**A Study to Design an Ultrasound Cylindrical Phased Array Used for Hyperthermia Treatment**

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**Abstract:** Breast cancer is usually treated with surgery, radiotherapy and chemotherapy. Fever-range hyperthermia treatments (HT) enhance the effect of radiotherapy and chemotherapy in terms of local tumor control and survival rates. Electromagnetic (EM) radiation is commonly used, however there is an increasing interest for using ultrasound (US) due to the larger penetration depth and better focusing capabilities. An adequate applicator for fever-range HT treatment of tumors in the entire intact breast region is not yet available. This work describes the theoretical design and characterization of an ultrasound cylindrical phased-array applicator. The US applicator is used to compute heating profiles in breast tumors and the results are obtained. The objectives of this paper is to describe the system of imaging using ultrasound, to analyze the current therapies of breast cancer, to simulate the fetus phantom using field ii program and then apply this program to the breast cancer, and to evaluate the heat distribution in the breast using k-wave toolbox.

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## 1. Introduction

In cancer treatment, hyperthermia became important as it increased significantly the therapeutic success and clinical management. Numerous biological and clinical investigations have demonstrated that hyperthermia in the 40-45°C range can significantly enhance clinical responses to radiation therapy, and has potential for enhancing other therapies, such as chemotherapy, immunotherapy and gene therapy [1] .

Furthermore, high temperature hyperthermia (greater than 50°C) alone is being used for selective tissue destruction as an alternative to conventional invasive surgery. The degree of thermal enhancement of these therapies is strongly dependent on the ability to localize and maintain therapeutic temperature elevations, due to the often heterogeneous and dynamic

Properties of tissues, most notably blood perfusion and the presence of thermally significant blood vessels, therapeutic temperature elevations are difficult to spatially and temporally control during these forms of hyperthermia therapy. However, ultrasound technology has significant advantages that allow for a higher degree of spatial and dynamic control of the heating compared to other commonly utilized heating modalities. [1]

## 2. Basic characteristics of ultrasounds

### 2.1 Ultrasound waves

Ultrasound is a mechanical vibration of matter that perturbs the particles of the medium around their mean positions. The frequency of the excitation is above the audible range, which is usually taken to be 20 kHz, but in practical systems the ultrasound frequencies used are between 2 and 20 MHz‘s. If the medium is elastic, the oscillating particles produce adjacent regions of compression and rarefaction and in this way the vibration initiated at one location can propagate through the medium. The origin of an ultrasound wave is, therefore, the pressure change that occurs when an elastic medium is compressed or expanded. It is this pressure disturbance that propagates and no net displacement of the particles occurs. [2]

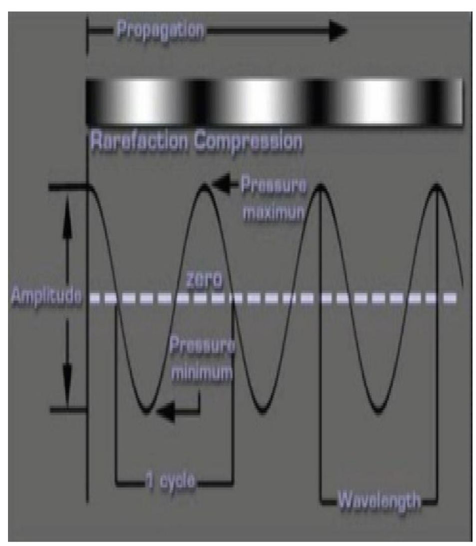


Figure 1: Propagation of sound waves. [2]

### 2.2 Description of basic system of ultrasound imaging

#### 2.2.1 Generation of ultrasound

Before analyzing these steps we have first to mention how the ultrasounds are created. In the figure below we can see the generation of an ultrasound with the use of piezoelectric effect.

