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Validation of Radio Frequency Telemetry Concept in the Presence of Biological Tissue-Like Stratified Media

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Summary

In this paper we discuss a novel radio frequency (RF) telemetry concept for biomedical applications. The concept consists of a miniaturized spiral inductor/antenna for bio-MEMS sensors and an external pick-up antenna integrated into a hand-held device. The measured relative signal strength in the presence of biological phantoms ranged from –5.9 to –7.5 dB for antenna separations of 5 and 10 cm. These relative signal strengths are easily measurable, therefore validating the RF telemetry concept for biomedical applications

I. Introduction

The National Aeronautics and Space Administration (NASA) through its Office of Biological and Physical Research (BPR) and Human Exploration and Development of Space (HEDS) Enterprises is investigating novel technologies for monitoring the health of astronauts inhabiting current and future space platforms such as the Space Transportation System (i.e., space shuttle), the International Space Station (ISS) and other manned space platforms. In particular, NASA seeks to develop telemetry based implantable sensing systems to monitor physiological parameters of humans in any of the aforementioned scenarios [1].

In general, currently existing telemetry systems for biomedical diagnosis consist of battery powered implants and/or feed-through leads, which limits mobility, shorten device useful life and increases the risk of infections.

In this paper, we discuss a novel radio frequency (RF) telemetry concept for the contact-less powering and data acquisition from implantable bio-MEMS sensors [2]. While others have demonstrated RF telemetry, their approach have relied on larger physical dimensions, as well as higher currents [3–6]. In contrast, we have maintained great coupling sensitivity for smaller antenna dimensions and lower power requirements. This feature will be demonstrated via experimental results based on signal coupling between the miniaturized inductor/antenna and the hand-held device as a function of distance and through stratified media, represented by muscle tissue-like and fatty tissue-like phantoms.

II. RF Telemetry Concept

Figure 1(a) shows a schematic of the miniaturized spiral inductor/antenna circuit for powering and telemetry and intended for integration with a bio-MEMS pressure sensor. The strip and gap widths

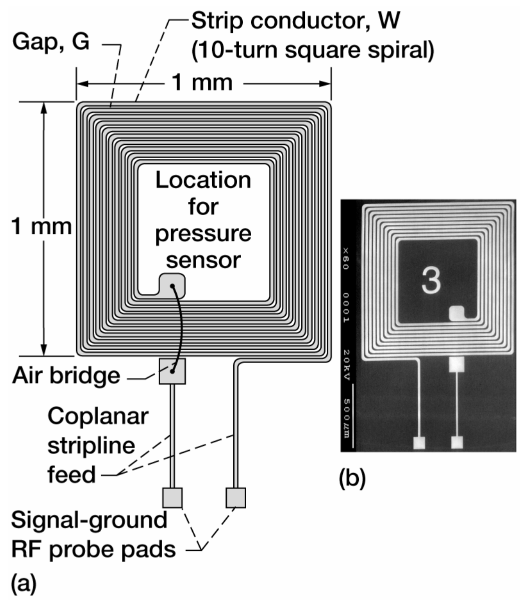

Figure 1.—(a) Schematic of miniaturized spiral inductor on high resistivity silicon. (b) Actual photomicrograph of inductor antenna.

are indicated by W and G, respectively. The outer dimensions of the inductors are approximately 1 by 1 mm. The inductor is fabricated using a high resistivity silicon wafer ($\rho \geq 2{,}500$ Ω-cm) to reduce the attenuation of the signals. The above dimensions and substrate material are very convenient for an implantable sensor. In a previous work, we have demonstrated that for the case of a pressure sensor, miniaturized spiral inductors with inductance (L) of 150 nH and quality factor (Q) about 10, are more than adequate for biomedical applications [7]. As currently designed, this prototype can operate within the 200 to 700 MHz frequency range. Characterization of the inductor was performed using signal-ground RF probes via short length coplanar striplines (CPS). Figure 1(b) shows a scanning electron microscope (SEM) micrograph of a typical inductor/antenna circuit. Several inductors with strip and gaps dimensions in the range of 10 to 15 μm were fabricated in order to optimize the circuit. For all the circuits, chrome/gold metallization of 20 nm and 1.5 to 2.25 μm, respectively, was chosen to minimize resistive losses.

