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Transparent Spherical Spiral Antenna for Capsule Endoscopy Systems

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***Abstract*—A transparent spherical spiral antenna for endoscopy capsule systems for gastrointestinal monitoring is presented in this article. The capsule antenna is designed for operating in the Medical Implant Communication Systems frequency band (i.e., 401-406 MHz) and has an impedance bandwidth of 397-409 MHz. The transparency of the antenna allows it to be implemented in front of the camera. This leads to more available space inside the capsule for embedding more subsystems. The proposed antenna also has a circularly polarized omnidirectional radiation pattern. These characteristics allow a stable wireless communication link during the monitoring operation.**

***Index Terms*—transparent antenna, capsule endoscopy, spherical helical antenna, circular polarization, MICS.**

I. INTRODUCTION

Wireless endoscopy capsule systems allow visual examination of the small and large intestines and can replace or complement traditional diagnostic systems. In these systems, an ingestible capsule that is swallowed by the patient takes images of the gastrointestinal tract. These images can be sent out of the body by a wireless communication link, which typically consists of a capsule antenna and an on-body antenna [1-2].

The most important challenge facing endoscopic capsule systems is the limited energy source, which leads to reduced operating time, data rate, and image resolution. The transmitter can consume at least half of this limited energy source. Therefore, designing optimal antennas is a vital task that can lead to an improvement in operation time or image quality.

Due to the change in the direction of the capsule, as it travels through the folded and coiled intestinal structure, circular-polarized (CP) antennas can provide better performance compared to their linear polarized counterparts. Several CP antennas have been introduced for capsule endoscopy so far. However, some of the introduced antennas are relatively bulky. Antennas introduced in [3-4], for example, occupy the interior space of the capsule hemispherical end. The antenna proposed in [5] also occupies a significant portion of the capsule body. These large antennas decrease the space available inside the capsule and make it difficult to embed other essential subsystems.

In some designs, like those reported in [6-7], the antenna radiation pattern is not omnidirectional, and circular polarization is not available at all angles. This can deteriorate radio link conditions during capsule journeys through the human body.

Addressing the above concerns, we propose a transparent CP antenna operating in the Medical Implant Communication System (MICS) frequency band (i.e., 401–406 MHz). The proposed antenna can be implemented in the interior surface of the optical dome, the hemispherical end that the camera is located in. Due to the use of transparent conductors, the antenna will not obstruct the camera view, and the image quality will not deteriorate. Additionally, placing the antenna in front of the camera creates extra space inside the capsule that can be used to add more modules.

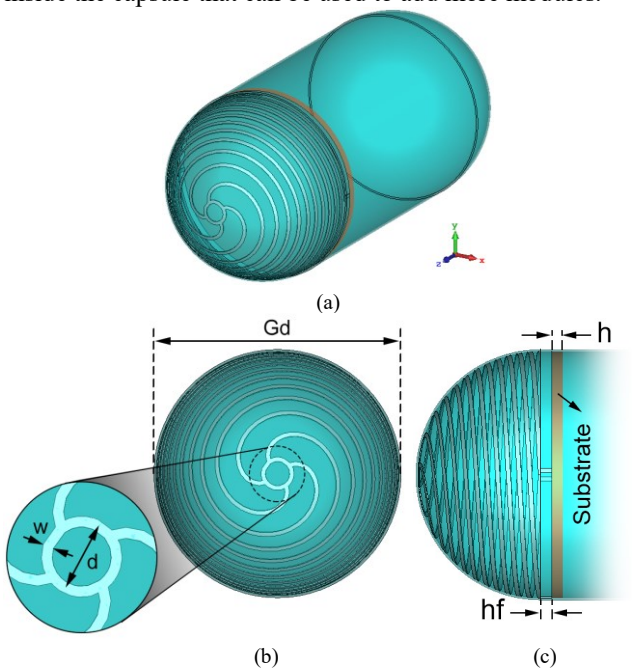


Fig. 1. Geometry of the proposed antenna: (a) 3D view, (b) front view, and (c) side view.

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I. ANTENNA GEOMETRY

The geometry of the proposed antenna embedded in a capsule shell is illustrated in Fig. 1. The dimensions and thickness of the capsule shell are 26×11 and 0.1 mm, respectively. It assumes that the capsule is made of Polyethylene (ε_r=2.25).

The antenna consists of four conductive spiral strips winding along the inner surface of the spherical end of the capsule. The base of each spherical spiral arm is connected to the ground plane by a straight strip located on the cylindrical surface of the capsule. One of these straight strips is considered as the feed point. At the pole of the hemisphere, the helical arms are connected by a circular strip. The width of all stripes is the same. The ground plane is on a 0.5 mm thick substrate (ε_r=10) and covers the cross-section of the capsule. While the ground plane is PEC, the strips are assumed to be made of AgHT-4, with 70% optical transparency which has an electrical conductivity of 2.2e5 S/m.

