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Design and development of a miniaturized coaxial probe for intracavitary application of hyperthermia at 434 MHz

Shabeeb Ahamed K P [(1)], Thomas Samuel Ram [(2)] and Kavitha Arunachalam[(3)]
(1) Department of Biotechnology, Indian Institute of Technology, Madras
(2) Department of Radiation Oncology, Christian Medical College, Vellore
(3) Department of Engineering Design, Indian Institute of Technology, Madras

Abstract

Biological rationale of hyperthermia is well established and is being clinically practiced. However, endocavitary and interstitial hyperthermia treatments, in spite of the advantage of targeted heat delivery, are scarcely used especially at 434 MHz. In this paper, we investigate a folded monopole antenna for endocavitary hyperthermia applicator development. Based on the numerical simulations, a prototype applicator was fabricated by modifying 22 Fr Foley catheter. The return loss measurements of the fabricated applicator are in good agreement with the simulations.

Keywords: coaxial antenna, hyperthermia treatment, intracavitary, monopole.

1. Introduction

Hyperthermia treatment (HT) of cancer involves selective elevation of cancerous tissue temperature to 40-45 °C for 30-60 minutes. The clinical rationale of hyperthermia due its direct effects and when administered as an adjunctive therapy to radiotherapy (RT) or chemotherapy (CT) is well established [1]. Several randomized clinical trials have proven the potential of hyperthermia as an effective adjuvant therapy for cancer treatment [2]. Gynaecological cancers are the most prevalent cancers in Indian women and among them cervical cancer ranks second in terms of incidence and mortality rate [3], [4]. In spite of the marginal decrease in the incidence over the past few years, cervix cancer statistics in India still demand the need for effective treatment modalities for disease management.

HT of cervical cancer using an external deep heating antenna array has shown promising clinical results [5]. Unlike external heating devices, endocavitary and interstitial applicators have an added advantage as they can deliver heat at or near the tumour target with minimum dose to the neighboring healthy tissues. However, endocavitary applicators have been scarcely explored for treatment of cancer. The choice of antenna for EM power deposition in tissue is limited for endocavitary and interstitial devices as the applicator size has to fit inside the natural orifice of the human body. Thus, mainly wire type [6],[7] and few patch antennas were investigated for selective power deposition [8]. Wire antenna has the largest length to diameter, L/D ratio which will enable it to become a suitable candidate for forming array which is essential for conformity of the dose distribution to the tumour shape. Furthermore, very few endocavitary applicators are reported with antenna cooling which is also essential for effective delivery of HT without charring the adjacent healthy tissues [9]. Applicators reported in literature are typically developed by modifying Foley catheters to incorporate a radiating wire antenna for treating transurethral HT of prostate at 915MHz [10] and benign prostate hyperplasia at 650 MHz [11]. Various types of monopole, slot and spiral antennas have been analyzed at higher frequencies like 2.45 GHz and 915 MHz for interstitial microwave ablation [12],[13]. Very few antenna designs are investigated at 433 MHz [14] as the length of conventional wire antenna to operate at this frequency is large and may not be feasible for interstitial application.

In this paper a miniaturized folded monopole coaxial antenna is designed for developing the endocavitary hyperthermia applicator for treatment of cancer of cervix. Based on the 3D numerical simulations, a prototype applicator has been realized using a 22 Fr Foley catheter.

2. Design of folded monopole antenna

2.1 Antenna model

Figure 1(a) shows the cut plane view of the folded monopole antenna designed in Ansys, HFSS Version 17.0. The coaxial transmission line is based on RG405/U standard. In the antenna model, a section of the outer conductor of the coaxial cable was removed from the distal end of the cable. The dielectric insulation was extended till the end as shown in Figure 1(a). The exposed inner conductor was folded back over the dielectric to form a simple folded monopole antenna.

2.2 Antenna simulations

The folded monopole was modelled inside a 3D model of the 22 Fr Foley catheter with de-ionized, (DI) water as the coupling medium. The lengths of the extended inner conductor (L_e) and folded sections (L_f) were optimized for resonance at 434 MHz with the Foley catheter immersed in human muscle tissue. The Cole-Cole dispersion model of human muscle tissue was used in the simulations [15]. Figure 1(b) shows the 3D cut section of the applicator inside the muscle tissue.