The pick-up antenna in the hand held device is a printed multi-turn loop antenna [8], whose input impedance at about 330 MHz is matched to input impedance (50 Ω) of an MMIC LNA chip in the receiver to increase sensitivity. The antenna is fabricated on 0.79 mm thick RT5880 Duroid (ε_r=2.22) using standard printed circuit fabrication techniques. A circuit diagram for this antenna is shown in Figure 2(a). A schematic illustrating the overall implementation of the RF telemetry concept under discussion is shown in Figure 2(b).

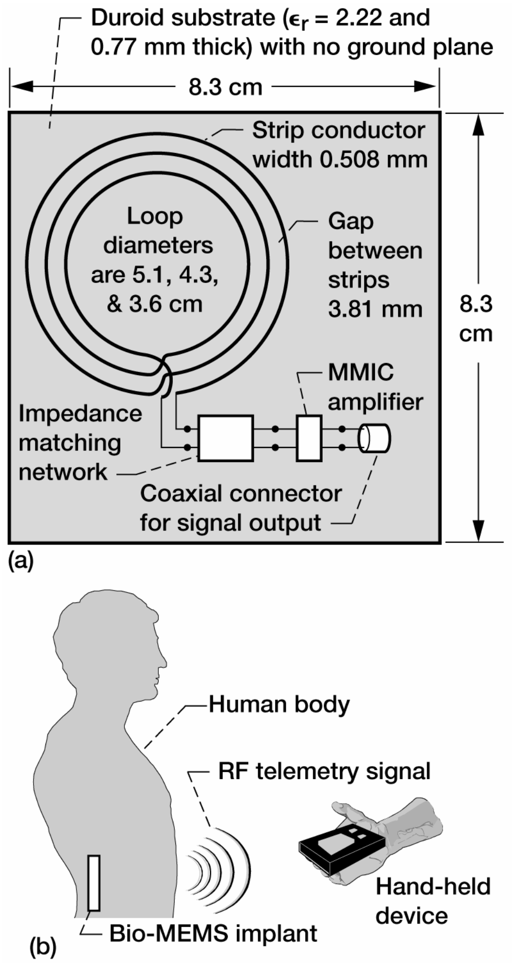

Figure 2.—(a) Schematic of pick-up multi-turn loop active antenna for hand-held unit. (b) Contact-less powering and telemetry concept.

III. Experimental Results and Discussions

A. Performance of Telemetry Concept in Free Space

Experimental validation of the telemetry concept was performed using an HP 8510 C Automatic Network Analyzer (ANA) in the configuration shown in Figure 3(a). In this arrangement, the pick-up antenna assembly is held at a fixed height and coaxial with the miniaturized transmitting inductor/antenna. The latter is configured to resonate at about 330 MHz. When coupled to a signal source and the frequency is swept, the inductor radiates energy. The received power as measured at the coaxial connector port of the receive antenna for heights of 5 and 10 cm are shown in Figures 3(b) and 3(c), respectively. Note that maximum coupling occurs at 330 MHz and that the intensity drops as the separation increases. Nonetheless, even at 10 cm of separation the signal strength of the received signal is still well defined.