The optimized values of geometrical parameters specified in Fig. 1 are summarized in Table I.

II. ANTENNA PERFORMANCE

To investigate the performance of the proposed antenna in the human body, we assume that the capsule is surrounded by a homogenous material with ε_r=57.1 (the permittivity of the muscle tissue at 403 MHz [8]).

Figure 2 shows the reflection coefficient of the proposed antenna while it is excited with a 150Ω feeder. The antenna resonance frequency occurs at about 403 GHz. The impedance bandwidth (S_{11}≤-10dB) of the proposed antenna is 397-409 MHz, which covers the MICS spectrum (gray region) effectively.

TABLE I. GEOMETRICAL PARAMETERS OF PROPOSED ANTENNA

Parameter	Value (mm)	Parameter	Value (mm)
Gd	11	h	0.5
w	0.2	hf	0.5
d	1.3	-	-

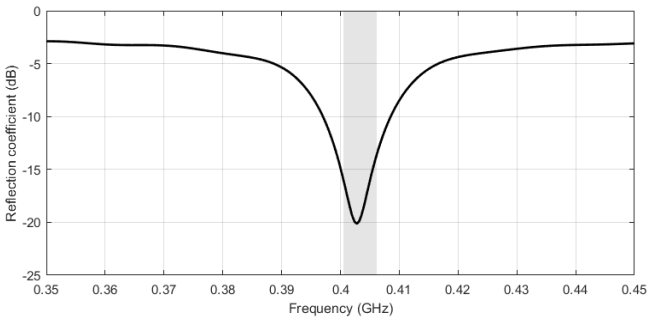


Fig. 2. Simulated reflection coefficient of the proposed antenna.

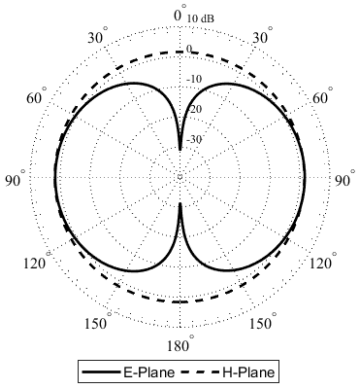


Fig. 3. Simulated radiation patterns of the proposed antenna in E- and H-plane at 403 MHz.

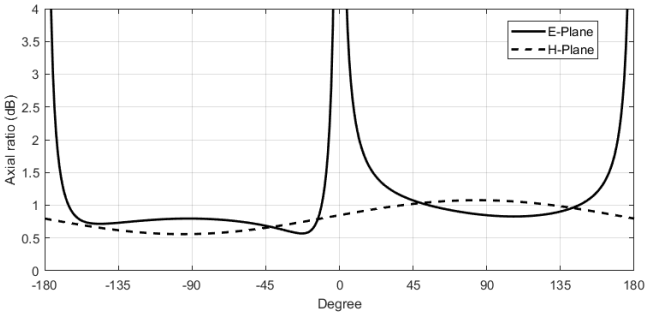


Fig. 4. Simulated axial ratio of the proposed antenna in E- and H-plane at 403 MHz.

Radiation patterns of the proposed antenna at 403 MHz are depicted in Fig. 3. As can be seen, the antenna has an omnidirectional radiation pattern with a 1.75 dBi gain. The nulls are along the symmetry axis of the capsule. The axial-ratio (AR) of the antenna at the same frequency is shown in Fig 4. Except for angles close to the radiation nulls, the AR is lesser than 3 dB. The axial ratio in most angles is less than 1.2 dB.

The simulated radiation efficiency of the antenna is about 17% (-7.65 dB). It should be reminded that transparent conductors offer a tradeoff between optical transparency and electrical conductivity. In other words, the use of transparent conductors reduces the radiation efficiency of antennas, especially in lower frequencies. As the frequency decreases, the skin depth of the transparent conductor increases, and consequently more losses are imposed on the antenna. In this regard, exploring new transparent conductors with better electrical and optical characteristics in the MICS band is an essential task to develop more efficient transparent capsule antennas.

III. CONCLUSION

A transparent spherical spiral antenna is proposed in this article for endoscopy capsule systems. The antenna is designed to operate in the MICS frequency band. The omnidirectional CP radiation pattern of the antenna can provide a stable wireless communication link during the

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capsule journey in the gastrointestinal tract. The transparency of the antenna also makes it possible to implement it in front of the capsule camera. This leads to more space inside the capsule to integrate other subsystems. However, all these features come at the cost of radiation efficiency. To improve efficiency, new transparent conductors with better optical and electrical properties in the MICS spectrum should be developed.

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