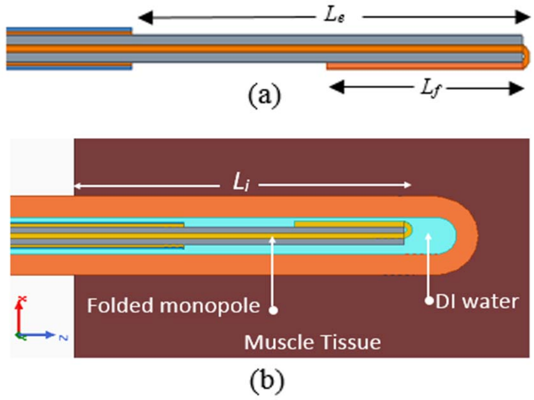

Figure 1. Antenna simulation model. (a) Cut plane view of the folded monopole, (b) cut section showing intracavitary applicator inside the muscle tissue for simulations.

Figure 2 shows the power reflection coefficient of the water cooled intracavitary applicator for varying length of the folded section (L_f). The resonance of the folded monopole also varied with the antenna insertion depth (Li) in muscle tissue. Unlike a quarter wave monopole antenna model ($L_f = 0$mm and $L_e = 85$mm) the proposed folded monopole antenna resonates at 434 MHz for a shorter extension ($L_e = 40$mm).

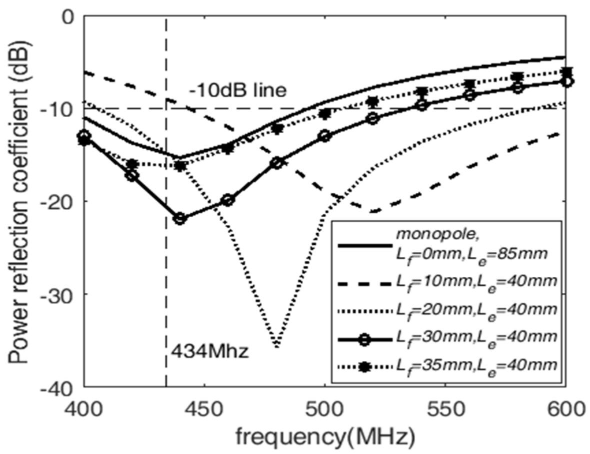

Figure 2. Power reflection coefficient of a folded monopole with $\boldsymbol{L_e = 40\mathrm{mm}}$ and $\boldsymbol{L_i = 100\mathrm{mm}}$ for varying length of L_f

As the tissue specific absorption rate (SAR) for the folded monopole was asymmetric, a triaxial folded section was added to the monopole as shown in Figure 3(a). The increase in the number of folded sections improve the tissue SAR pattern without altering the resonance behavior. Figure 3(b) shows the symmetric tissue SAR pattern for the triaxial folded monopole. Simulation result is shown for 20 W input power.

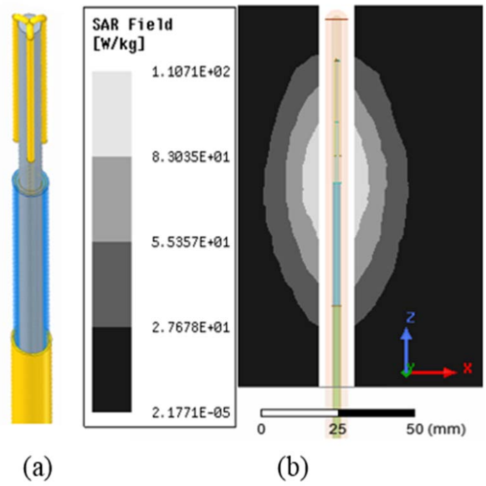

Figure 3. (a) Triaxial folded monopole antenna, (b) SAR pattern in muscle tissue for 20W input power with $\boldsymbol{L_f = 30\mathrm{mm}}$ and $\boldsymbol{L_e = 40\mathrm{mm}}$ at $\boldsymbol{L_i = 100\mathrm{mm}}$

3. Endocavitary applicator prototype

3.1 Fabricated prototype

A 3 channel Foley's irrigation catheter was modified to form an intracavitary hyperthermia applicator with water cooling. The irrigation channel of the catheter was connected to the drain channel (lumen) of the catheter to circulate temperature controlled water for antenna cooling. The folded monopole antenna shown in Figure 4(a) was inserted in the applicator drainage channel. The antenna was locked using a rubber cork which was sealed using silicone glue to avoid water leakage. The fabricated intracavitary hyperthermia applicator with the folded monopole antenna is shown in Figure 4(b).

