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Design of Microstrip Capsule Antenna

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***Abstract*:**
The trend in today's wireless application is to design antennas that are compact, robust and ease to integrate with RF circu it components. Microstrip patch antenna is one such type that satisfies the above requirements. The performance parameters such as, bandwidth, gain and return loss of the proposed antennas are analysed. Proposed microstrip capsule antenna provides UWB, reduced SAR and stable impedance matching. In the past, wideband outer-wall antennas have been proposed for capsule type applications. The outer wall is not a good choice for placing capsule antennas, since such a choice exhib its a high specific absorption ratio, low gain, and low efficiency. Hence we propose an antenna in the inner wall of a capsule shell, and it provides a wide impedance bandwidth. Furthermore, the impedance matching remains stable even there is a change in the operating environment. Th is design operates at 2.4 GHz frequency which is in ISM band is well suitable for wireless capsule endoscopy application.

Keywords:
Conformal capsule antenna, inner wall, patch-slot antenna, high gain.

I. INTRODUCTION

The trend in today's wireless application is to design antennas that are compact, robust and ease to integrate with RF circu it components. Mainly in wireless capsule endoscopy the antenna should be very small in size so that adaptable to the human. Microstrip antenna is one that suits these requirements . INGESTIBLE electronics have been receiving increasing attention of biosensor designers in recent years which is the major part of Wireless Capsule Endoscopy (WEC). The antenna plays a vital role when one attempt to communicate with an ingestible device. Table I

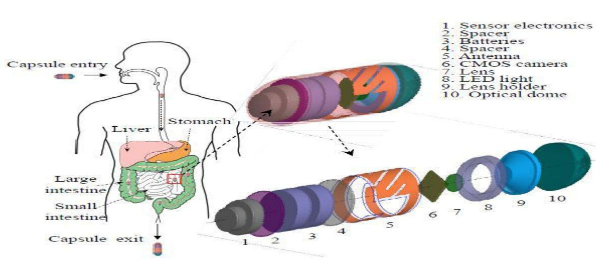


Fig 1. Ov erv ie w o f w ire les s caps u le en d os cop y

shows that the dielectric properties at 2.4 GHz changes rapidly fro m tissue to tissue. Thus, when a capsule traverses the digestive system, its surrounding environment experiences significant changes which can adversely affect the performance of the antenna. Current designs of capsule antennas are typically narrowband and hence, they are vulnerable to changes in the operating environment. Dielectric loading has been proposed as a way to obtain wideband impedance matching in , and wideband spiral antennas have been employed in and however, these designs are not conformal.

Conformal capsule antennas, which allocate space inside the capsule for battery and circuits, and still realize wide impedance bandwidths, have been proposed in. However, the antenna described in has a very high specific absorption ratio (SAR).

TABLE I

DIELECTRIC PROP ERTIES OF D IFFERENT TISSU ES AT 2. 4 GHz

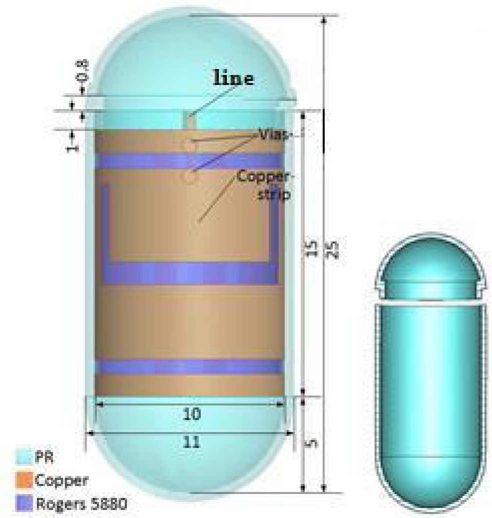
Tissue	Conductivity σ(S/m)	Relative Permittivity εr
Muscle	1.74	52.73
Stomach	2.21	62.16
Small Intestine	3.173	54.43
Colon	2.04	53.88

Of these, the antennas in the past printed on the outer wall of the capsule shell. Consequently, although the high permittivity accompanied by a large loss in the tissues helps to extend the bandwidth of the antenna, exposing the antenna to tissues becomes a safety concern from the point of view of biocompatib ility. The antenna on the outer wall is essentially short circuited by the surrounding tissues and thus causes undesirable problems. The conformal microstrip capsule slot antenna proposed in this paper is an inner-wall type, which provides an operating bandwidth much wider than other inner-wall designs that have been proposed in the past. Additionally, the proposed antenna maintains a very stable impedance matching characteristic even when there is a change in the surrounding environment; and, hence, it is very desirable for use in an ingestible capsule system. In this paper, we carry out parametric studies to investigate the characteristics of the microstrip patch with slot - type antennas and fabricate a prototype of the same to validate the design.

