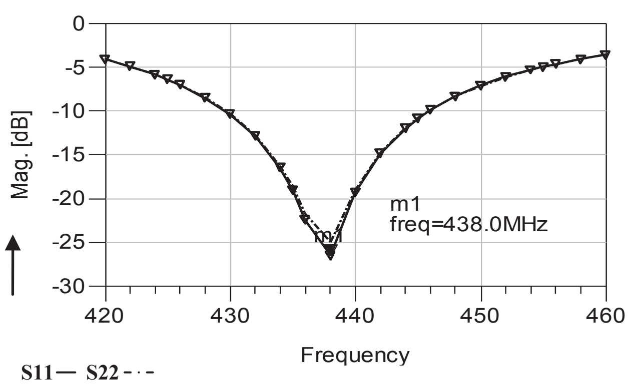

Figure 6: Folded antenna Computed S11and S22 results

Table 1. Comparison of Loop Antennas

Antenna with no tuning capacitor	Beam width 3dB	Gain dBi	VSWR
Loop no GND	100°	0	4:1
Loop with GND	100°	0	2:1

The computed 3D radiation pattern and the coordinate system used in this paper are shown in Fig 11. Computed S11 of the Loop Antenna with a tuning capacitor is given in Figure 12. For frequencies ranging from 415MHz to 445MHz the antenna has V.S.W.R better than 2:1 when there is no air spacing between the antenna and the patient body. The radiation pattern of the Loop Antenna (without ground) on human body is presented in Figure 13.

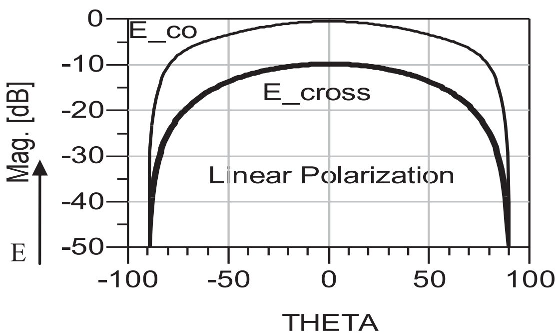

Figure 7: Folded antenna Radiation pattern

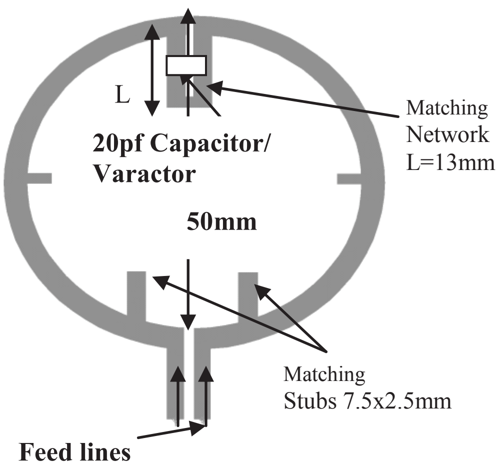

Figure 8: Loop antenna without ground plane

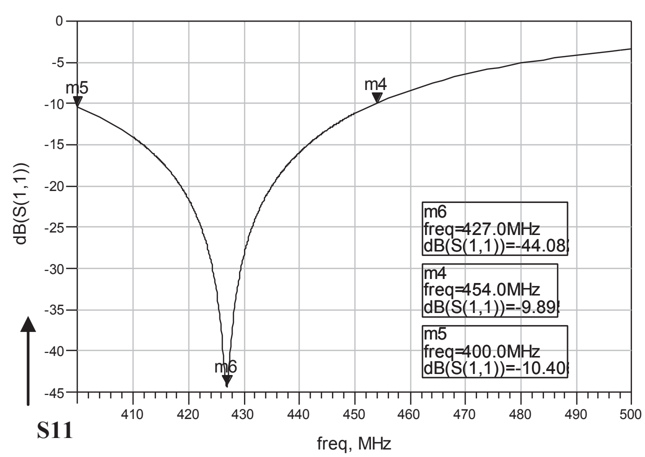

Figure 9: Computed S11 of new Loop Antenna

4. ANTENNA S11 VARIATO IN VICINITY TO HUMAN BODY

The Antennas input impedance variation as function of distance from the body had been computed by employing ADS software. The analyzed structure is presented in Figure 14. The patient body thickness was varied from 15mm to 300mm.