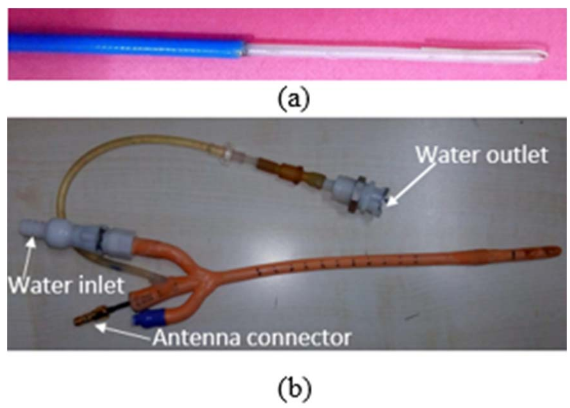

Figure 4. Fabricated applicator prototype. (a) Folded monopole antenna, (b) 22 Fr Foley catheter modified for intracavitary HT.

3.2 Measurements

The power reflection coefficient of the applicator was measured in a water tank as human muscle tissue has 70-80% water content. Figure 5 shows the experimental setup for applicator measurement in the water tank. Applicator measurements for the folded monopole with L_f of 30 mm and L_e of 40 mm was recorded for Li of 100 mm using a vector network analyzer (S331L, Anritsu [SiteMaster]). Applicator measurement in the water tank was compared with simulation result obtained for the applicator immersed in water. Figure 6 shows the comparison of the measurement with the simulated power reflection coefficient. The measurement is in good agreement with the simulation. The simulated and measured power reflection coefficients indicate resonance near 434 MHz. The power reflection coefficient at 434 MHz is –17.88 and –20.2dB in measurement and simulation respectively. The -10 dB bandwidth of the fabricated intracavitary applicator is 140 MHz which is wide enough to accommodate change in applicator in resonance due to the potential variation in the tissue electrical impedance of patient population.

Figure 5. Experimental setup showing the applicator supported with clamps inserted inside water bath with connecting cables to vector network analyser.

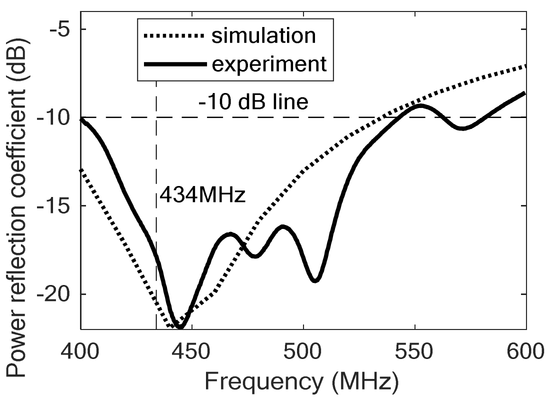

Figure 6. Comparison of theoretical (simulated) and experimental reflection coeficient of a folded monopole with $\boldsymbol{L_f = 30\text{mm}}$ and $\boldsymbol{L_e = 40\text{mm}}$ at $\boldsymbol{L_i = 100\text{mm}}$

6. Conclusion

A miniaturized 434 MHz folded monopole antenna was presented for design of endocavitary hyperthermia applicator. The proposed design is simple and differs from the slot and sleeve dipole antennas reported in literature. The asymmetric power distribution of the single folded monopole antenna was compensated with triaxial folded design. For proof of the concept, the single folded monopole antenna was fabricated and assessed using a modified 22 Fr Foley's catheter with water cooling. The measurements indicated resonance at 434 MHz in agreement with the simulation and -10 dB bandwidth of 140 MHz. The proposed folded monopole is shorter $L_e = 40\text{mm}$ compared to the traditional monopole $L_e = 85\text{mm}$ thus, enabling design of endocavitary hyperthermia applicators at 434 MHz at insertion depth, $L_i = 100\text{mm}$. In the proposed coaxial probe design, measures have to be taken to reduce shaft heating due to the tail effect and also make the design independent of the insertion depth by designing an efficient choke at 434 MHz.

7. References

1. K. Engin, "Biological rationale and clinical experience with hyperthermia," *Controlled Clinical Trials*, vol. 17, no. 4. pp. 316–342, 1996.