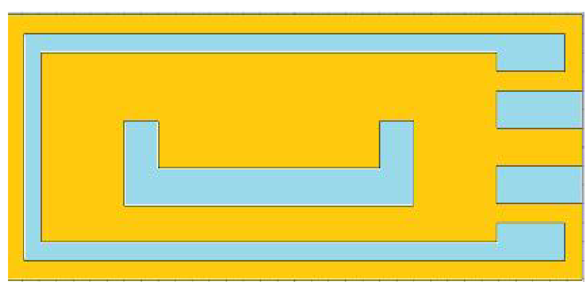
II. ANTENNA DESIGN

A. Antenna Geometries

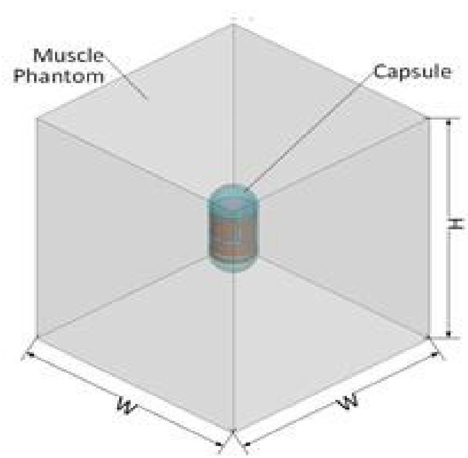
The proposed capsule antenna, shown in Fig. 1(a), is a wrapped slot-loop antenna fed by a microstrip feed line, with a slot introduced at its inner patch to realize an additional resonance. The capsule shell consists of a cylinder at the center which has two hemispherical caps at its top and bottom. As may be seen from the bottom right inset, which displays the cross section of the capsule, the center cylinder and the bottom cap are conjoined, and the top cap can be connected to the bottom part. The inside diameter and inside height of the capsule shell are 10 and 25 mm, respectively, the same as those of a typical capsule for endoscope applications.



2 (a)



2 (b)



2 (c)

Fig 2 (a) Geo metry of the proposed capsule antenna. (b) Geo metry of the proposed capsule antenna before it is wrapped (front view). (c) Simu lation set up.

For those applications which require d ifferent capsule sizes, the proposed structure can easily be tailored to fit their needs. The capsule is made of photosensitive resin (PR) and is fabricated by using the 3-D printing technology. As shown later, it is desirable to use a thinner shell to achieve a wider impedance bandwidth. We choose the thickness of the capsule shell to be 0.5 mm, because of limitation of our fabricat ion facilit ies.

B. Inner Wall Versus Outer Wall

As mentioned above, conformal capsule antennas that are printed on the outer wall of the capsule shell and a wide bandwidth has been obtained using this type of design. In this section, we discuss the disadvantages of printing antennas on the outer wall of a capsule shell by carry ing out a comparat ive study of the bandwidth, SAR, gain, and the efficiency of loop antennas conformed to the inner wall and outer wall of a capsule shell, when the geometries of the loop antennas in the two cases are identical.

The efficiencies of the two cases are presented in Table II, and we note fro m this table that the efficiency of the outer- wall capsule antenna is only 24.4% of that of the inner-wall antenna. A low efficiency imp lies a shorter battery life, since we would need to increase the transmitting power to deliver the same amount of power to the receiving antenna. For other antenna types, such as dipoles, the simu lations show that the antennas suffer fro m high peak SA Rs, low gains, and low efficiencies when printed on the outer wall of a capsule shell.

Although they do achieve antenna miniaturization and wider bandwidths. Furthermore, the disadvantages of the outer-wall capsule antenna become even more pronounced when placed in a lossier environment, as for instance in the small intestine. Therefore, based on the discussion in this

+ section, we can conclude that the inner wall of the capsule shell is a good choice for printing conformal capsule antennas.

TABLE II

COMPARISON OF INNER A ND OUTER WA LL

ANTENNA OF A CAPSULE SHELL

	Inner-wall	Outer-wall
Peak average SAR (W/Kg)	93.0	295.1
Peak local SAR (W/Kg)	1917.8	67106
Peak current (A/m^2)	2521.3	15230
Peak gain	-22.1	-25.3
Efficiency	0.262%	0.064%

C. Operating Mechanism

The conformal inner-wall capsule antenna are shown in Fig. 3

Fig 3 The proposed antenna within the capsule

The bandwidth of the loop antenna is only 15.6% whereas the slot-loop antenna which is complementary to the loop has a much wider bandwidth of 34.4%. Such a phenomenon can only be *qualitatively* explained by using the theory of complementary antennas because the loop and slot-loop antennas are not rigorously complementary, and also because they are not operating in a homogeneous mediu m. For co mp lementary antennas, we have

$$Z_l.Z_s = \eta^2 /4 \quad (1)$$

where Z_l and Z_s are the input impedances of an antenna and its complement, respectively, and η is the effective wave impedance. The impedance of the loop antenna changes dramatically with frequency, while the impedance of the slot- loop antenna varies relatively smoothly. Z_s is calculated by using (1), where Z_l is the impedance of the loop antenna, and wave impedance η is assumed to be 143+j 17.4 Ω. The profile of Z_s is found to be very similar to the profiles of the impedance of the slot-loop antenna.

