Time-Domain Focusing Radar for Medical Imaging

Shu Xiao[1], Karl H. Schoenbach[2], and Carl E. Baum[3]

[1]Frank Reidy Research Center for Bioelectrics, Old Dominion University, Norfolk, VA, 23508, USA, sxiao@odu.edu

[2] Frank Reidy Research Center for Bioelectrics, Old Dominion University, Norfolk, VA, 23508, USA, schoenbach@ece.odu.edu

[3]Department of Electrical & Computer Engineering, University of New Mexico, Albuquerque, NM, 87131, USA, carl.e.baum@ieee.org

Abstract

A biomedical imaging system based on a high power, focusing, wideband antenna system is discussed. It will allow us to record spatial and temporal changes of electrical properties of tissues in the human body, particularly cancerous tissue, which differs greatly in both conductivity and permittivity from healthy tissue. Focusing is achieved by means of a prolate-spheroidal reflector, which focuses the radiation generated by high voltage (kV) pulses of approximately 100 ps duration into a volume with centimeter dimensions. The high power of the source allows a high signal-to-noise ratio even for signals strongly attenuated by the conductive tissue.

1. Introduction

The development of radiators for very high power, short-rise-time, electromagnetic radiation has been driven, to a large extent, by their use in nonlethal weapons technology [1]. With advances in pulsed power technology, it is now possible to generate short pulses with amplitudes that are orders of magnitude higher than those of commercially available pulse generators. Much higher electric fields can be achieved when the electromagnetic energy is focused in the near-field region, for example, through a prolate-spheroidal reflector. These pulse power systems allow the detection of inhomogeneities of dielectric properties of biological specimens even at large depths. This is relevant for the detection of tumors, which have been shown to differ in conductivity and permittivity from healthy tissue [2]. For example, breast tumors have a conductivity and permittivity nearly one order of magnitude higher than the surrounding healthy tissue [3]. This wide-band imaging method could, therefore, be complementary to conventional imaging methods for the detection of cancer. For the short duration pulses, no thermal damage is expected to the biological cells/tissues [4].

2. Antenna Concept

A design that allows us to produce very high electric fields in restricted volumes is based on a geometrical optics concept. The power radiated from a point source located in one focal point of a prolate-spheroidal reflector is focused in the second focal point.

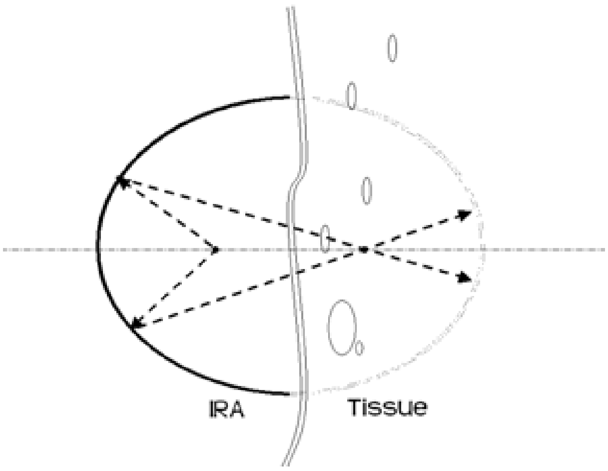

Figure 1. Schematics of focusing antenna (left) delivering electromagnetic energy to a focal point in matter (right).

This concept, and its application in focusing the electromagnetic energy within a small volume inside a tissue, is illustrated in Figure 1. The source is located in the focal point of the prolate-spheroidal reflector, respectively, on the left side. The electromagnetic waves reflected from the reflector are focused in the second focal point (right side), which is located within the tissue.

