Simulation Study of a Modified Rectangular Microstrip for the Hyperthermia Breast Cancer Procedure with SEMCAD X Solver

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Abstract. A modified rectangular microstrip is introduced and presented as an applicator for hyperthermia cancer procedure. SEMCAD X solver is used as the simulation tool to investigate the rectangular microstrip, which is applied and radiated to the breast phantom. The research is carried out in order to enhance the penetration depth, which is up to 100mm and improve the focusing capability, which means that to reduce the unwanted hot spots at the vicinity area of the treated tissue. The specific absorption rate (SAR) distributions of 1 and 10 g weights of breast tissue are obtained as simulation results. The operating frequency utilized for the study is 915 MHz, with three operating powers of 10, 100, and 200 W. Beside rectangular, a circular microstrip applicator with microstrip feed line is also simulated in order to determine which shape of the microstrip applicator presented the greatest results in term of the depth penetration and focusing capability. As expected, the greatest SAR is provided by the microstrip applicator with rectangular shape. By that, the rectangular microstrip applicator is further explored and modified. From the outcomes, the rectangular microstrip with structure 4 presents the utmost specific absorption rate deposition; the required penetration depth is achieved, and focusing is enhanced with minimal unwanted hot spots at the vicinity of the treated area.

1. Introduction

Microstrip antenna introduces many inventive works and is one of the most dynamic fields in communication applications. Microstrip patch is generally designed and developed with various shapes, such as square, rectangular, circular, triangular, and elliptical or some other common shape. The most widely used among all are rectangular and circular shapes.

The fundamental structure of microstrip antenna comprises a metallic radiating patch element, which is integrated into a grounded dielectric substrate. Rectangular and circular patches are extensively used because they easily provide feed line flexibility, multiple frequency operation, linear and circular polarizations, frequency agility, and good bandwidth [1]. The basic configurations of both patches are illustrated in Figures 1 (a) and (b).
Microstrip patch antennas are currently highly demanded in a broad range of microwave system applications, such as satellite communications, missile systems, and global positioning system for remote sensing. They have been introduced for biomedical use in this recent year as well. For instance, they are employed in hyperthermia cancer procedure [2], [3]. In articles, single and array arrangement of microstrip antenna is proposed, with different shapes, sizes, and structures. In [2], a circular patch with an operating frequency of 434 MHz was designed and developed to observe the radiation deposition into the area to be radiated. The effective field size (EFS) resulted from the simulation study was approximately 4 cm in diameter and 2 cm in penetration depth. Depth penetration was achieved with a wide range of radiation deposition. John Stang proposed an array arrangement of microstrip patch antennas in [3]. This arrangement aimed to enhance the focusing capability toward the targeted area to be radiated. Hence, the unwanted hot spots, which might lead to damaging of other healthy surrounding tissue, could be minimized.

Depth penetration and focusing capability are two crucial factors in the hyperthermia cancer procedure, especially when it involves a non-invasive microwave or radio wave applicator. In such an applicator, penetration depth and focusing capability may be needed to enhance to ensure the accessibility toward deep targeted areas and to minimize the effect of the unwanted hot spots resulted from the radiation absorption distribution by the applicator. In this study, rectangular and circular patch microstrip antennas, which are also called “applicators for hyperthermia procedure,” are introduced. The specific absorption rate (SAR) is simulated to determine and observe the radiation deposition of the applicators into the targeted area to be treated, which is the breast phantom in this research.

