A Study of Coaxial Cable Designs in Microwave Ablation Applications

Mohammad Al-Khaldi
Department of Electrical & Computer Engineering
The Ohio State University
Columbus, OH, 43212
al-khaldi.2@osu.edu

Robert Nevels
Department of Electrical & Computer Engineering
Texas A&M University
College Station, Texas, 77843-3128
nevels@ece.tamu.edu

***Abstract*—RF ablation of aberrant tissue has become a successful medical procedure in applications involving the removal of cancerous tumors. It has also seen exceptional growth in the treatment of cardiac arrhythmia, atrial fibrillation, and preventricular contractions. However, even though microwave ablation tools have been studied almost since the beginning of ablation therapy, their use remains limited due to a perceived lack of effective control of the ablation volume as compared to more predictable RF ablation methods. Here we address some of the issues having to do with coaxial ablation tool designs, including efficiency, bandwidth, ablated area uniformity, and temperature dependence.**

Keywords—microwave, ablation, bio-heat, metamaterial, coaxial cable

I. Introduction

Researchers have explored the potential of microwave ablation on a variety of specific cancers including brain tumor and bile duct carcinoma [1], hepatic tumors [2], and lung and liver [3] cancer. A lesser used application of microwave ablation is the creation of endocardial lesions for removing the atrial or ventricular extra systole in the treatment of tachycardia arrhythmias, preventricular contractions, and atrial fibrillation [4]. Much of the medical community hesitancy in adapting heart related microwave ablation tools has to do with the perceived lack of control of the ablation volume as compared to more predictable RF ablation methods. Here we analyze some ablation tool design features, and draw some conclusions concerning their effectiveness in a medical setting.

II. Applications

The designs in this paper are primarily intended for use in heart ablation procedures, but their applications can be generalized to other locations within the body that require ablation. RF ablation procedures require the device to come in physical contact with the aberrant tissue in order to allow for the flow of current from the tip of the catheter to an electrode pad placed on the skin's surface. One of the numerous advantages of microwave ablation is that direct physical contact is not necessary because heat is delivered to the infected area through microwave radiation. However, for minimally invasive applications the microwave signal requires a waveguide, typically a coaxial cable, which along with the confined space through which it must navigate, places significant restrictions on the radiating antenna at the tip. The antenna design is therefore typically based on a coaxial feed mechanism. Below we only consider coaxial feed antenna designs.

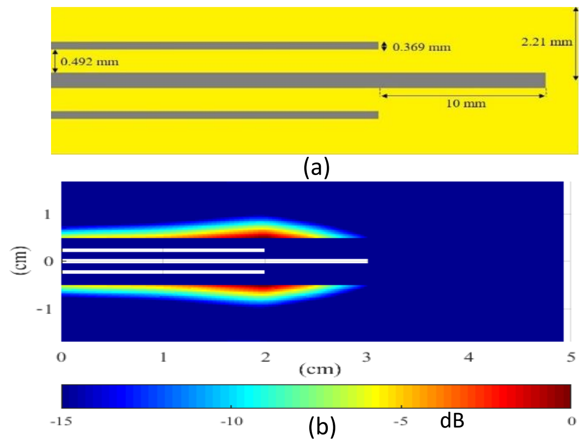

Fig. 1 Coax- monopole (a) diagram (b) power pattern.

The basic design in shown in Fig. 1a, which depicts in outline of the coaxial cable on the left with the center conductor extending into a monopole antenna to the right and the entire structure coated in Teflon, the material commonly used in commercial coaxial cables. The radiation pattern for this arrangement, Fig. 1b, contains very little power near the antenna tip, which is the portion of the antenna that is in closest proximity to the infected tissue. Also, as seen in Fig. 1b, some of the power is captured in an unwanted surface wave traveling back down the outside of the coaxial cable. To remedy these situations and to achieve a lower resonant frequency for the antenna, a shorting plate is placed at the distal end of the antenna and a balun is added both to dampen the surface wave and impedance match the antenna [4]. Two examples are shown in Fig. 2, one with a shorted sleeve balun and the other with an open, or floating, sleeve. S_{11} shown in Fig. 3 indicates the open sleeve is a better impedance match than the shorted sleeve. However, in Fig. 2 it appears that a small amount of power is still captured in a surface wave in the open sleeve case. Subsequent calculations showed that more power is transferred to the far field with the shorted sleeve than the open sleeve and, although small, in excess of 130% more power is captured in a

