Feeding Network for Microwave Hyperthermia Treatment of Brain Tumor Using Wideband In-Phase Power Divider

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Abstract—**An in-phase power divider as a feeding network for two-element antenna array for microwave hyperthermia treatment of brain tumor is presented. The proposed power divider is used for the simultaneous power distribution between two element antenna array, where equal amplitude and in-phase signals are required. It is designed using two pairs of coupled lines to achieve 100% fractional bandwidth. The antenna array is designed using corrugated tapered slot antennas to cover more than 100% fractional bandwidth. The whole structure is optimized using CST MWS. The performance of the power divider and the antenna array is analyzed by means of simulations across the band 1-3 GHz, which is used in most if not all microwave hyperthermia applications. To be able to control the direction of the array's mainbeam, a phase shifter is included in the feeding line of one of the antenna elements. The whole structure is tested on a realistic head phantom to investigate the penetration of the fields inside the head.**

Keywords—Feeding network; in-phase power divider; antenna array; microstrip circuits; microwave hyperthermia.

I. INTRODUCTION

Microwave-induced hyperthermia has received increased attention in recent years in the treatment of cancer [1]. It is an effective way to treat tumors. The main objective of this treatment is to elevate the temperature of cancerous tissue above 42°C to induce cell death while maintaining normal temperature in the surrounding normal tissues. Recently, microwave hyperthermia of brain tumor has gained attention due to advances in microwave hardware [2]-[5].

In a microwave hyperthermia system, the effective way to shape the temperature distribution can be realized by optimizing the electric field distribution inside the head via optimizing the excitation signals of the used antenna elements. As a result, a beamforming network [6] is required to control the phase and amplitude of each antenna for an accurate focusing of microwave power at a tumor location inside the head. In this case, the power divider is highly demanded in microwave hyperthermia as a feeding network. Since different hyperthermia applications require different frequencies of operation, a global feeding network needs to be designed to cover the whole bands usually used in microwave hyperthermia. Though this task ultimately requires tunable power dividers or tunable phase shifters, this work focuses on fixed wideband power divider as an initial step.

In this paper, a modified Wilkinson power divider with compact size and wideband performance in combination with dual element antenna array is proposed. The power divider act as the feeding network which is designed for microwave systems aiming to serve in head imaging (1 to 2 GHz). The two devices operate from 1 to more than 3 GHz assuming 10 dB of return loss as the reference. For the power divider, the high isolation between the output terminals is important to avoid any mutual effects between the antenna elements. Thus, the presented power divider has more than 15 dB of isolation across the band of interest. As a proof of concept, the design feeding network is tested in the presence of a realistic head phantom to show the distribution of electric fields in the head.

II. IN-PHASE POWER DIVIDER

The configuration of the proposed single layer in-phase power divider is exhibited in Fig.1. The three ports of the divider are at the top layer of the substrate, while the ground plane is at the bottom layer. A stepped impedance T-junction of microstrip lines are used at the input which is responsible for dividing the input signal into two equal parts. These two signals are supplied to the two input terminals which is connected to two pairs of parallel coupled lines afterwards. As depicted in Fig. 1, each pair of coupled lines has four ends. Two of them represent input and output terminal whereas the other two are left open.

The T-junction uses stepped impedance microstrip at the input and a pair of microstrip lines at the output to improve the matching with the input microstrip port and the coupled structure. The two sides of pair of the coupled structure has loose coupling whereas the central section has tight coupling. The design of the coupled structure follows the guidelines presented in [7].

The length of the stepped impedance T-junction connected to the input port, L_1 is chosen to be around a quarter of the effective wavelength at the center frequency of operation (2