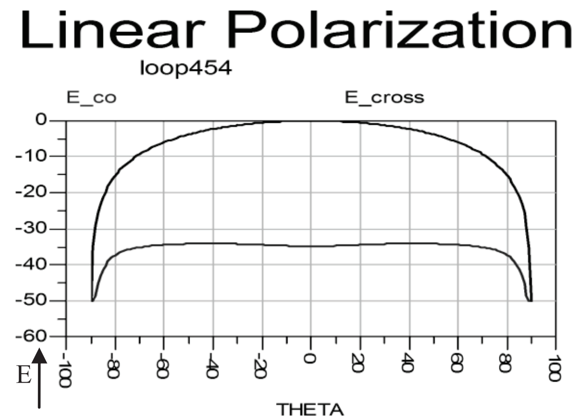

Figure 10: New Loop Antenna Radiation pattern

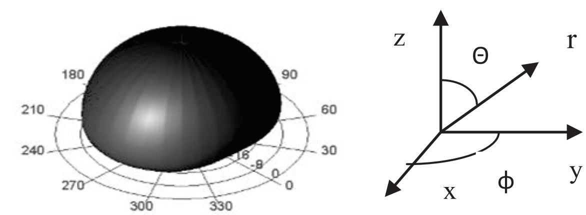

Figure 11: New Loop Antenna 3D Radiation pattern on Human body

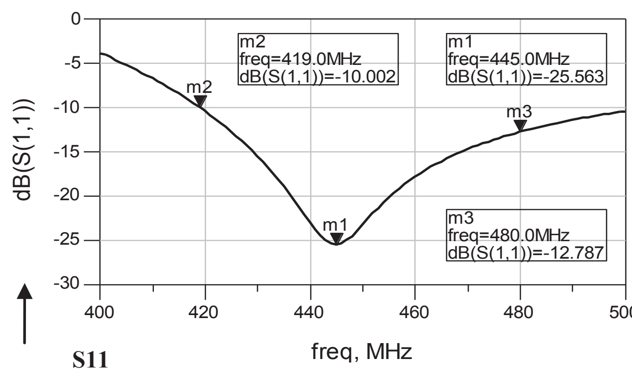

Figure 12: Computed S11 of Loop Antenna, without ground plane, with a tuning capacitor

The location of the antenna on human body may be taken into account by calculating S11for different dielectric constant of the body. The variation of the dielectric constant of the body from 40 to 60 shifts the antenna resonant frequency up to 2%. The antenna was placed inside a belt with thickness between 2 to 4mm with dielectric constant from 2 to 4. The air layer between the belt and the patient shirt may vary from 0mm to 8mm. The shirt thickness was varied from 0.5mm to 1mm. The dielectric constant of the shirt was varied from 2 to 4. Properties of human body tissues are listed in Table II see [8]. These properties were employed in the antenna design. Figure 15 presents S11 results (of the antenna shown in Figure 1) for different belt thickness, shirt thickness and air spacing between the antennas and human body. One may conclude from results shown in Figure 15 that the antenna has V.S.W.R better than 2.5:1 for air spacing up to 8mm between the antennas and the human body. Results shown in Figure 15 indicates that the antenna has V.S.W.R better than 2.0:1 for air spacing up to 5mm between the antennas and patient body.

Table 2. Properties of human body tissues

Tissue	Property	434 MHz	600 MHz
Skin	σ ε	0.57 41.6	0.6 40.43
Stomach	σ ε	0.67 42.9	0.73 41.41
Colon, Muscle	σ ε	0.98 63.6	1.06 61.9
Lung	σ ε	0.27 38.4	0.27 38.4

Figure 16 presents S11 results for different position relative to the human body of the folded antenna shown in Figure 5. Explanation of Figure 16 is given in Table III. If the air spacing between the sensors and the human body is increased from 0mm to 5mm the antenna resonant frequency is shifted by 5%. The antenna shown in Figure 8 has V.S.W.R better than 2.0:1 for air spacing up to 5mm between the antennas and patient body. If the air spacing between the sensors and the human body is increased from 0mm to 5mm the computed antenna resonant frequency is shifted by 2%. However, if the air spacing between the sensors and the human body is increased up to 5mm the measured loop antenna resonant frequency is shifted by 5%. Explanation of Figure 17 is given in Table IV. A voltage controlled varactor may be used to control the wearable antenna resonant frequency at different locations on the human body, see [18].