2. N. Cihoric, A. Tsikkinis, G. van Rhoon, H. Crezee, D. M. Aebersold, S. Bodis, M. Beck, J. Nadobny, V. Budach, P. Wust, and P. Ghadjar, "Hyperthermia-related clinical trials on cancer treatment within the ClinicalTrials.gov registry," *Int. J. Hyperth.*, vol. 31, no. 6, pp. 609–614, 2015.

3. .NCRP, "Three-Year Report of Population Based Cancer Registries Incidence and Distribution of Cancer 2012-2014 (Report of 27 PBCRs in India)," 2016.

4. de S. S. Bruni L, Barrionuevo-Rosas L, Albero G, Serrano B, Mena M, Gómez D, Muñoz J, Bosch FX, "Human Papillomavirus and Related Diseases in India. Summary Report," *ICO Inf. Cent. HPV Cancer (HPV Inf. Centre)*, pp. 1–80, 2017.

5. J. van der Zee, D. González González, G. C. van Rhoon, J. D. van Dijk, W. L. van Putten, and A. A. Hart, "Comparison of radiotherapy alone with radiotherapy plus hyperthermia in locally advanced pelvic tumours: a prospective, randomised, multicentre trial. Dutch Deep Hyperthermia Group.," *Lancet (London, England)*, vol. 355, no. 9210, pp. 1119–25, Apr. 2000.

6. S. L. Broschat, C. K. Chou, K. H. Luk, A. W. Guy, and A. Ishimaru, "An Insulated Dipole Applicator for Intracavitary Hyperthermia," *IEEE Trans. Biomed. Eng.*, vol. 35, no. 3, pp. 173–178, 1988.

7. D.-J. LI, K. H. LUK, H.-B. JIANG, C.-K. CHOU, and G.-Z. HWANG, "Design And Thermometry Of An Intracavitary Microwave Applicator Suitable For Treatment Of Some Vaginal And Rectal Cancers," *Int. J. Radiat. Oncol. Biol. Phys.*, vol. 10, pp. 2155–2162, 1984.

8. T. Rajendran and K. Arunachalam, "Comparison study of microwave patch antennas at 434 MHz for intra cavitary hyperthermia applicator design," *2015 Int. Symp. Antennas Propag.*, pp. 1–4, 2015.

9. G. B. Gentili, F. Gori, L. Lachi, and M. Leoncini, "A water-cooled EM applicator radiating in a phantom equivalent tissue - experiments and numerical analysis," *IEEE Trans. Biomed. Eng.*, vol. 38, no. 9, pp. 924–928, 1991.

10. T. Z. Wong, E. Jonsson, P. J. Hoopes, B. S. Trembly, J. A. Heaney, E. B. Douple, and C. T. Coughlin, "A coaxial microwave applicator for transurethral hyperthermia of the prostate.," *Prostate*, vol. 22, no. 2, pp. 125–138, 1993.

11. M. A. Astrahant, M. D. Sapozinkt, D. Cohent, and G. Luxton, "Microwave applicator for transurethral hyperthermia of benign prostatic hyperplasia," vol. 5, no. 3, pp. 283–296, 1989.

12. P. Prakash, M. C. Converse, J. G. Webster, and D. M. Mahvi, "An Optimal Sliding Choke Antenna for Hepatic Microwave Ablation," *IEEE Trans. Biomed. Eng.*, vol. 56, no. 10, pp. 2470–2476, 2009.

13. H. Luyen, S. C. Hagness, and N. Behdad, "A balun-free helical antenna for minimally invasive microwave ablation," *IEEE Trans. Antennas Propag.*, vol. 63, no. 3, pp. 959–965, 2015.

14. Y. Jiang, J. Zhao, W. Li, Y. Yang, J. Liu, and Z. Qian, "A coaxial slot antenna with frequency of 433 MHz for microwave ablation therapies: design, simulation, and experimental research," *Med. Biol. Eng. Comput.*, vol. 55, no. 11, pp. 2027–2036, Nov. 2017.

15. S. Gabriel, R. W. Lau, and C. Gabriel, "The dielectric properties of biological tissues: III. Parametric models for the dielectric spectrum of tissues," *Phys. Med. Biol.*, vol. 41, no. 11, pp. 2271–2293, Nov. 1996.