Experimental phantoms for the assessment of medical implant leads induced SAR under a linear-phase incident field condition

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Abstract

The induced SAR at the lead tip of medical implant leads can exceed the value reached under resonance conditions if the phase of the incident electric field tangential to the lead is varied even if the field amplitude remains constant. An approximately linear-phase (i.e. constant phase gradient) incident field condition is found to maximize the energy deposition at the tip. Here, we develop experimental phantoms for the assessment of induced SAR on medical implant leads under a constant-amplitude and linear-phase incident field condition. Two different phantoms are developed to accommodate lead testing for a wide range of constant phase gradients. The incident fields along the lead paths in the phantoms are numerically validated prior to construction of the phantoms.

1. Introduction

The induced SAR at the tip of an insulated wire depends on many parameters including: the lead physical dimensions, the topology of the lead, the permittivity and thickness of the insulation, the dielectric properties of the immersion medium (or surrounding tissue), and the phase gradients of the incident field. The effect of the phase gradient of the incident field has been described by the authors of [1] where a moment method implementation is used to calculate the current on a thin insulated wire [2]. It shows that the current maximum moves toward the end of the wire if the phase of the incident field changes. This results in a steeper gradient of the currents at the tip and therefore to an increased displacement current giving rise to a higher SAR. The authors of [1] identify an approximately linear phase change in the incident field, with the gradient equal to the real part of the wavenumber in the surrounding medium, as condition to maximize the energy deposition at the tip for straight bare wires. Figure 1 replicates the results of [1].

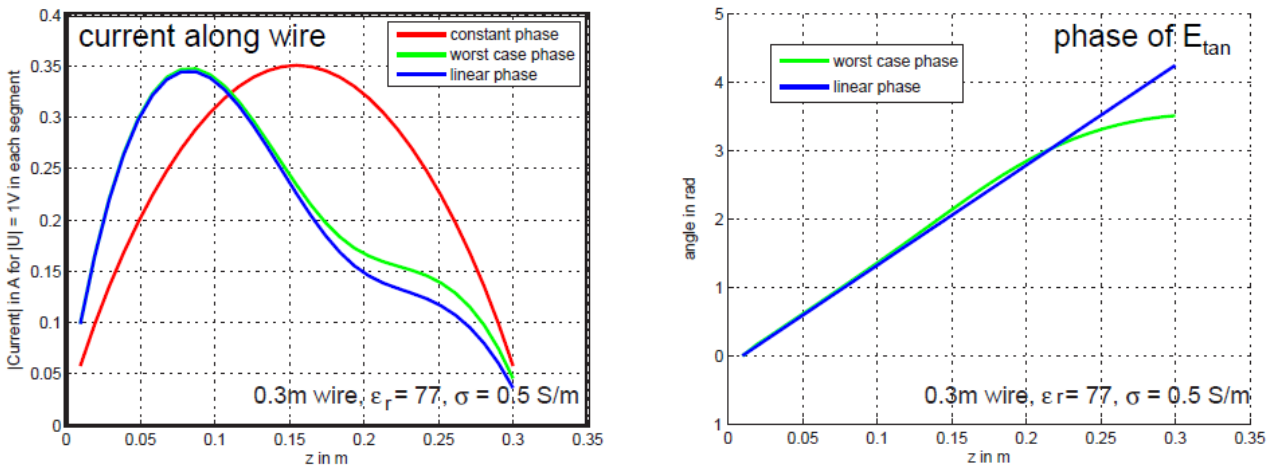

Figure 1. Asymmetric current distribution along a lead (left) exposed to an incident electric field with constant amplitude and linear phase gradient (right).

The worst-case phase gradient of which the maximum SAR is observed also depends on other aforementioned factor. Figure 2 shows the maximum SAR increase for a straight insulated lead as a function of lead length and the phase gradient. The increase in SAR is normalized to the values at resonance length and zero phase gradient. The lead with a conductor radius of 1.2mm, insulation thickness of 0.4mm, and insulation permittivity of 4 embedded in homogeneous muscle tissue, and fat tissue simulants are illustrated. For the case of the lead in homogeneous muscle

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tissue simulant, with increasing phase gradient, the SAR peak at resonance frequency disappears. A higher worst-case phase gradient, in comparison to fat tissue simulant, is observed.