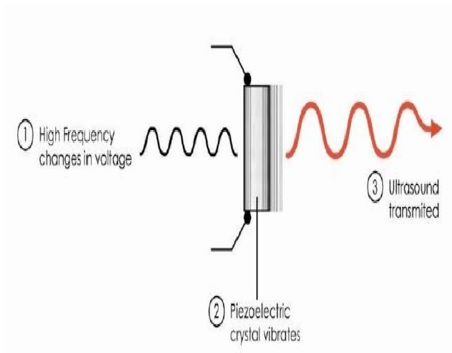


Figure 2: Generation of an ultrasound wave with the use of piezoelectric effect. [2]

The way that an ultrasound wave is generated in almost all the available transducers is the use of piezoelectric crystal. Piezoelectric comes from the Greek words –Piezo which means "puss of exert pressure" and –electric" which means –electricity". As it is obvious the terms piezoelectric refers to materials which when a voltage is applied on them then convert the signal into pressure oscillations in their surface via mechanical deformations. With the same way if a mechanical force is applied on the material this is then converting into electrical energy. This way by applying an electrical signal on one piezoelectric material we can monitor it, just by monitoring the voltage at the edges of the material. [2]

The beam shape that is generated by a transducer is determined by the design and construction of the probe. The two main categories are:

**Flat crystals**: create a straight acoustic beam up to a distance slightly higher than half the wavelength, which then starts diverging. The flat crystals can be divided into two main categories as following.

1) Linear arrays: acquire a rectangular image. The most widely used multi-element transducer. Typically, linear array consists of 64 to 256 elements, which are formed by slicing the ceramic into individual elements, each of them having its own electrical connection. The geometry of a linear array is shown in figure 3.

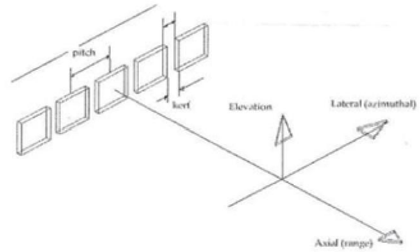


Figure 3: Geometry of a linear array and definitions of spatial imaging directions. [2]

The center to center distance is called pitch and the gap between elements is the kerf of the array. The direction of the elements is called lateral (or azimuthal). The height of the elements corresponds to the elevation direction and the direction perpendicular to the transducer surface is the axial (or range direction).

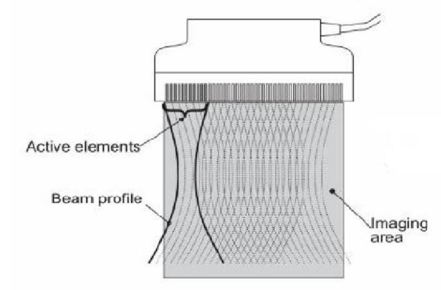


Figure 4: linear array imaging. [2]

2) Phased arrays: these transducers have the same geometry as the linear arrays, but they have a much smaller footprint and can scan an area much smaller than the size of the aperture.

For typical frequencies of 2 to 10 MHz, phased arrays are about 1 to 3 cm long, while the linear arrays are about 10 cm long.

They have a smaller number of elements compared to the linear array, typically 32 to 128 and their pitch is $\lambda/2$. It is possible to scan an area much larger than the size of the aperture in the azimuthal direction.

Phased array imaging essentially implements electronically the scanning process of a mechanically rotating single – element transducer. All elements are used both in transmit and in receive. As in linear array imaging, only a single transmit focus is possible for every emission, while several receive focal zones can be applied. The idealized beam pattern sketched in figure 2.6 corresponds to three different receive foci. Phased arrays are used in cardiology, where there is only a small –acoustic window between the ribs and the labs [2].

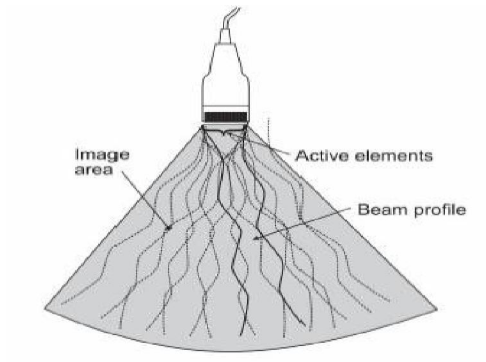


Figure 5: Phased array imaging. [2]

**Concave crystals** create a larger imaging region.

1) Convex arrays: in order to scan a sufficiently large region, the array has to be large. An alternative way to obtain a larger imaging region is to use a rectilinear (or convex) array, in which the elements are placed on a convex surface as shown at the figure 2.7. The method for focusing and scanning is essentially the same as in linear array imaging. In this case, a sector scan is obtained, which is scan converted before display.