5. APPLICATIONS

An application of the proposed antenna is shown in Figure 18.
Three to four folded dipole or loop antennas may be assembled in a belt and attached to the patient stomach.

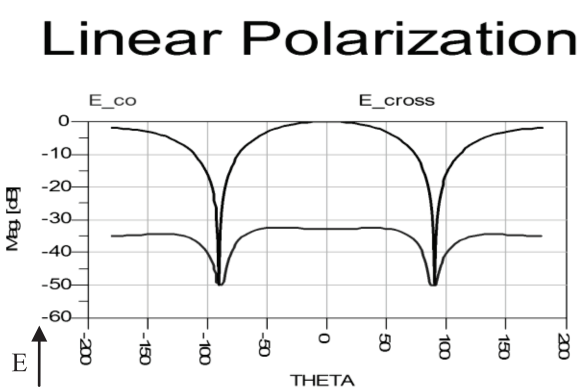

Figure 13: Radiation pattern of Loop Antenna (without ground) on human body

The cable from each antenna is connected to a recorder. The received signal is routed to a switching matrix. The signal with the highest level is selected during the medical test. The antennas receive a signal that is transmitted from various positions in the human body. Folded antennas may be also attached on the patient back in order to improve the level of the received signal from different locations in the human body. In several applications the distance separating the transmitting and receiving antennas is less than $2D^2/\lambda$. D is the largest dimension of the radiator. In these applications the amplitude of the electromagnetic field close to the antenna may be quite powerful, but because of rapid fall-off with distance, the antenna do not radiate energy to infinite distances, but instead the radiated power remain trapped in the region near to the antenna. Thus, the near-fields only transfer energy to close distances from the receivers. The receiving and transmitting antennas are magnetically coupled. Change in current flow through one wire induces a voltage across the ends of the other wire through electromagnetic induction. The amount of inductive coupling between two conductors is measured by their mutual inductance. In these applications we have to refer to the near field and not to the far field radiation.

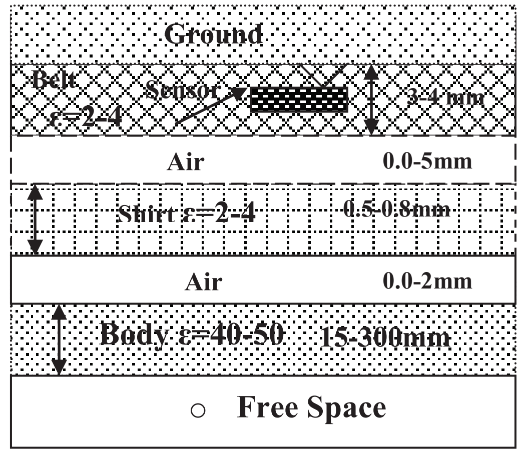

Figure 14: Analyzed structure for Impedance computations

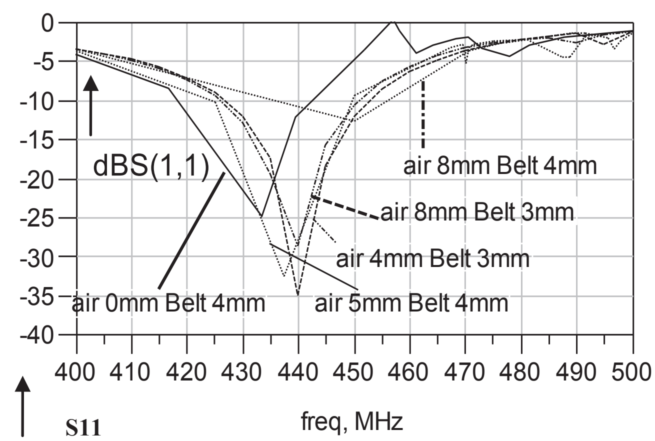

Figure 15: The S11 of the antenna with different thicknesses And spacing relative to the human body