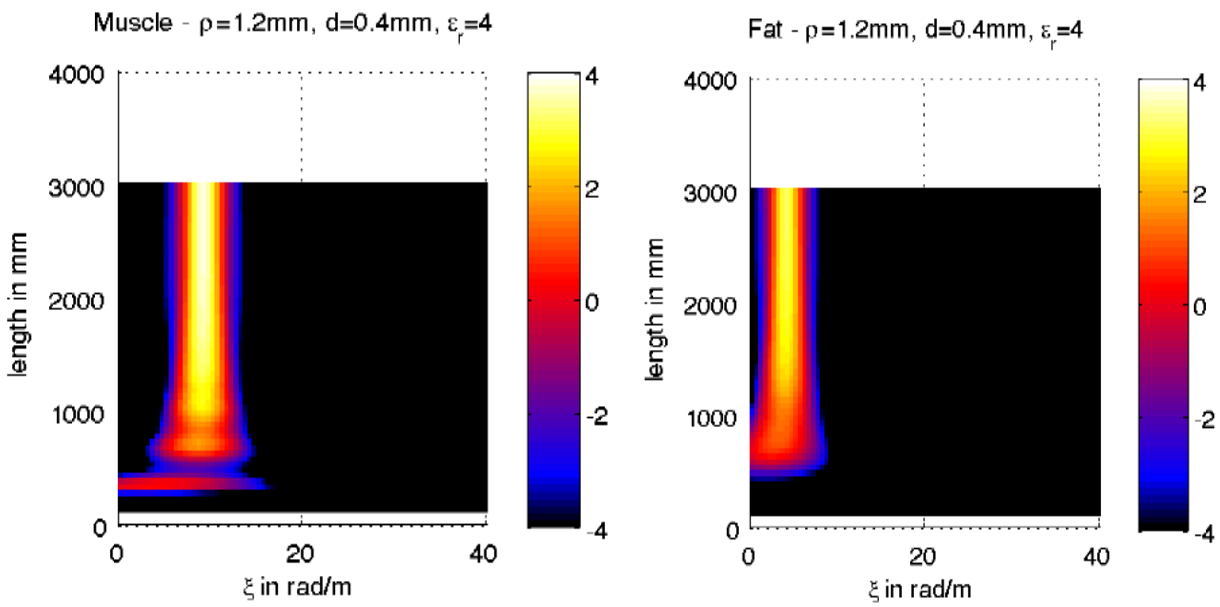


Figure 2. Worst-case SAR increase for straight insulated wires in homogeneous muscle tissue (left) and fat tissue (right) simulants.

The worst-case phase gradient also depends on the lead topology. Figure 3 illustrates the local SAR distribution, 0.2 mm above the lead tip, along a 200-mm length helical insulated wire exposed to different phase gradient in comparison to the FDA-lead of the same length (straight). Although leads with a high inductance generally have a significantly lower SAR at the tips in comparison to straight leads, an increase of the SAR due to the phase gradient of the incident field can already be observed at a short length. The SAR at the tip of a helical wire is approaching the SAR of the FDA wire.