2. Design of simulation (DoS)

SEMCAD X is used as a simulation tool to design, develop, and investigate the rectangular and circular patches toward the hyperthermia breast cancer procedure. Before simulating SAR, the applicators and breast phantom are required to be constructed. The length and width of the rectangular patch are calculated with Equations (1)–(7) [1], [4]–[6]. For the rectangular patch, $w/L >> \lambda/2$, and the dielectric constant is usually in the range of $2.2 < \varepsilon_r < 12$ [4]. The radius of the circular patch is presented Equations (8) and (9) [1], [6], [7]. The operating frequency to be used is 915 MHz, which is included under the industry, scientific, and medical (ISM) frequency. The substrate used for the investigation is silicon with $\varepsilon_r = 11.9$.

\[
w = \frac{c}{2f} \sqrt{\frac{2}{\varepsilon_r + 1}}
\]  
(1)
\[ \varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[ 1 + \frac{10h}{w} \right]^{0.5} \quad (2) \]

\[ L_{\text{eff}} = \frac{c}{2f} \sqrt{\varepsilon_{\text{eff}}} \quad (3) \]

\[ \Delta L = 0.412XhX \frac{\varepsilon_{\text{eff}} + 0.3}{\varepsilon_{\text{eff}} - 0.258} X \frac{w}{h} + 0.264 X \frac{w}{h} + 0.8 \quad (4) \]

\[ L = L_{\text{eff}} - 2\Delta L \quad (5) \]

\[ L_g = 6h + L \quad (6) \]

\[ W_g = 6h + w \quad (7) \]

\[ a = \frac{F}{\left( 1 + \frac{2h}{\pi \alpha F} \left[ \ln \left( \frac{2h}{\pi \alpha} \right) + 1.7726 \right] \right)^{1/2}} \quad (8) \]

Where,

\[ F = \frac{8.791 \times 10^9}{f \sqrt{\alpha \varepsilon}} \quad (9) \]

In the above equations, \( w \) is the width of the patch; \( L \) is the length of the patch; \( \varepsilon_{\text{eff}} \) and \( L_{\text{eff}} \) are the effective dielectric constant and the effective length of the patch, respectively. \( c \) is the free-space velocity of light, \( h \) is the substrate thickness, \( \Delta L \) is the extension of length caused by the fringing effect, \( f \) is the frequency, and \( a \) is the radius of the circular patch. According to [8], Equations (8) and (9) for circular patch do not consider the fringing effect. The fringing effect makes the patch electrically large. Hence, the effective radius, \( a_e \), as written in Equation (10), is used.

\[ a_e = a \left( 1 + \frac{2h}{\pi \alpha a} \left[ \ln \left( \frac{2h}{\pi \alpha} \right) + 1.7726 \right] \right)^{1/2} \quad (10) \]

After constructing the applicators, the breast phantom, which consists of the breast fat and breast cancer/tumor, is developed. The breast cancer/tumor phantom is positioned 100 mm deep from the outer side of the breast skin. The radius for the breast fat is 100 mm, whereas the breast tumor phantom has a radius of 50 mm. The electrical and thermal properties are provided in Table 1. The properties are retrieved from the Gabriel database of the SEMCAD X solver. The simulation is conducted with the applicator 2 mm from the breast phantom.

Further modification on either one of the patches, which provides the utmost SAR deposition with required penetration depth and focusing capability, is conducted to further enhance the outcomes and to observe the effect of the various shapes and structures on the SAR deposition of the breast phantom.

The simulation study also includes the investigations on the different operating powers and applicator distances from the breast phantom. Finally, water bolus is integrated into the hyperthermia procedure. Water bolus is used to provide a cooling environment to minimize skin burn and to provide a comfortable situation to the patient during the hyperthermia procedure. Distilled water is utilized as a coolant fluid, with \( \varepsilon_r, \alpha, \rho \) of 76.7, 5e-005, and 1000, respectively. The thickness of the water bolus is stipulated to 15 mm.
Table 1. Breast phantom electrical and thermal properties

|                  | 915 MHz                  |
|------------------|--------------------------|
| Relative         | Electrical                |
| Permittivity, εr | Conductivity, σ          |
| (S/m)            | (S/m)                    |
| Breast Fat       | 4.6988 0.125134          |
| Breast Cancer/   | 48.3624 2.65306          |
| Breast Tumor     | 1000 2348.33 0.209       |

The summary of the DoS is illustrated in Figure 2.