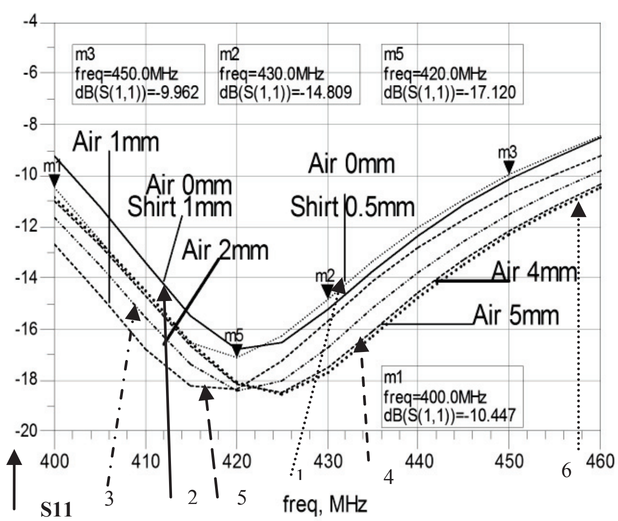

Figure 16: Folded antenna S11 results for different antenna position relative to the human body

In Figure 19 and 20 several microstrip antennas for medical applications at 434MHz are shown. The diameter of the loop antenna presented in Figure 19 is 50mm. The dimensions of the folded dipole antenna are 7x6x0.16cm.

Table 3. Explanation of Figure 16

Picture #	Line type	Sensor position
1	Dot ·········	Shirt thickness 0.5mm
2	Line ——	Shirt thickness 1mm
3	Dash dot - · - ·	Air spacing 2mm
4	Dash - - - -	Air spacing 4mm
5	Long dash — —	Air spacing 1mm
6	Big dots ·····	Air spacing 5mm

Table 4. Explanation of Figure 17

Picture #	Line type	Sensor position
1	Dot ·········	Body 15mm air spacing 0mm
2	Line ——	Air spacing 5mm Body 15mm
3	Line ——	Body 40mm air spacing 0mm
4	Dash dot ▬ ▪	Body 30mm air spacing 0mm
5	Dash dot - · - · -	Body 15mm Air spacing 2mm
6	Dot ·····	Body 15mm Air spacing 4mm

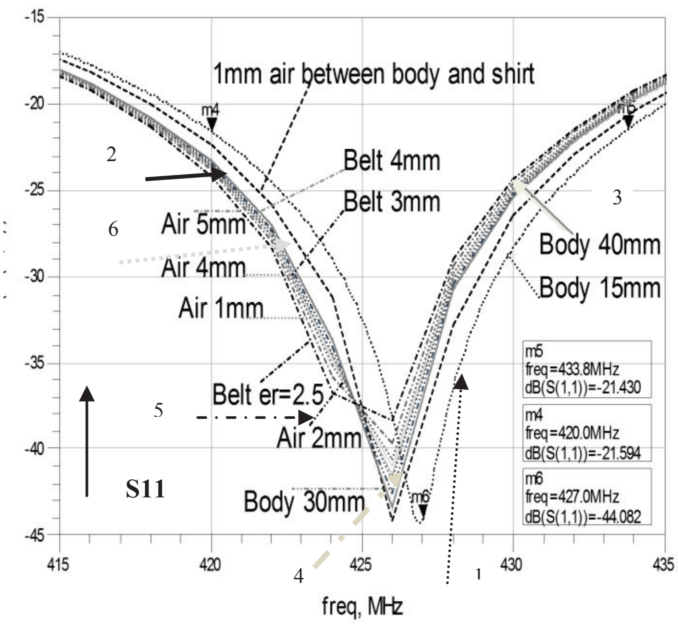

Figure 17: Loop antenna S11 results for different antenna position relative to the human body

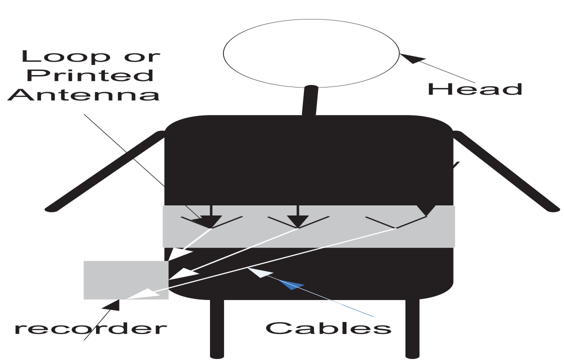

Figure 18: Printed Wearable antenna

Antennas may be located on the back and front of the human body for different medical applications.