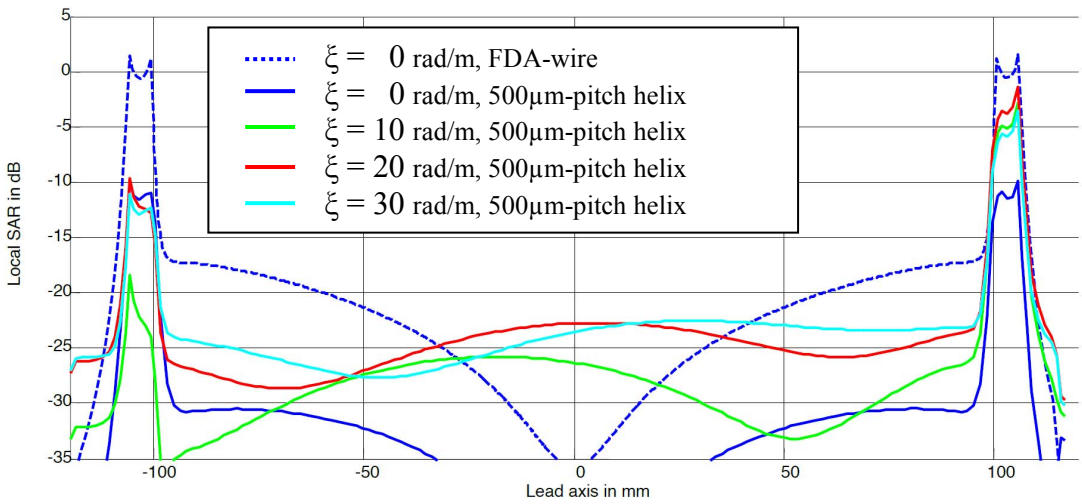
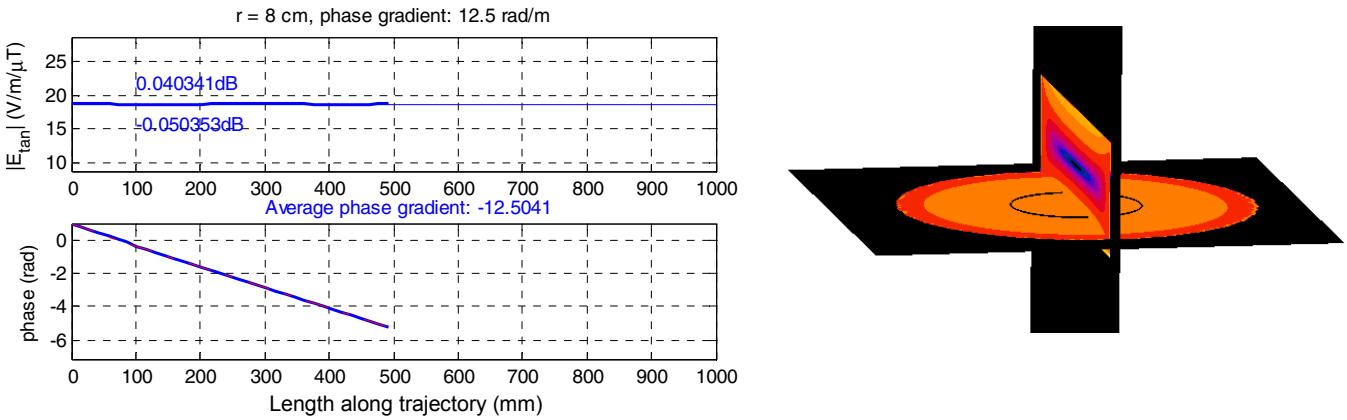


Figure 3. SAR distribution (0.2mm above the lead) along the lead (500µm-pitch, 0.5 mm radius, 200 mm lenth, insulation: 0.7 mm radius, $\varepsilon_r = 3$) for different phase gradients in comparison to the FDA-wire (straight) at a constant phase.

To this end, we have designed two experimental phantoms to accommodate testing of leads under incident exposure with phase-gradient ranging from 5 rad/m to 35 rad/m. This may allow the worst-case phase factor [3] to be determined experimentally.The design of the phantoms are described in the proceeding section.

