Auto-Phase Calibration Loop of a Transmission Array for Development of New Diathermy Using Focused Microwave

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Abstract. We introduce an automatic phase calibration loop circuit and an extended time reversal method for a focused microwave thermotherapy system. We evaluate the loop circuit by measuring the phase errors at the array antenna feeding port. We compare these measurements with those without a loop. The results reveal that the reductions of overall phase are enough to focus fields at a target point.

I. INTRODUCTION

Diathermy is electrically induced heat as a form of physical therapy. The diathermy is commonly used for muscle relaxation, and as a method of heating tissue for therapeutic purposes. Recently, new diathermy techniques have been introduced. Focused microwave thermotherapy was introduced as a treatment for breast cancer by Alan J. Fenn [1], and its application can be extended to multiple disease of soft tissue, including musculoskeletal system. An advanced and focused microwave thermotherapy system for cases involving diseases of the leg is designed in this paper. Sections of the human leg are relatively complicated compared to breast cases. Many array elements with antennas, 16 for this application, are required, and each array has its own power transmitter for which the phase and magnitude are controlled. This concept is shown in Fig. 1.

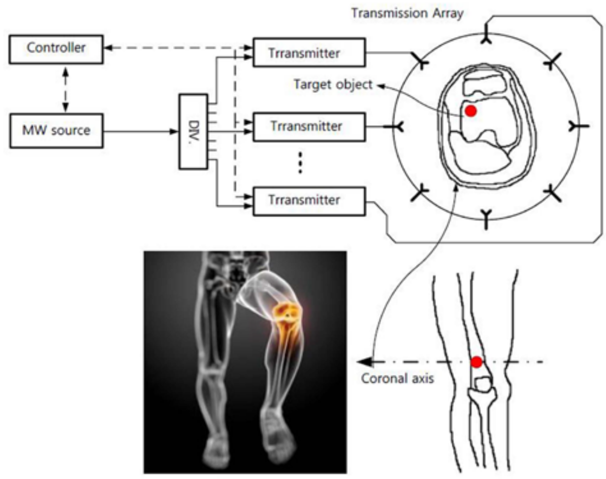

Fig. 1. Focused microwave thermotherapy system for human legs.

The initial phase to do this at each array element can be calculated using our extended time-reversal analysis concept. The original time-reversal method was introduced to focus ultrasound signals by Fink and others [2] - [4]. If one source is located at our target point, we can observe propagated sounds, $p(r, t)$ at our transmitter locations. When we transmit timereversed sounds, $p(r, -t)$, in reverse to the target point, the sounds will be focused and magnified at the point with inphase characteristics. However, microwaves differ from sound [5]. A simple change of the time direction cannot have any effect for microwaves. If we consider that they are plane waves, the measured field at distance d from the origin source has the standing $-\beta d$ and initial $-\phi$ phases of the origin, which are independent of time. We should reverse these phases and not the time, as we can then focus the fields transmitted from the array onto the target point. This concept is shown in Fig. 2. These reversed phases are assigned to and controlled by transmission array elements and are fed into the antenna ports. This procedure is also shown in Fig. 3.

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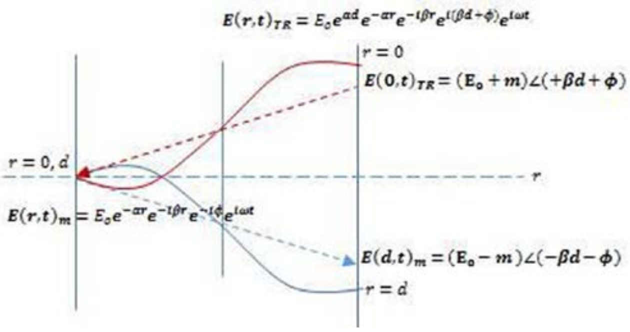

Fig. 2. Time-reversal propagation by the ray-tracing method

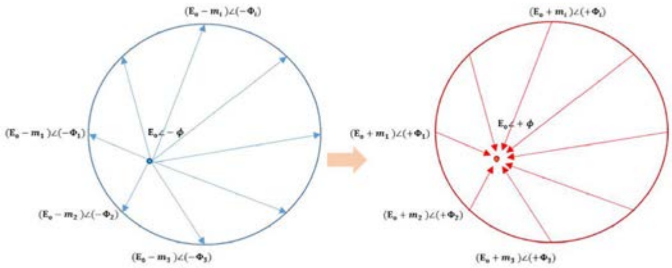

Fig. 3. Initial phase and magnitude design of transmission array

However, sections of human legs are not clear and simple. Control of the phase and magnitude should be accurate so as to focus the beam well and accurately within complicated leg tissues. If not, there will be burning of normal tissues and hazards in addition to poor targeting. When simulating the focusing of microwaves, phase errors of less than 11.25 degrees with five-bit control are acceptable, but component errors including those of the phase shifters, attenuators, cables and others when combined can practically exceed this value. An auto-phase calibration loop of a transmission array can be introduced to overcome this issue.