3. Result and discussion

Based on Equations (1)–(7), the parameter specifications of the rectangular and circular microstrip applicators are provided in Table 2.

Table 2. Rectangular microstrip applicator specifications

| Dimension          | 915 MHz       |
|--------------------|---------------|
| Dielectric Constant (εr) | Silicon 11.9 |
| Substrate Thickness (h)     | 2 mm         |
| Length (L)               | 48 mm        |
| Width (W)                | 65 mm        |
| Ground Length (Lg)        | 60 mm        |
| Ground Width (Wg)         | 77 mm        |
| Radius (a)               | 1 mm         |
| Effective Radius (ae)     | 2 mm         |

Table 3 shows the SAR deposition for the rectangular and circular patches with an operating frequency of 915 MHz and an operating power of 10 W. Based on this table, the rectangular patch provides the utmost result of SAR deposition compared with the circular patch. The rectangular patch is then modified to enhance the required penetration depth and focusing capability toward the breast phantom. The SAR distributions of different rectangular structures and operating powers are provided in Table 4. The rectangular patch with structure 4 provides the utmost results. Meanwhile, in terms of different powers, the SAR distribution is wider, when higher operating power is utilized. In addition, the SAR value increases when the operating power increases, either for 1 or 10 g weight of the breast tissue. The brightest color of the SAR deposition represents the highest radiation absorption. SAR refers to the transferred power divided by the mass of the object, which is provided in Equation (11). According to[9], SAR takes a value proportional to the square of the electric field around the antenna and is equivalent to the heating source generated by the electric field in the tissue.

\[
SAR = \frac{\sigma |E|^2}{2 \rho} \text{ (W/kg) or (mW/g)}
\]

where \(\sigma\) is the conductivity of tissue (S/m), \(E\) is the electric field (V/m), and \(\rho\) is the density of tissue (kg/m\(^3\)).
Table 3. SAR deposition for rectangular and circular patches

| Patch/Mass of Breast Tissue | Rectangular Patch | Circular Patch |
|-----------------------------|-------------------|---------------|
| 1 g                         | ![Image]          | ![Image]      |
| 10 g                        | ![Image]          | ![Image]      |

The SAR deposition of different distances of the rectangular patch with structure 4 applicators from the breast phantom is indicated in Table 5, either with the addition of water bolus to the treatment procedure or without water bolus. From the simulated SAR distribution in Table 5, 2mm water bolus thickness and 2mm distances without water bolus have presented the greatest results of penetration depth and focusing capability of the applicator.
### Table 4. SAR for different rectangular structures and operating powers

| 915 MHz | Operating Power / Rectangular Structures | 10 W | SAR 1 g | SAR 10 g |
|---------|---------------------------------------|------|---------|----------|
|         |                                       |      |         |          |
| 2 mm    |                                       |      |         |          |

### Table 5. SAR for different rectangular patches with structure 4 applicator distance and different operating powers

| 915 MHz | Operating Power / Distances | 10 W | 100 W | 200 W |
|---------|----------------------------|------|--------|--------|
| Without Water Bolus | SAR 1 g | 2 mm | 1.46 × 10^4 mW/g | 1.46 × 10^5 mW/g | 2.92 × 10^5 mW/g |
With Water Bolus

| Operating Power /Distances | 10 W  | 100 W | 200 W |
|---------------------------|-------|-------|-------|
| SAR 1 g                   |       |       |       |
| 2 mm                      | 29.7 mW/g | 297 mW/g | 594 mW/g |
| 10 mm                     | 11.4 mW/g | 114 mW/g | 228 mW/g |
| 100 mm                    | 0.162 mW/g | 1.62 mW/g | 3.24 mW/g |
4. Conclusion
Rectangular patch applicator provides better SAR deposition than circular patch applicator. When the rectangular patch is modified, the rectangular patch with structure 4 presents the utmost SAR deposition, in which the penetration depth and focusing capability are at the greatest agreement.

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