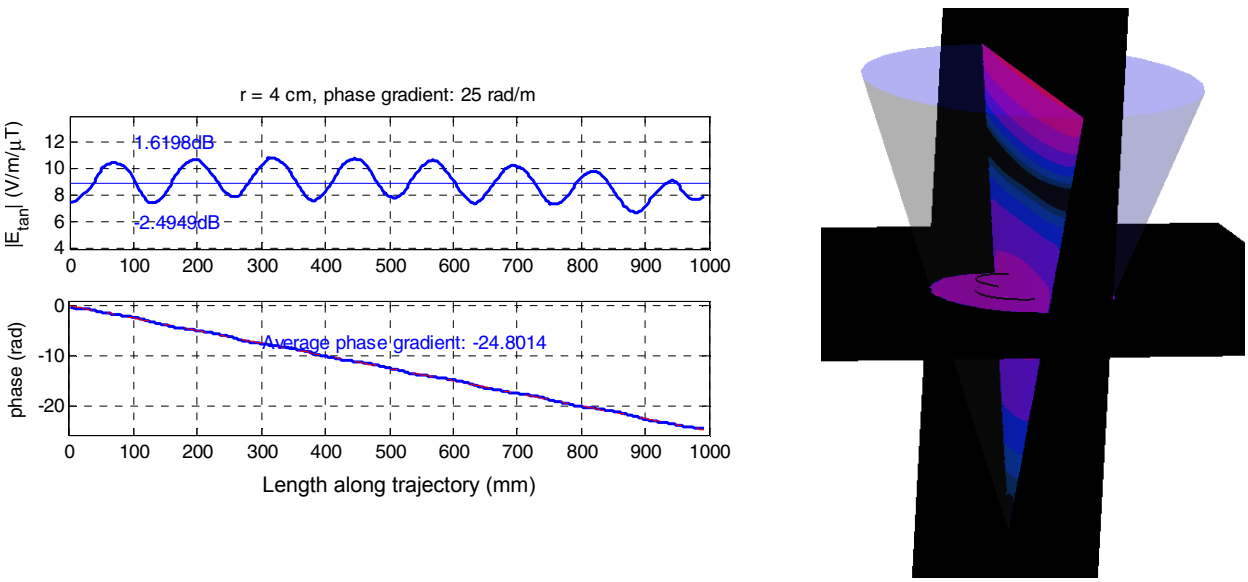
2. Design of the phase phantoms

Two phantoms are implemented for lead testing within MR environment with circularly polarized RF electric fields. A constant-amplitude and linear-phase incident fields can be achieved along any circular trajectory centered around the axis of the coil. The phase gradient is determined by the inverse of the radius of the trajectory. Therefore, the lowest achievable phase gradient is bound by the physical size and volume of the phantom that can be supported by the coil. A cylindrical phantom can accommodate the testing of reasonable lead lengths under incident phase gradients of 5 rad/m up to 12.5 rad/m. In order to support the testing of leads of reasonable lengths under higher incident phase gradients, a conical phantom is developed. The electric fields in the phantom are designed to have constant-amplitude and linear phase along helical trajectories centered around the axis of the coil. Figure 4 and 5. give example of the field distributions along a trajectory in each of the two phantoms. Figure 6 illustrates an experimental setup with the cylindrical phantom for 12.5 rad/m phase gradient exposure to a lead sample.



(a) (b)

Figure 4. Electric fields distribution in the cylindrical phantom. (a) Tangential electric fields along a circular trajectory with radius, r = 8cm. (b) RMS amplitude of the electric fields through the center (vertical) plane and through the plane of the circular trajectory in (a). The trajectory is visualized by the black solid line.



(a) (b)

Figure 5. Electric fields distribution in the conical phantom. (a) Tangential electric fields along a helical trajectory with radius, r = 4cm. (b) RMS amplitude of the radial component through the center vertical plane and through the plane partially containing the helical trajectory in (a). The trajectory is visualized by the black solid line.

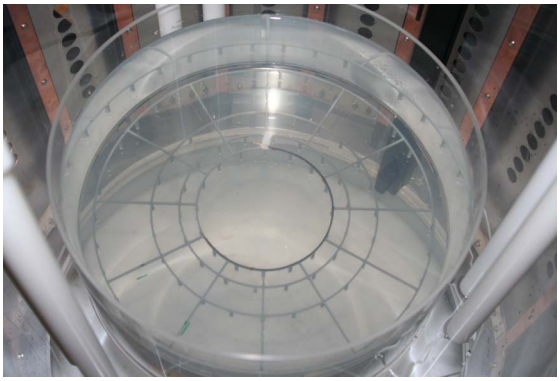


Figure 6. Experimental setup with the cylindrical phantom. Lead is position along a circular trajectory with r = 8 cm for exposure to phase gradient of 12.5 rad/m.

3. Conclusion

Past studies showed the dependence of induced SAR on medical device leads to the phase of the incidence field condition even if the amplitude of the fields remains constant. Here, we present two phantom designs that would accommodate the testing of medical device leads induced SAR under exposure with phase gradient ranges from 5 rad/m to 35 rad/m.

4. References

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