The Effects of an Ingested Source's Movement in a Human Body Model on the Electromagnetic Propagation

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Abstract

FDTD simulations on electromagnetic field radiated from an intestine-ingested source in a human body model are performed. For vertically different point of the ingested source, the specific frequency corresponding to signal drop at some receiving points is analysed here.

Keywords : Electromagnetic propagation FDTD Human body Movement of ingested source

1. Introduction

As one of ingestible wireless biomedical devices, a capsule endoscope [1] moves through the gastro-intestinal (GI) tract of the human body and transfers captured images using wireless communication method. Thus propagation characteristics of electromagnetic fields radiated from the capsule endoscope through the complex human body have been widely studied. The dominant propagation paths from an intestine-ingested source in the human body model and the corresponding phenomenon were numerically investigated [2]. Moreover, the effect of the ingested source's movement was analyzed as the source was moved along the forward and backward directions on the same horizontal plane in the human body model [3].

However, the effects of an ingested source's movement along the vertical direction of the human body model on the propagation of electromagnetic fields and corresponding phenomenon are not considered yet. Thus those effects are analyzed in this paper. The location of the intestine-ingested source employed in [3] is vertically shifted to another horizontal plane of the human body model and the vertically polarized current density is excited. Then the radiated electric fields which have the same polarization with the source are saved at 26 receiving points placed on the abdomen of the human body model. Finally, the dominant propagation path as well as the corresponding phenomenon is analyzed.

2. Numerical Computation

The electromagnetic fields radiated from an ingested source in the small intestine of the human body model are numerically computed using the simulator developed in our laboratory. The simulator is consisted of the finite-difference time-domain (FDTD) method [4], the human body model [5], and the frequency dependent dielectric properties of 32 internal organs [6]. The vertically polarized current density (J_z) with the maximum operation frequency of 800 MHz is employed as a substitute for a capsule endoscope [1]. The waveform of J_z is given by the differential Gaussian pulse as

$$J_z(t) = 2\left(\frac{t-t_d}{t_w}\right)\exp\left(-\left(\frac{t-t_d}{t_w}\right)^2\right), \qquad (1)$$

where the initial delay (t_d) is 6.25 ns and the pulse width (t_w) is 1.25 ns. Thus the spatial resolution ($\Delta = \Delta x = \Delta y = \Delta z$) is uniformly taken by 4 mm after considering the maximum frequency of the current density and the dielectric properties of the internal organs. Then an air layer with 20Δ is placed between the human body model and the perfect matched layer (PML) [7], which is implemented by 4 layers. Finally, a time step (Δt), 0.6982 ns, is taken by considering the stability condition of the FDTD method.

To analyze the effect of the ingested source's movement in vertical direction along the GI tract in the human body model, the location of the ingested source (S) employed in [3] is vertically moved up 8 mm, as illustrated in Fig. 1. Thus the source is excited at S'. Among the radiated electric fields, the *z*-components of the electric fields are saved at the 26 receiving points (M1'-M26') vertically placed along the abdomen of the human body model with the uniform distance step of 8 mm. The calculated electric fields at the 26 receiving points are transferred to the frequency domain and normalized by the amplitude received at the point M1' and at the frequency 100 MHz simultaneously.

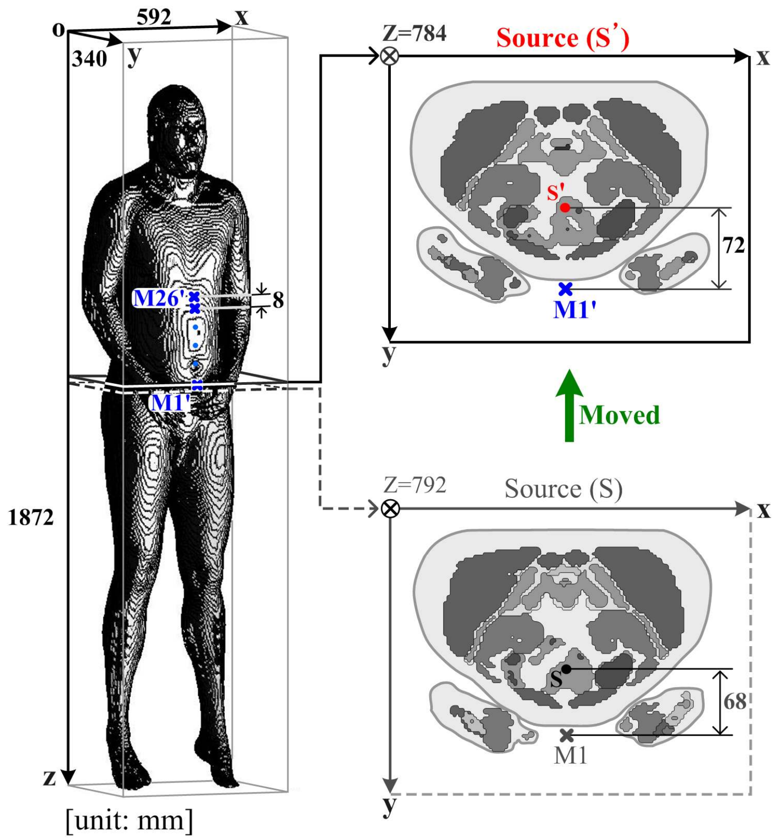

Figure 1: Human body model with the vertically moved ingested-source (S') from the reference (S) and the 26 receiving points (M1'-M26') placed on the abdomen of the model.