6. COMPACT MICROSTRIP ANTENNA

A new compact microstrip loaded dipole antennas has been designed. The antenna consists of two layers. The first layer consists of FR4 0.25mm dielectric substrate. The second layer consists of Kapton 0.25mm dielectric substrate. The substrate thickness determines the antenna bandwidth. However, with thinner substrate we may achieve better flexibility. The proposed antenna is dual polarized. The printed dipole and the slot antenna provide dual orthogonal polarizations. The dual polarized antenna is shown in Figure 21. The length and width of the coupling stubs in Figure 21 are 10mm by 5mm. Small tuning bars are located along the feed line to tune the antenna to the desired resonant frequency. The antenna dimensions are 5x5x0.05cm. The antenna may be attached to the patient shirt in the patient stomach or back zone. The antenna has been analyzed by using ADS software. There is a good agreement between measured and computed results.

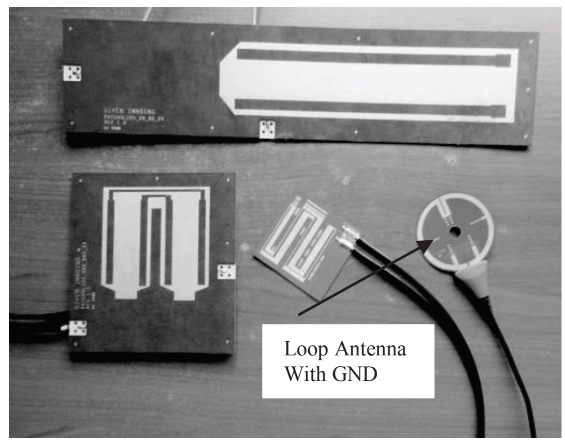

Figure 19: Microstrip Antennas for medical Applications

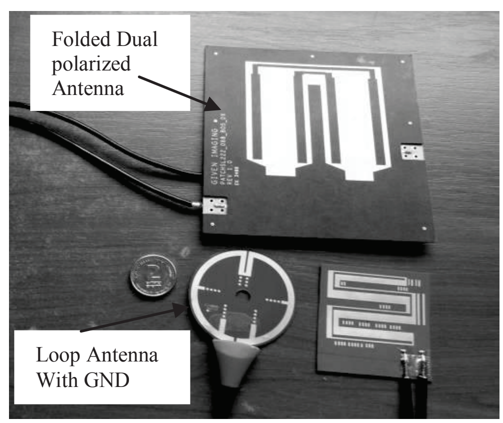

Figure 20: Microstrip Antennas for medical Applications

The antenna bandwidth is around 10% for VSWR better than 2:1. The antenna beam width is around 100º. The antenna gain is around 0dBi. The computed S11 parameters are presented in Figure 22. Figure 23 presents the antenna measured S11 parameters. The antenna cross-polarized field strength may be adjusted by varying the slot feed location. The computed 3D radiation pattern of the antenna is shown in Figure 24. The computed radiation pattern is shown in Figure 25.