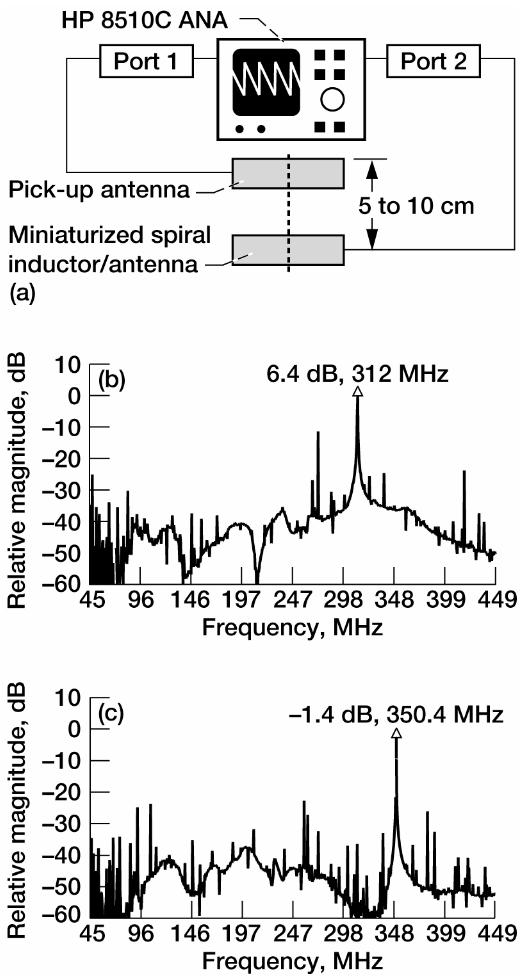

Figure 3.—(a) Schematic of experimental set-up. (b) Measured received relative signal strength versus frequency for pick-up antenna at a height of 5 cm and (c) 10 cm.

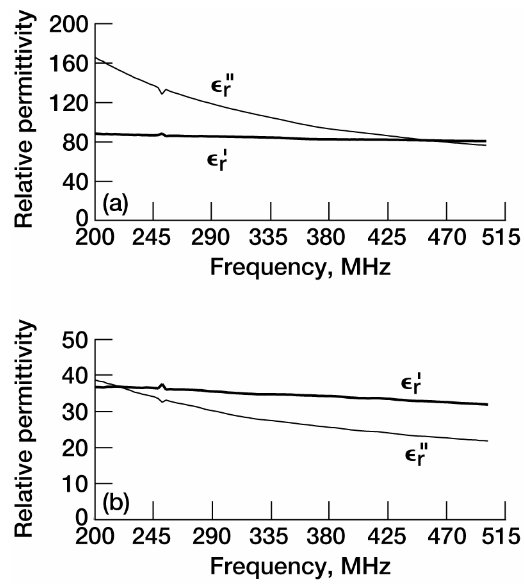

Figure 4.—Relative dielectric permittivity of phantoms. (a) Muscle tissue-like. (b) Fatty tissue-like.

B. Performance of Telemetry Concept in the Presence of biological Tissue-like Stratified media

To simulate a typical operating condition for medical diagnostic applications, the aforementioned tests were performed using muscle tissue-like and fatty tissue-like phantoms. These phantoms were obtained from Computerized Imaging Reference Systems, Inc., Norfolk, VA [9]. Basically, the muscle tissue-like phantom is a water-based polymer gel, while the fatty tissue-like phantom is made of 50% oil-50% water emulsion fixed in water-based polymer gel. These phantoms have an area of nearly 16 by 8 cm, and are approximately 3.8 cm thick. These dimensions were chosen arbitrarily due to sample availability. The dielectric properties of these phantoms were measured using an Agilent 85070D Dielectric Probe Kit (frequency range 200 MHz to 20 GHz) in conjunction with an HP 8510C Network Analyzer. Figures 4(a) and 4(b) show the real (ε_r') and imaginary (ε_r'') parts of the relative permittivity of the two phantoms, respectively.

Figures 5(a) and 5(b) show the coupling results in the presence of the muscle tissue-like phantom. Note that at a separation distance of 5 cm, the magnitude of the relative signal strength only dropped by 2.5 dB as compared to that in free space. Likewise, the relative signal strength at 10 cm dropped by only 4.2 dB with respect its free space counterpart.

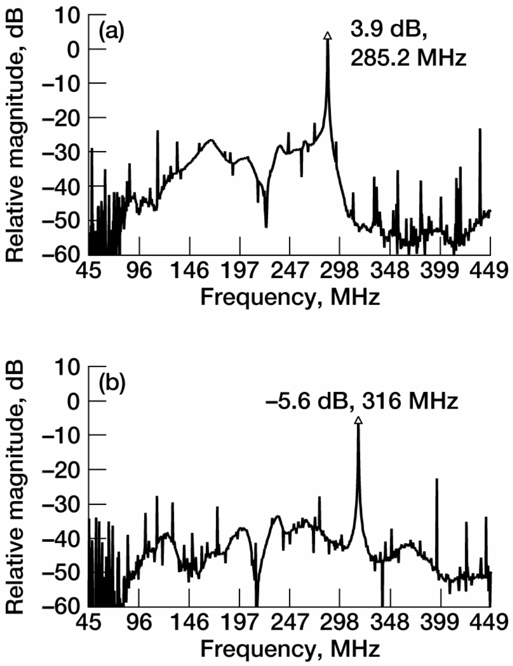

Figure 5.—Measured received relative signal strength versus frequency in the presence of a muscle tissue-like phantom. (a) Pick-up antenna at a height of 5 cm and (b) 10 cm.

