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60° of arc with a radius of 5λ and a height 10λ with $\lambda = 1$ m. A vertical dipole is placed at a distance of 10λ from the centre of the cylinder. Fig. 1 shows the interpolated values for the amplitude and the phase of the current on the cylinder. The difference between these values and the exact ones are shown in Fig. 2. As shown in Fig. 2 the interpolation error is negligible. The maximum relative errors in this case are 2.0×10^{-4} for the amplitude and 4.0×10^{-5} for the phase.

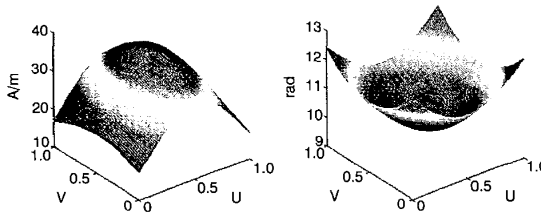

Fig. 1 *Interpolated amplitude and phase of current induced by dipole on a section of cylinder with 60° of arc*
a Amplitude
b Phase

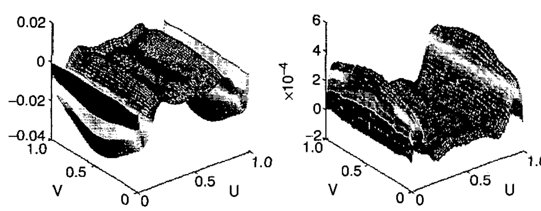

Fig. 2 *Error of interpolated amplitude and phase functions for current induced by dipole on a section of cylinder with 60° of arc*
a Amplitude functions
b Phase functions

Conclusions: A new method to represent the induced current in an accurate and efficient way has been presented. The method is based on the interpolation of the amplitude and phase by means of Bézier surfaces. An example has been shown to prove the potential of the method to represent the current with a negligible error using a low amount of sample points. This method can be used to analyse large problems by rigorous methods, or to obtain higher-order reflections in an iterative way by using asymptotic techniques.

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Radiation from ingested wireless devices in biomedical telemetry bands

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The performance of wireless devices, using electrically small antennae, in the human intestine is investigated using the finite difference time domain method in recommended biomedical device telemetry bands. The radiation field intensity was found to depend on position but more strongly on frequency, with a transmission peak at 650 MHz.

Introduction: There is an increasing number of applications for wireless devices designed for use close to or inside the human body. The design of such devices poses many problems, not least of which is the effect of the environment on radio signals. In this Letter we consider the effect of the human body on the propagation of radio signals from a wireless ingested diagnostic device in the gastro-intestinal tract (GIT), in the 150 MHz to 1.2 GHz range, encompassing several international medical telemetry bands (pan-European allocation [1] and the US Federal Communications Commission allocations — regulations S5.150, US209 and US350).

Human body model: The visible human male project yielded a complete electrical model for an average American male [2]. In the model 23 different tissue types are described. Each model cell is a 5 mm edged cube with different properties according to the tissue type. Similar accurate models have been used extensively to aid evaluation of the physiological effect of radio signals on the human body [3].

Analysis: For analysis the finite difference time domain method was used. A monofilar helix antenna with a diameter of 8 mm and four turns on a 1 mm pitch was used since it is easy to implement in a cylindrical capsule. Owing to the small size of the helix antenna with respect to the human body model's mesh we have implemented a model using a similar technique to that used in [4]. In this way, after validation of the model against a conventional detailed helix antenna model on a 0.5 mm mesh, the helix can be reliably modelled on a 5 mm mesh. A 10 × 10 mm generic patch antenna with a separation of 5 mm and dielectric constant of 2 was also used in the simulations. The patch antenna had a radiation pattern similar to that of the helical antenna and yielded similar results.

Many simulations were carried out for a capsule in five distinct locations in the GIT. The locations were: near the skin; top of the small intestine, behind the stomach; right extremity of the small intestine next to the colon; a central location; and the bottom of the small intestine. For each location we have modelled the radiation pattern for three Cartesian orientations, x, y and z, where the x-axis runs from the left to the right side of the body, the y-axis runs from the posterior to the anterior of the body, and the z-axis runs vertically from head to foot. In Fig. 1 we present patterns for three different antenna positions with the antenna aligned to the z-axis (vertically) in all cases.