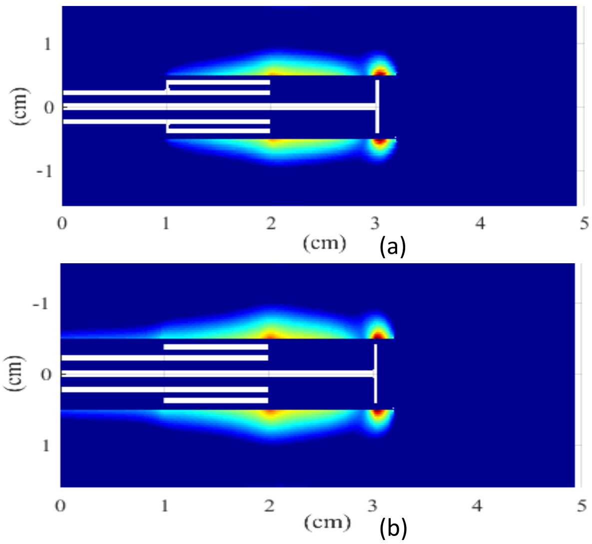

Fig. 2 Coax fed ablation tools with terminating disk with a (a) shorted sleeve balun (b) floating sleeve.

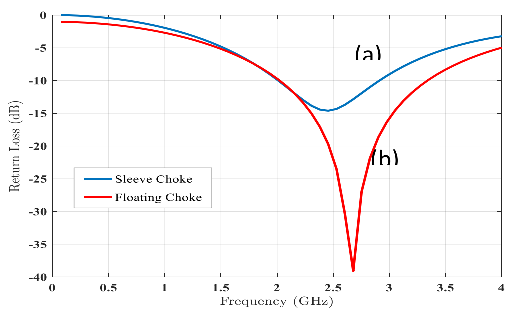

Fig. 3 S_{11} for a (a) shorted (b) floating choke

surface wave in the floating sleeve case, regardless of the thickness of the Teflon coating.

Another observation is that the near field power falls short of the desired uniform pattern. In an attempt to achieve uniformity, we inserted a metamaterial plug between the coax aperture and the dielectric plate. A property of 'usual' material is the field decays away from the source, in this case the extended center conductor antenna. But, in a metamaterial the evanescent near field increases away from the source, thus it behaves like a lens. A result is shown in Fig. 4, where a very nice uniform pattern is produced. However, S_{11} is approximately the same as for the shorted sleeve in Fig.3. Unexpectedly, the near field power is very low although relatively uniform on the sides, but remarkably higher off the end. This suggests a possible design for spot ablation, by far the most common type of RF ablation now used in practice.

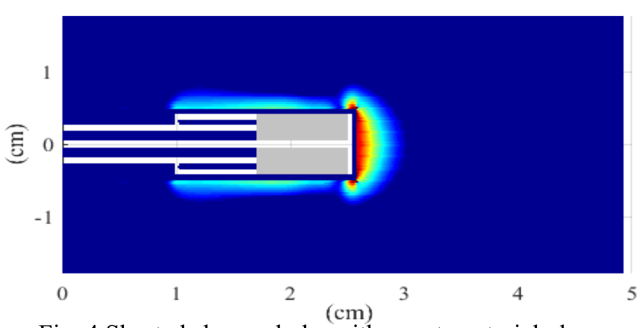

Fig. 4 Shorted sleeve choke with a metamaterial plug.

As a final example we show a case where the impedance match is internal Fig. 5. This particular design capitalizes on the creation of a high impedance feed point that acts as natural choke point thereby prohibiting power from coupling into surface waves [5]. This design is highly effective at eliminating surface waves and improving the distance to which power is deposited inside the adjacent tissue.

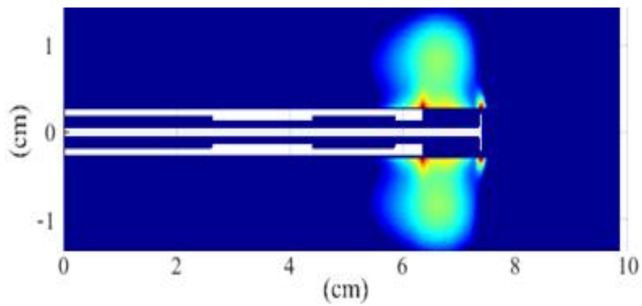

Fig. 5 Internal impedance match.

III. Conclusions

Several microwave ablation structures were analyzed and compared in terms of impedance matching capability, elimination of surface waves and uniformity of the near field power pattern. The sleeve choke proved to be effective at eliminating the surface wave while attaining a satisfactory return loss. The floating sleeve partially lessened surface waves, while achieving a return loss of -39.08 dB at resonance. A metamaterial plug produced a surprising end-fire pattern. An internal match design proved successful at eliminating the surface wave while attaining a return loss of -49.39 dB.

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