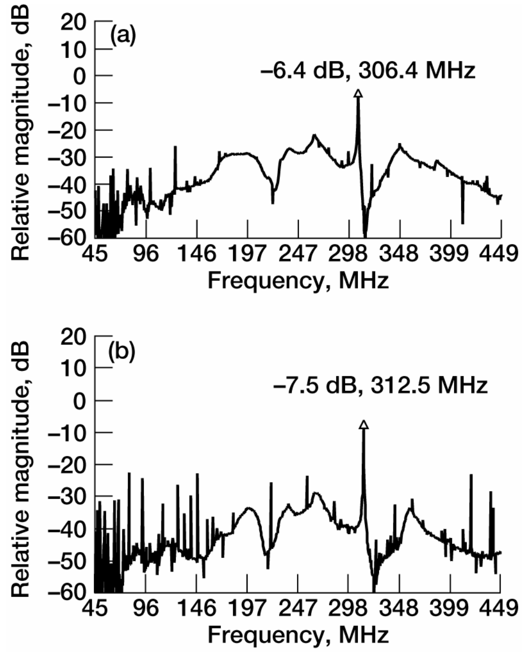

Figure 6.—Measured received relative signal strength versus frequency in the presence of a muscle tissue-like phantom with packaged pick-up antenna. (a) Pick-up antenna at a height of 5 cm and (b) 10 cm.

In order to evaluate the telemetry concept with a packaged receiving antenna typical of a hand-held device, tests were performed with the pick-up antenna enclosed in a semi-rigid foam packaging material approximately 0.64 cm thick. Figures 6(a) and 6(b) show the relative signal strength results obtained using this configuration with muscle tissue-like phantom placed between the two antennas. Observe that the relative signal strength is in the –6.4 to –7.5 dB range for the two separations. The concept was also tested with a fatty tissue-like phantom and as shown in Figure 7, the relative signal strength of –5.9 dB. Results of all coupling tests are summarized in table I. These results show that the telemetry concept discussed in this work provides excellent sensitivity for biomedical applications.

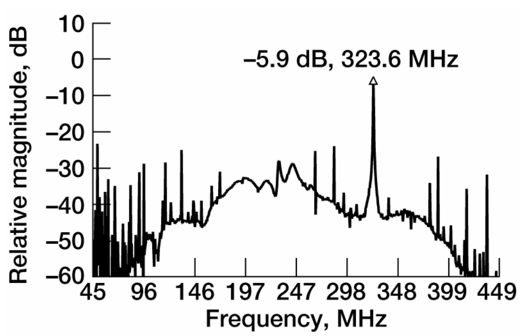

Figure 7.—Measured received relative signal strength versus frequency in the presence of a fatty tissue-like phantom with packaged pick-up antenna at a height of 5 cm.

TABLE I: SUMMARY OF EXPERIMENTAL RESULTS

Experimental configuration of miniaturized spiral inductor/antenna and pick-up antenna	Separation, cm	Relative signal strength, dB	Frequency, MHz
Separated by air gap only	5	6.4	312.0
Separated by air gap only	10	–1.4	50.4
With muscle tissue-like phantom	5	3.9	285.2
With muscle tissue-like phantom	10	–5.6	316.0
With packaging and muscle tissue phantom	5	–6.4	306.4
With packaging and muscle tissue-like phantom	10	–7.5	312.5
With packaging and fatty tissue-like phantom	5	–5.9	323.6

IV. Conclusions

A novel RF telemetry concept for biomedical applications has been presented. The sensitivity of the concept has been demonstrated by successful coupling of electromagnetic signal through biological phantoms at relevant coupling distances and frequencies near 300 MHz. The measured relative signal strength in the presence of the phantom materials ranged from –5.9 to –7.5 dB for antenna separations of 5 and 10 cm. These relative signal strengths are easily measurable thereby validating the RF telemetry concept.

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