II. LOOP DESIGN

Total phase error compensation including the phase shifter itself is the function of the auto-phase calibration loop. The total phase error *Δø* is the summation of the variable attenuator error *δø1*, phase shifter error *δø2*, cable error *δø3* and the solidstate power amplifier error *δø4*. The circuit block diagram in Fig. 3 consists of a microwave transmission path and a feedback loop with phase detection. The circuit of a Costas loop is applied for phase detection. If the transmitted signal has not only a controlled phase ø but also errors *Δø* at the antenna feeding port, this can be detected and the loop controller changes the phase value to *ø-Δø* continuously until the error is minimized. The controller has a logic flow which determines the proper quantized phase, as each phase shifter has its own error.

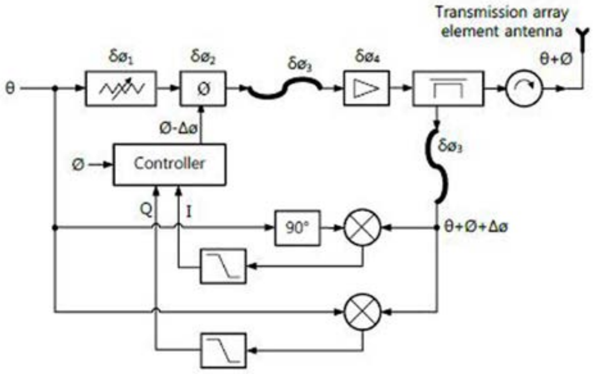

Fig. 4. Designed auto-phase calibration loop of a transmission array

III. AUTO CALIBRATION RESULT

The implemented voltage-controlled 30 dB attenuator has a maximum error of 15 degrees at 915 MHz, which is the system operating frequency. A five-bit digital phase shifter with low and high pass filters is designed for phase control. It has a maximum error of 12 degrees. The total maximum error is 27 degrees before the working of the loop. This is considerably far from our ideal requirement because the system only allows a maximum phase error of around 11.25 degrees. This is shown in Fig. 5.Equations should be centred and should be numbered with the number on the right-hand side.

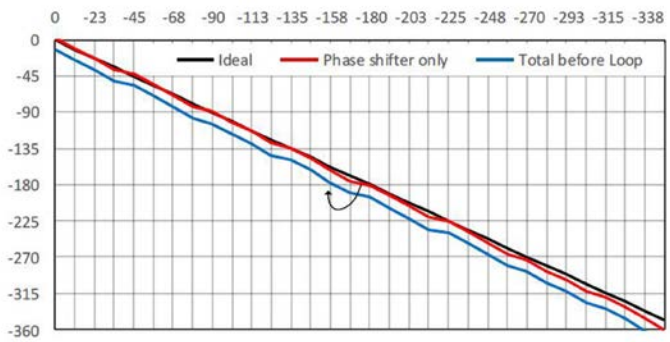

Fig. 5. Phase response before the working of the auto-phase calibration loop

After operating the auto-phase calibration loop, the total phase error including the phase shifter is reduced from 27 degrees to 7 degrees at a maximum. This result is feasible because it is superior to that of the phase shifter. This result is depicted by the curves shown in Fig. 6. The black line shows the ideal case as reference-controlled without any component phase errors.

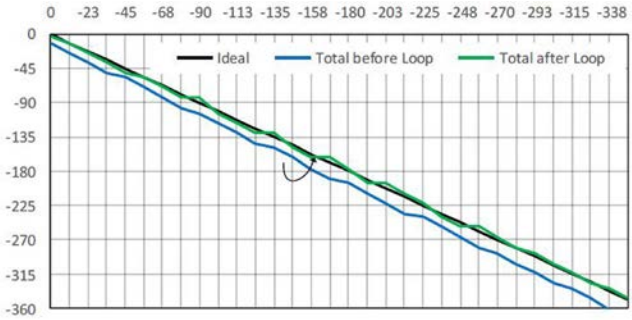

Fig. 6. Phase response after the working of the auto-phase calibration loop

IV.CONCLUSION

One dilemma associated with the focused microwave thermotherapy system involves measurements while it is working, as it is difficult to gain feedback except by inserting field devices or temperature sensors invasively inside the body. Even worse is that the system cannot guarantee exact signal phases, which are most important when attempting to focus the fields from the antenna ports. Inserting the auto-phase calibration loop reduces the phase error at the array antenna port from 27 degrees at a maximum to 7 degrees at a maximum. This is sufficient to focus fields at one point because the system requirements account for a maximum phase error of 11.25 degrees. For the next phase, we will build the full system and apply it in a preclinical study.

This work was supported by Electronics and Telecommunications Research Institute (ETRI) grant funded by the Korean government. [16ZR1300, Research on Beam Focusing Algorithm for Microwave Treatment]

References

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