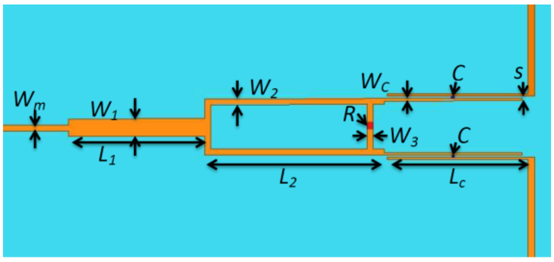


Figure 1: The whole configuration of the proposed power divider

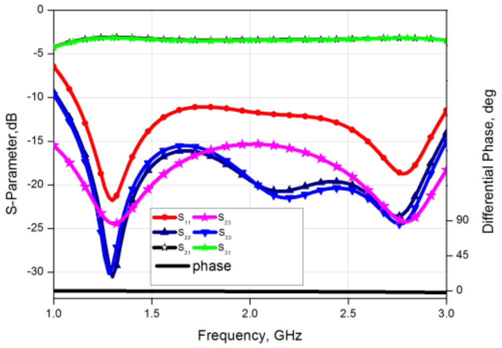


Figure 2: Performance of the power divider

GHz for the targeted band 1-3 GHz). The width of the input and output microstrip lines is chosen to be *Wm* which is a characteristic impedance of (Z_o) 50 Ω. Moreover, a pair of microstrip line with acceptable width of W_2 and suitable impedance transformation ratio of around Z_o is used to enable achieving the required matching. The length of microstrip line L_2 , is chosen to be a quarter of the effective wavelength at the center frequency of operation.

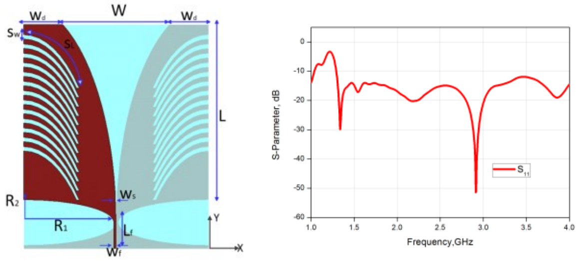
To achieve the required matching at the two output ports across a wide frequency band, this proposed device utilizes a pair of quarter wavelength coupled micorstrip lines which have an even- and odd-impedance of Z_{ce} and Z_{co} and electrical length of θ_c, are used to connect the output ports Moreover, to improve the isolation, two resistors (R) are connected between the microstrip line L_2 for an enhanced isolation between the output ports and to realize tight coupling between the central section of the coupled lines a chip capacitor is connected between the coupled lines to decrease its odd mode impedance.

The device is designed in Rogers RO6010 dielectric substrate with dielectric constant=10.2 and thickness= 0.635 mm using the simulation tool HFSS. The proposed design is compact with total dimensions of 30 mm × 60 mm. Based on the even-odd mode analysis, it is possible to conclude that the design parameters should have the following values calculated at the wavelength (λ) of the centre frequency (2 GHz): Z_1=Z_o/2, Z_2=Z_o, Z_{ce}= 75Ω, Z_{co}=40Ω, θ_1= θ_2= θ_c= λ/4, θ_3= λ/8, R=2Z_o, and C=2pF whereas the parameters of the divider in (mm) were found to be *Wm* =1.146, *Wc* = 0.29, *Lc* =10.7, *s*=1,L_1 =15, L_2=9.5, W_1=0.5, and W_2=W_3 =0.7.

Figure 2 illustrates the simulated results of the scattering parameters for the proposed power divider. The return loss at the input and output ports of the device is more than 10 dB across the band from 1 GHz to 3 GHz, whereas the isolation between the two output ports is more than 15 dB across the same band. It is found that the two output signals are in phase with less than 2° phase difference in the band from 1 GHz to 3 GHz as shown in Fig. 2.

III. ANTENNA

In this work, a wideband exponentially corrugated tapered slot antenna is implemented [8]. The geometry and the detailed parameters of the antenna are shown in Fig 3(a). The radiating structure of the antenna is in the form of antipodal corrugation. The width of the antenna is equal to the half of the effective wavelength at the lowest frequency of operation (1 GHz). The slot of the radiators and the ground plane of the Microstrip is tapered exponentially. The major and secondary radii of this ellipse are chosen using the guidelines presented in [10]. The dimensions of the antenna using the substrate Rogers RO3010 with dielectric constant = 10.2 and thickness = 1.28 mm are W = 90 mm, W_d = 2 mm, L = 95 mm, L_f = 15 mm, R_1 =43.8 mm, R_2 = 8.7 mm, and W_f = 1.189 mm. The slots used for the corrugations have a length S_L = 43.5 mm, whereas the space between each neighbouring pair of slots is S_w = 1 mm. Fig. 3(b) illustrates that the antenna has more than 10 dB reflection coefficient across the utilized band.