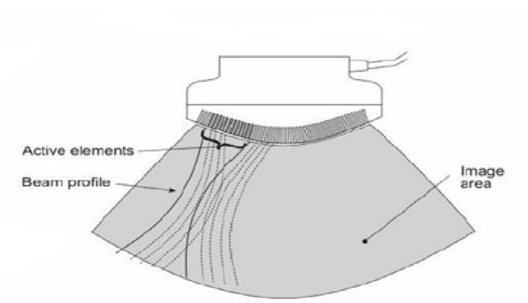


Figure 6: Convex array imaging. [2]

## 3. Breast Cancer

### 3.1 Introduction to breast cancer

Breast cancer is a type of cancer originating from breast tissue, most commonly from the inner lining of milk ducts or the lobules that supply the ducts with milk.[3] Cancers originating from ducts are known as ductal carcinomas, while those originating from lobules are known as lobular carcinomas. Breast cancer occurs in humans and other mammals. While the overwhelming majority of human cases occur in women, male breast cancer can also occur. [4]

The benefit versus harms of breast cancer screening is controversial. The characteristics of the cancer determine the treatment, which may include surgery, medications (hormonal therapy and chemotherapy), radiation and/or immunotherapy.[5] Surgery provides the single largest benefit, and to increase the likelihood of cure, several chemotherapy regimens are commonly given in addition. Radiation is used after breast-conserving surgery and substantially improves local relapse rates and in many circumstances also overall survival. [6]

### 3.2 Risk Factors

The primary risk factors for breast cancer are female sex and older age. [7] Other potential risk factors include: lack of childbearing or lack of breastfeeding, [8] higher levels of certain hormones, [9-10] certain dietary patterns, and obesity.

### 3.3 Prevention

Women may reduce their risk of breast cancer by maintaining a healthy weight, drinking less alcohol, being physically active and breastfeeding their children. [11] These modifications might prevent 38% of breast cancers in the US, 42% in the UK, 28% in Brazil and 20% in China. [11] The benefits with moderate exercise such as brisk walking are seen at all age groups including postmenopausal women. [11,12] Marine omega-3 polyunsaturated fatty acids appear to reduce the risk. [13]

## 4. Hyperthermia therapy

### 4.1 Introduction

Hyperthermia therapy is a type of medical treatment in which body tissue is exposed to slightly higher temperatures to damage and kill cancer cells or to make cancer cells more sensitive to the effects of radiation and certain anti-cancer drugs. [14] When combined with radiation therapy, it is called thermoradiotherapy. Whole-body hyperthermia has also been found to be helpful for depression. [15] local hyperthermia for certain small tumors is generally accepted, similar to surgically removing a tumor. whole body hyperthermia is generally considered to be a promising experimental cancer treatment.

Hyperthermia is only useful for certain kinds of cancer, and is not in widespread use. Hyperthermia is most effective when used alongside other therapies, so it is almost always used as an adjuvant therapy. [16,17] the most effective uses are currently being studied.

### 4.2 Mechanism

Hyperthermia may kill or weaken tumor cells, and is controlled to limit effects on healthy cells. Tumor cells, with a disorganized and compact vascular structure, have difficulty dissipating heat.

Hyperthermia may therefore cause cancerous cells to undergo apoptosis in direct response to applied heat, while healthy tissues can more easily maintain a normal temperature. Even if the cancerous cells do not die outright, they may become more susceptible to ionizing radiation therapy or to certain chemotherapy drugs, which may allow such therapy to be given in smaller doses.

### 4.3 Heat sources

There are many techniques by which heat may be delivered. Some of the most common involve the use of focused ultrasound (FUS or HIFU), infrared sauna, microwave heating, induction heating, magnetic hyperthermia, infusion of warmed liquids, or direct application of heat such as through sitting in a hot room or wrapping a patient in hot blankets.