3. Ground-Cone Feeding, Impulse Radiating Antenna (IRA)

The design of the focusing antenna using a prolate-spheroidal reflector is shown in Figure 2. It consists of a conical wave launching system and a reflector [5]. The wave launching system has rotational symmetry about the z-axis (Figure 2). The apex of the cone is at the first focal point F1. It is connected to the inner conductor of a coaxial cable feed. Such a conical wave launcher above the ground plane is an unbalanced structure, thus, no balun is required to feed the wave launcher. The wave emitted from F1 is a spherical TEM wave with its source at F1. The launched wave is reflected by the prolate-spheroidal reflector surface to converge at the second focal point (F2). The electric field at F2 consists of prepulse, impulse and postpulse components. The prepulse, caused by diffraction at the edge of the wave launcher cone, has the same polarity as the impulse. Due to rotational symmetry, the electric field at the second focal point has only longitudinal components.

Another antenna concept, has been proposed by Carl E. Baum [6]. In his configuration, symmetrical conical arm feeds (either 4 or 2 arms) are extended from the first focal point to the reflector. A balun has to be used to suppress the common mode signal. The focused electrical field has its largest component in the transverse direction.

Independent of the particular antenna structure, the electromagnetic wave will be focused in F2. The results of modelling for the structure shown in Figure 2, using FDTD software, MAGIC, show that the focus volume has an oval shape. Its size is 2-3 cm along the z axis and ~1cm along the x axis for Full Width at Half Maximum (FWHM). If we don’t consider the FWHM as defining the dimension of the focal spot size, but the full width at a given electric field value, then the dimension of the focal spot can be less than 1 cm, if a given field-value exceeds that of half of the peak value. This is the case if we consider nonlinear effects, which have a threshold at high electric fields.

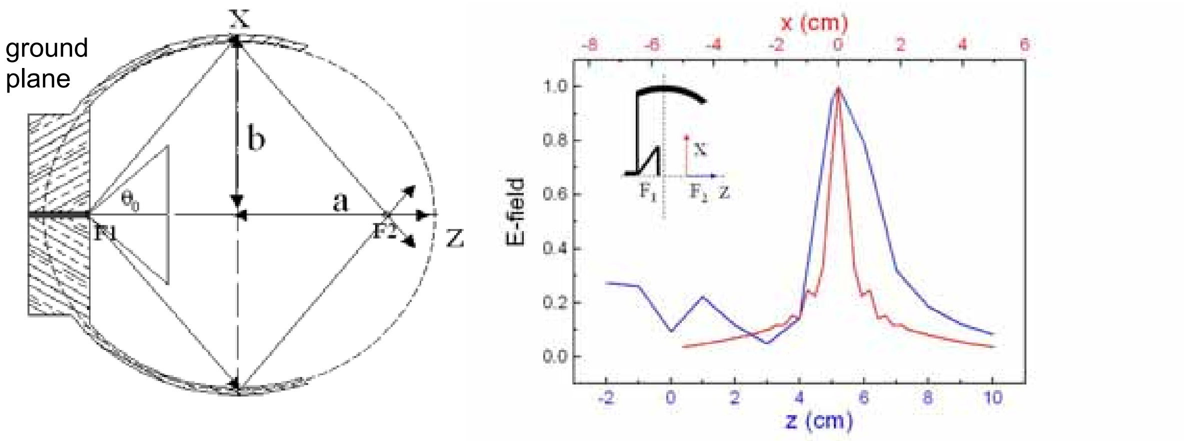

Figure 2. A high power impulse antenna; left: The prolate-spheroidal antenna is fed by a coaxial structure from the first focal point F1 and focuses the radiation at the second focal point F2; right: The distribution of the electrical field in the vicinity of F2 [5].

4. Arrangement of Antenna and Receiver

The antenna arrangement is dependent on the target position. For targets near the surface (skin), an arrangement as shown in Figure 3 could be used [7]. Instead of using paraboloidal antennas, prolate-spheroidal antennas can be used to focus the radiation considerably closer with a smaller spot size. In order to reduce reflections at the skin surface, a polarized beam would be directed to the surface at the Brewster angle. Because the Brewster angle is determined by the dielectric permittivity, by measuring the intensity of the reflection signal it is also possible to map the surface permittivity. We can use a twin-antenna system as both radiation and data acquisition system, also shown in

Figure 3. The emitting antenna can illuminate the potential inhomogeneity site at different angles and the receiving antenna can collect the signals at different locations, where the scattered wave may have different polarization.