Results: From the simulation results shown in Fig. 1 it is clear that the exact location of the capsule has a strong effect on the radiated field. The results shown in Figs. 1 and 2 are normalised using the overall maximum input power, which was for the source in Fig. 1*c*. As a consequence the field strength at the skin, where a receiving antenna can be positioned, will vary considerably. The simulation results show that the radiated field is predominantly strongest in the same horizontal transverse plane as the source and in the direction that is on the line from the source to the nearest body surface. This indicates that if a single receiving antenna were to be used as opposed to any array, an anterior location slightly to the left of centre of the abdomen would be optimal. The position is slightly to the left, as the small intestine does not extend so much to the right due to the presence of the colon.

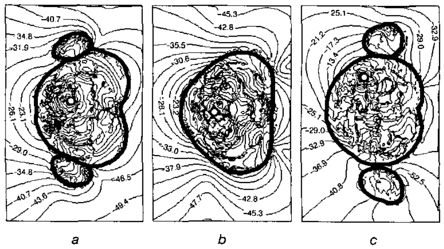

Fig. 1 *Normalised near fields in dB at different locations for a vertically oriented source (circle denotes source position)*

a Central location — most distant from any part of the colon than other positions
b Lower extremity of small intestine
c Near skin to left

The radiation characteristics have also been explored against frequency. The strength of the radiated field is modified by a number of competing effects including an increase in antenna efficiency with frequency and increasing absorption of the radiation with frequency. Figs. 2 and 3 show a typical spectrum for the radiated field strength. In general there is a peak in the transmitted power at approximately 650 MHz. As a consequence the antennae we have studied would be best suited for telemetry bands lying between 600 MHz and 1 GHz, corresponding well with US telemetry bands.

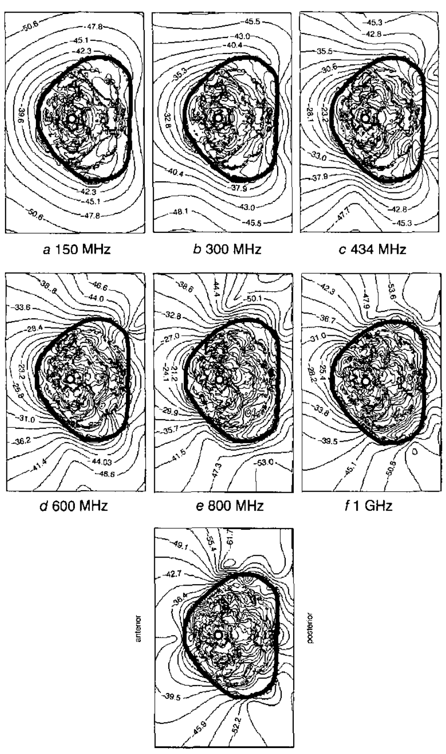

Fig. 2 *Normalised near fields in dB for vertically orientated ingested source at lower extremity of small intestine (circle denotes source position)*

Conclusion: We have studied the radiation emitted from two representative antennae built into an ingested medical device in detail. The peak in the radiated electric field intensity external to the body occurs at approximately 650 MHz. Simulations indicate that the optimum placement for a single receiving antenna is in front of the abdomen and slightly to the left.

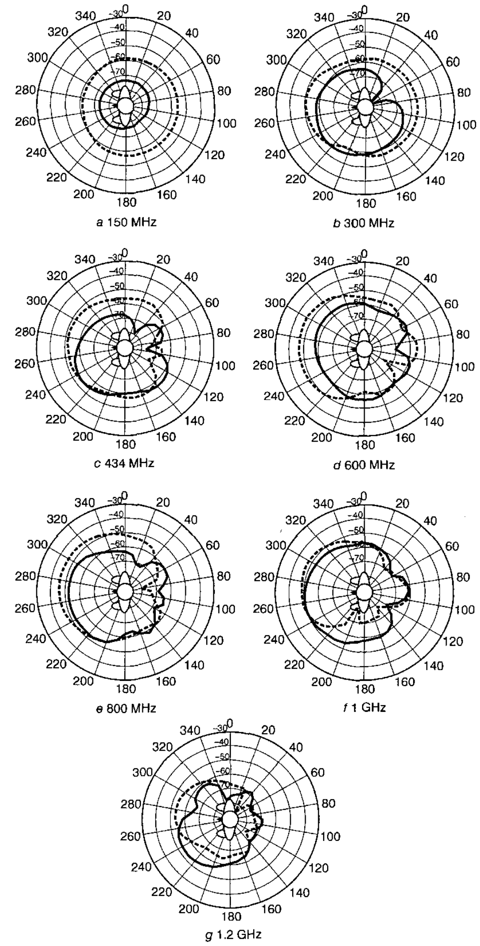

Fig. 3 *Azimuthal far fields in dB for vertically orientated ingested source at lower extremity of small intestine*

- - - - vertically polarised pattern
——— horizontally polarised pattern

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