3. Analysis of the Calculated Results

The normalized amplitudes of the electric fields at M1', M6', M11', M16', M21', and M26' are plotted in Fig. 2 in the frequency range of 100 to 700 MHz as some representatives. In Fig. 2, the normalized results received at M1', M6', and M11' attenuate monotonically according to the increments of frequency. But significant signal drops are observed at M16', M21', and M26'. Moreover, the frequency of each unusual dip is gradually decreases as the receiving point moves away from the source point.

Those unusual dip patterns are generated due to the interaction of the direct and surface waves [2] which propagate through the line-of-sight path and along the surface of the human body model, respectively. These results imply that electromagnetic fields propagate through above two dominant paths even though the ingested source is moved to another horizontal plane (*x*-*y* plane). Additionally, the relationship between the location of each receiving point and the frequency of each unusual dip is illustrated in Fig. 3. In Fig. 3, the location of each receiving point is represented as the incident angle (θ_{inc}), which denotes the altitude angle of the line-of-sight between the source and receiving points [3]. Fig. 3 illustrates an approximately linear relation between the dip frequency and the incident angle.

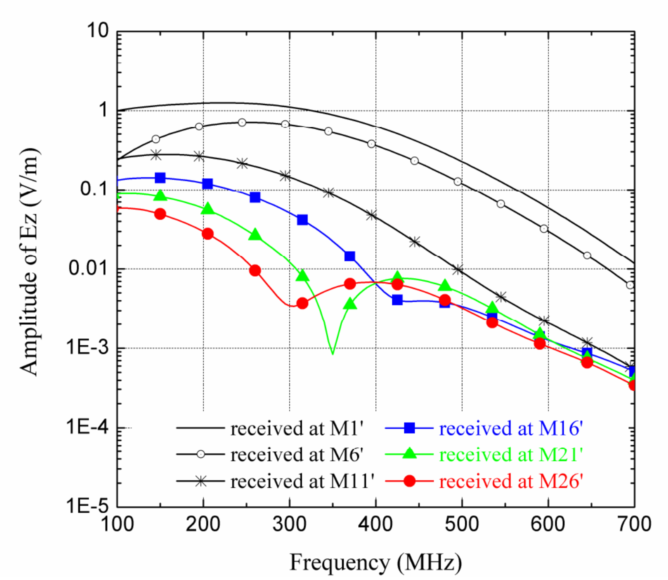

Figure 2: Normalized amplitude variations of the z-components of electric fields received at 6 selected receiving points.

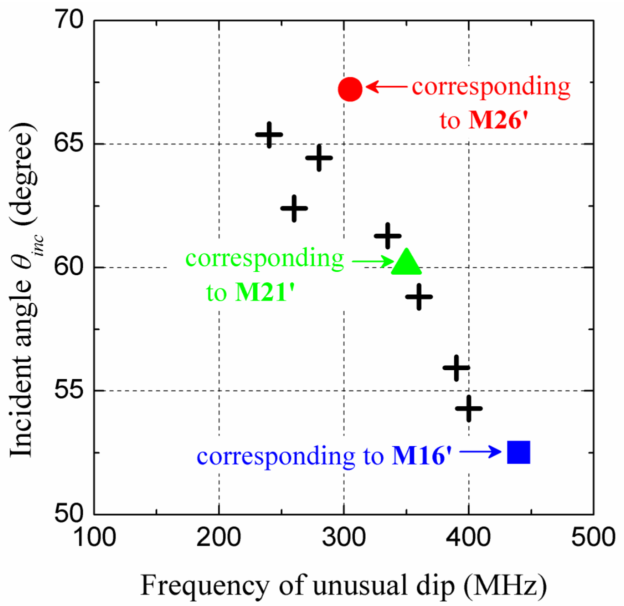

Figure 3: The relation between the frequency of unusual dip and the incident angle corresponding to each receiving point.

The similar linear relation in Fig. 3 was also obtained when the source was located at the reference point (S) [3]. Thus the frequencies of the unusual dips at same selected incident angles are compared and listed in Table 1.The compared results represent that the frequency of each unusual dip is slightly changed when the source is excited at another horizontal plane. However, those differences in the frequency of the unusual dip can be explained by the influence of the inhomogeneity of the human body model. The amplitude and phase of the direct wave which affects the frequency of the unusual dip are varied depending on the dielectric properties of the propagation path. The results mean that the overall propagation characteristics are not influenced by the movement of the ingested source in vertical direction of the human body model. However, specific phenomenon such as the frequency of the unusual dip can be slightly changed according to the location of source due to the complex and inhomogeneous organizations of the human body model.

Table 1: Frequencies of the unusual dips at some selected incident angles when the source is excited at S' or S.

Analyzed results (Location of ingested source: **S'**)		**Reference results [3]** (Location of ingested source: **S**)	
Incident angle	Frequency of unusual dip	Incident angle	Frequency of unusual dip
55.923°	390 MHz	55.923°	385 MHz
60.100°	350 MHz	60.100°	335 MHz
65.376°	240 MHz	65.376°	260 MHz

4. Conclusions

The radiated z-components of electric fields from the shifted ingested source were computed and saved at 26 vertically placed receiving points along the surface of the human body model. The calculated results showed unusual dip patterns even though the location of the ingested source was altered to another horizontal plane. Approximately linear relation was also observed between the frequency of the unusual dip and the incident angle corresponding to each receiving point. Only the frequency of the observed unusual dip was slightly changed. These results lead us to conclude that the movement of the ingested source in the vertical direction of the human body may be not severely affected on the overall propagation characteristics.

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