For recording changes in the electrical properties of deeper lying tissue, an IRA type of emitting antenna, which also includes a second cross polarization feeding arm as a sensor can be used. This allows a system which has both one emitter and two sensors (co-pol and cross-pol). The back-scattered signal, which has the same polarization as the emitting signal, will be picked up by the co-pol conical arm. Due to the symmetry, when the target is right at the center of the focal point, no signals can be picked up by the cross polarized channel. When the target is off the focal point, the signal from the cross polarized arm can be picked up. This will make full use of the antenna to record the signal in both intensity and polarization.

Other options are to include a focal lens on the surface of the biological target in order to achieve better spatial resolution [8]. Also, an IRA type of emitting antenna that operates as emitter and sensor, as well, can be used.

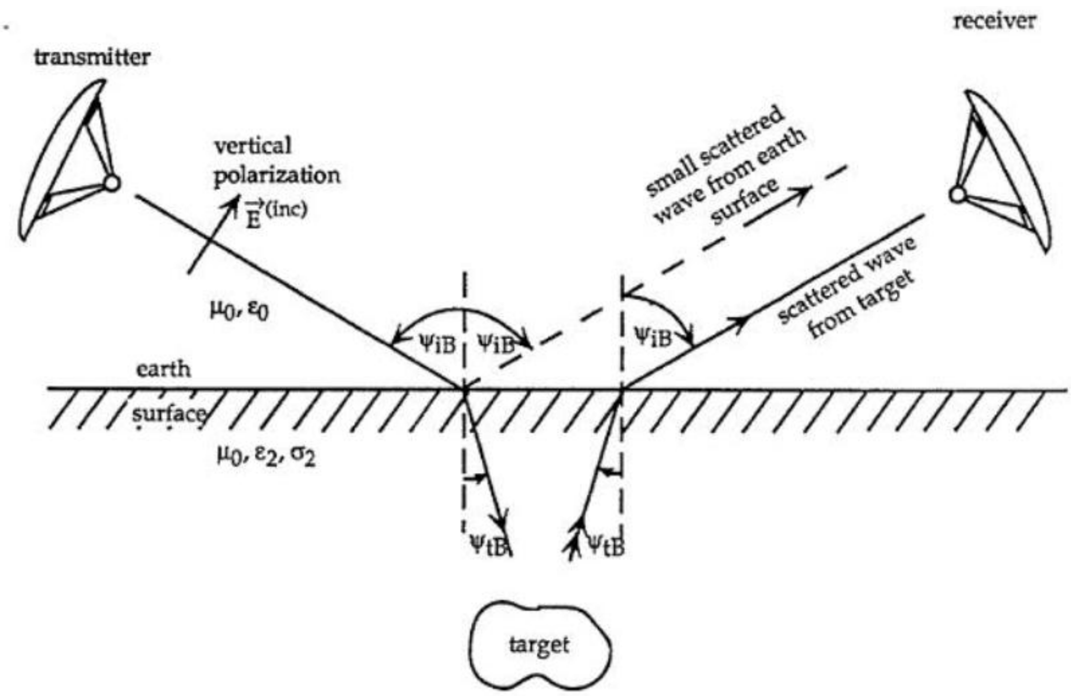

Figure 3. An antenna-receiver system which allows probing of inhomogeneities (tumors) in tissue below the skin. the reflection at the skin in minimized by operating the antenna at the Brewster angle [7].

5. Conclusion

The use of prolate-spheroidal reflectors as part of a sub-nanosecond Impulse Radiating Antenna (IRA) allows us to generate near-field electric fields inside biological tissue with high spatial resolution. With high-power sub-nanosecond electrical pulses, it becomes possible to record not only changes in the electric properties of tissue close to the skin, but also deep in the body, even though the tissue is a conductive medium with conductivities on the order of S/m. Such high power antennas can therefore be used to image tumors, which show large differences in electrical properties from surrounding healthy tissues.

6. Acknowledgments

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7. References

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