Although the parasitic patch could be modified to tune the antenna, it is found it is much easier to tune the slot antennas instead in order to introduce additional resonances. Based on the discussion in this section, we can say that the slot antennas have wider bandwidths and that they can easily be tuned to have additional resonances, when needed in other applications of the conformal capsule antennas.

D. Parametric Studies

The results of parametric studies, which have been carried out to investigate the characteristics of the proposed antenna, are presented in this section. We begin by investigating the effects of the U-slot at the center on the S11 of the antenna. The resonance around 2.4 GHz appears as we increase *sl*4, where *sl*4 is the length of vertical section of the U-slot.

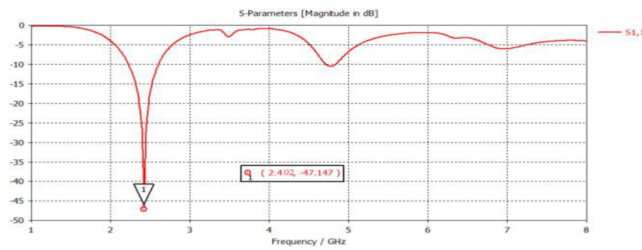
The substrate thickness has little in fluence on the antenna bandwidth. Thus, the antenna can be printed on the inner wall of the capsule shell if a 3-D printer capable of printing metal can be employed. In practice, there will be a battery as well as circuits inside the capsule and the conformal capsule antenna has to maintain stable performance when these components are in place. Locating the battery farther from the feed point will have even less effect on S11. Given that a battery size of 5 mm in height and 4.5 mm in rad ius is sufficiently large for a typical capsule system, we can conclude that the proposed antenna will wo rk stably when a battery and its associated circuits– are inserted in the capsule.

The thickness of the capsule shell has a significant impact on the impedance of the capsule antenna. The resonances shift toward lower frequencies in a monotonic manner as the shell thickness is decreased; hence, using a thinner capsule shell helps us to achieve antenna miniaturization.

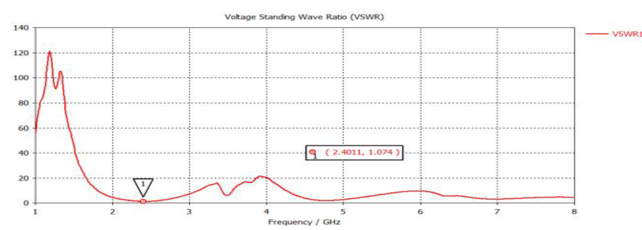
Besides, we note that the shell thickness has relatively lo w impact on the peak average SAR. The proposed antenna has a very wide impedance bandwidth Fig. 4 (a) shows that the S11 curve o f the proposed capsule antenna. Thus, the proposed capsule antenna is indeed quite insensitive to environmental variat ions, which is a very desirable characteristic that the designer seeks in the applications of the type being considered herein.

III. EXPERIM ENTS A ND DISCUSSION

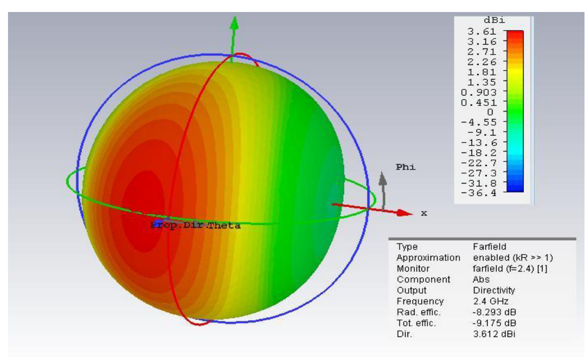
The fabricated prototype of the proposed antenna is shown in Fig. As shown in Fig, the measured S11



4 (a)



4 (b)



4 (c)

Fig 4 (a) S_{11} S-parameter curve (b) VSW R curve (c) Radit ion Pattern at 2.4 GHz of the proposed antenna is better than -10 dB across the frequency band ranging fro m 1.92 to 2.93 GHz (1.01 GHz), wh ich agrees well with the simu lation results.

As assumed in the simulat ion, the proposed capsule antenna still covers the desired frequency range satisfactorily. Hence, the antenna is indeed relatively insensitive to surrounding environments from the impedance matching point of view. The measured |S21| is about -45.6 dB at 2.4 GHz and, as a general trend, it decreases with an increase in frequency.

The VSWR of the antenna should be less than or equal to one. Here we obtain the VSWR as 1.0 at 2.4 GHz. The gain of the antenna is -4.8 d B. Thus the gain of the antenna is sufficiently increased compared to the antenna designed in the past .

I V. CONLUSION

This project is designed using Computer Simulat ion Technology (CST). This microstrip capsule antenna with rectangular patch and U-shaped slot is suitable for Wireless Capsule Endoscopy (WCE). The simu lated results shows that the designed antenna is suitable for the capsule type application in wireless endoscopy at the operating frequency of 2.4 GHz. This project deals with the Microstrip Rectangular Patch Antenna with U-shaped slot that operates at 2.4GHz . In future further reduction in size with wide bandwidth could be obtained which results in reduction of capsule size and increases the efficiency so that antenna transmits at a faster rate.

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