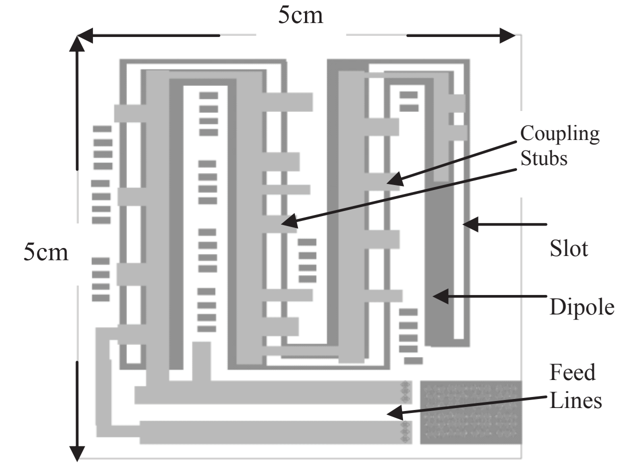

Figure 21: Printed Compact dual polarized antenna

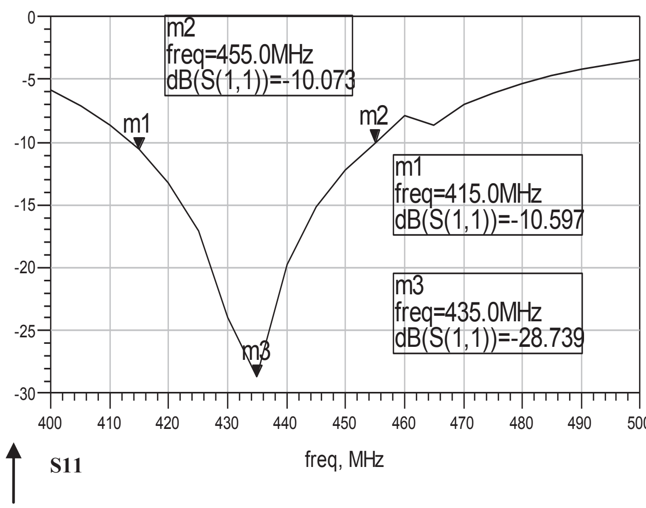

Figure 22: Computed S11 results of the compact antenna

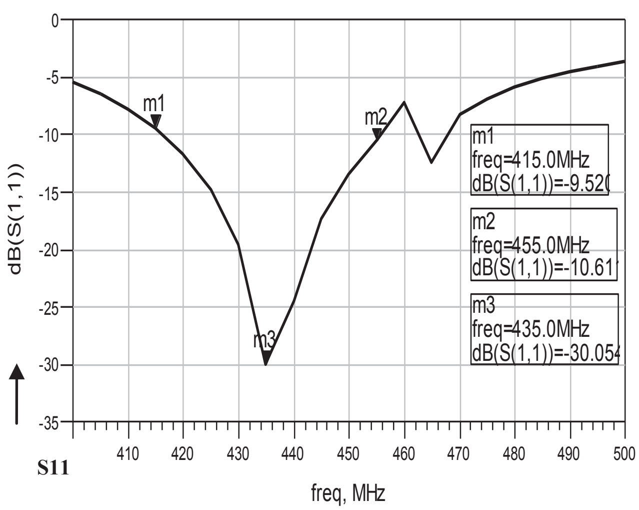

Figure 23: Measured S11 on human body

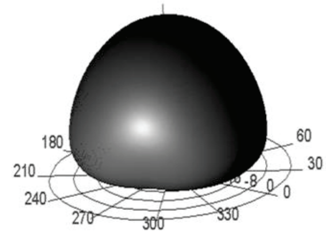

Figure 24: 3D Antenna Radiation pattern

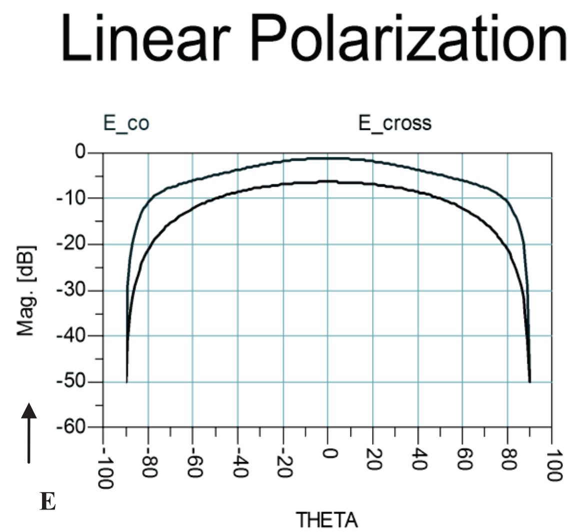

Figure 25: Antenna Radiation pattern

7. Tune-able Wearable Antennas

A voltage controlled varactor may be used to control the antenna resonant frequency. Varactors are connected to the antenna feed lines as shown in Figure 26. The antenna may be attached to the patient shirt in the patient stomach or back zone. The antenna has been analyzed by using Agilent ADS software. There is a good agreement between measured and computed results. Figure 27 presents the S11 parameters as function of different varactor capacitances. The antenna resonant frequency varies around 5% for capacitances up to 2.5pF.