(a) (b)

Figure 3: (a) Whole configuration and (b) performance of the antenna

IV. SIMULATION SETUP OF FEEDING NETWORK

The network consists of the proposed power divider, a phase shifter and the two elements of the tapered slot antenna. One of the possible circuits to be used as a phase shifter in this network is the coupled-line phase shifter presented in [9]. A combination of the far field patterns of the two antenna elements with same phase and amplitude at each antenna input port produces the required radiation pattern which is achieved using the circuit simulator CST Design Studio. The antenna element spacing is an important element in the antenna array which determines the directivity with minimum mutual coupling. In this case, the solution converges to a maximum for the spacing of 40 mm. The antenna array with the feeding network is shown in Fig. 4. In this case, each of the devices is placed into the CST DS schematic and linked to the full-wave electromagnetic simulator afterwards.

The S-parameter and the directivity of the complete system consisting of all the three connected blocks is obtained as

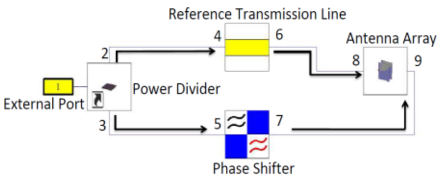


Figure 4: Schematic of the complete system

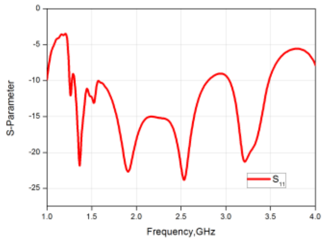
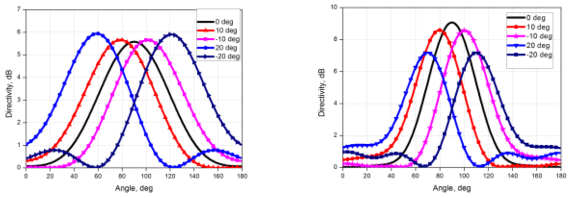


Figure 5: Reflection coefficient of the complete system



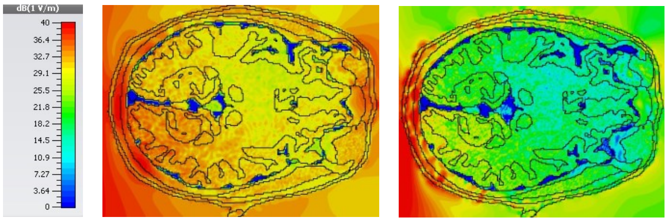
(a) (b)

Figure 6: Directivity of the complete system at (a) 2.5 and (b) 3.5 GHz

shown in Fig 5 and Fig 6. From the return loss of the complete system, it is found that the proposed two way modified Wilkinson power divider provides an in-phase signal to each port of the antenna, which generates more than 10 dB return loss over the band of the operating frequency (1 to more than 3 GHz).

As an example of how the presented feeding network can be used to control the direction of the mainbeam of the complete network, the phase shifter [9] is tuned to give 0°, 10° and 20° phase shift. The results depicted in Fig.6 at 2.5 GHz validates the controllability of the meanbeam direction.

Finally, as initial test on the feasibility of the designed network for brain tumor hyperthermia, a head phantom that includes the main tissues found in the human brain; skull, grey matter, white matter, and the cerebral spinal fluid (CSF) is placed in front of the network in the CST simulation environment. The electrical field distribution inside the head phantom is observed by the beamforming network at 1 GHz and 2 GHz, which shows penetration depth inside the head. It is clear that the low frequency 1 GHz has better penetration than the 2 GHz. However, it is expected that the focusing at 2 GHz will be better than the lower frequency bands. Thus, a compromise between the required hyperthermia focusing and head penetration will decide the best frequency for this application and this will be a topic for further research. To improve the performance of directivity of the network as well as to provide focused beam inside the head, tunable devices and full antenna array will be developed in the future for experimental validation.



(a) (b)

Figure 7: Electrical field distribution inside the head phantom at (a) 1 GHz and (b) 2 GHz.

V. CONCLUSION

A feeding network for brain tumor microwave hyperthermia has been presented. The network includes an in-phase power divider, phase shifter and two-element antenna array. It covers the band 1-3 GHz, which is usually used in microwave hyperthermia. The presented initial results prove the feasibility of the network. However, more work is need to improve the performance by building tunable power divider or tunable phase shifter across the band of interest, and optimize the number of antenna element and sued frequency.

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