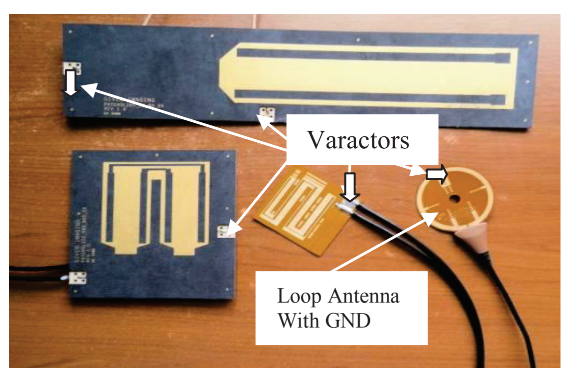

Fig. 26: Tunable Antennas for medical Applications

The antenna bandwidth is around 10% for VSWR better than 2:1. The antenna beam width is around 100º. The antenna gain is around 2dBi. Figure 28 presents measured S_{11} as function of varactor bias voltage. We may conclude that varactors may be used to compensate variations in the antenna resonant frequency at different locations on the human body.

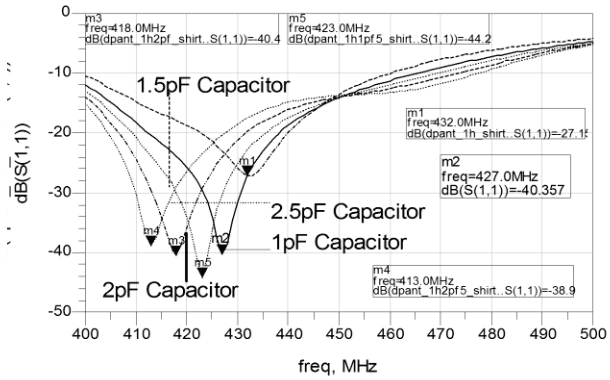

Fig. 27: S11 parameter as function of varactor capacitance

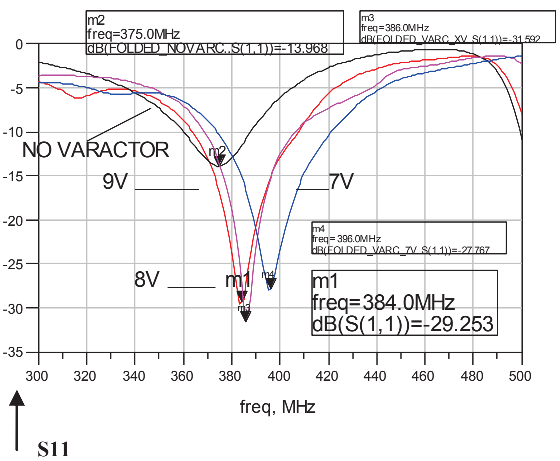

Figure 28: Measured S11 as function of varactor voltage

8. CONCLUSION

This paper presents wideband microstrip antennas with high efficiency for medical applications. The antenna dimensions may vary from 26x6x0.16cm to 5x5x0.05cm according to the medical system specification. The antennas bandwidth is around 10% for VSWR better than 2:1. The antenna beam width is around 100º. The antennas gain varies from 0 to 2dBi. The antenna S11 results for different belt thickness, shirt thickness and air spacing between the antennas and human body are presented in this paper. If the air spacing between the new dual polarized antenna and the human body is increased from 0mm to 5mm the antenna resonant frequency is shifted by 5%. Varactors may be used to compensate variations in the antenna resonant frequency at different locations on the human body. The proposed antenna may be used in Medicare RF systems.

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