### 4.4 Adverse effects

External application of heat may cause blisters, which generally heal quickly, and burns, which do not. [19] All techniques may result in pain or fatigue. Perfusion and moderate or high levels of hyperthermia can cause swelling, blood clots, and bleeding. [18] Whole-body hyperthermia, which is the riskiest treatment, usually results in diarrhea, nausea, vomiting, fatigue, and other symptoms of sunstroke; it may also cause cardiovascular problems. [17]

## 5. Results

### 5.1 Analysis of Field II, Methodology, Results

In order to achieve this kind of simulation we use Field II program which used for simulating ultrasound transducer fields and ultrasound imaging using linear acoustics. The program is capable of calculating the emitted and pulse-echo fields for both the pulsed and continuous wave case for a large number of different transducers.

The field II program is used in this paper to simulates the breast phantom which is used to apply the effects of changing the ultrasound transducer parameters and all the outputs photos will demonstrate that the output depend on some of parameters such that improve or abusive the clearance of the output, these parameters such as the transducer number of elements, transducer center frequency, the kerf (the spacing between elements), and the width of element.

#### 5.1.1 Results of Simulation in Field II

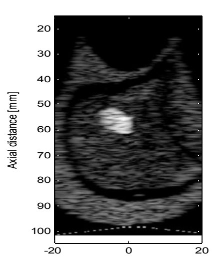


Figure 7: This phantom will be taken as the **reference** photo where changing the display angle of phantom to 80$^{o}$ in degree.

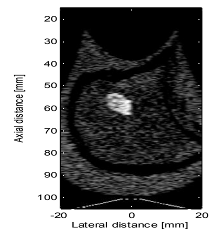


Figure 8: The number of physical elements is increased to 64 where the clearance of the breast phantom raised and the details is good.

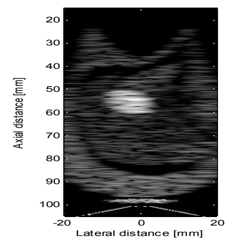


Figure 9: The number of physical elements is decreased to 16 where the clearance of the breast phantom is decreased and the details are very bad.

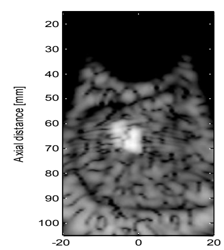


Figure 10: The transducer center frequency is decreased to 0.5 MHz where the clearance of the breast phantom is decreased and the details are lower than the reference output.

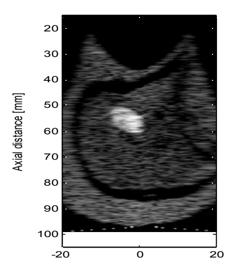


Figure 11: The transducer center frequency is increased to 5 MHz where the clearance of the breast phantom is increased and the details are very good compared with the reference output.

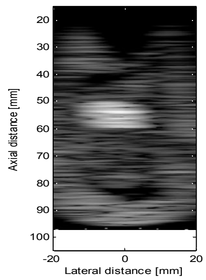


Figure 12: The width of element is decreased where the clearance of the breast phantom is decreased and the details aren't preferred compared with the reference output.

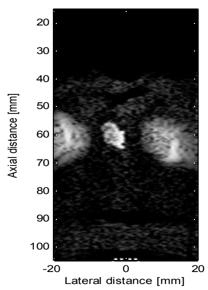


Figure 13: The width of element is increased where the clearance of the breast phantom is a very bad compared with the reference

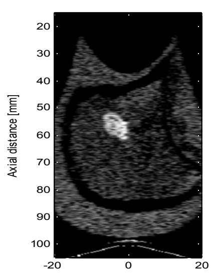


Figure 14: The transducer center frequency is increased to 5 MHz and the transducer spacing (kerf) to 100mm, and the transducer number of physical elements to 64 which demonstrates the best output compared with all previous outputs.

## 5.2 The k-Wave Toolbox analysis

The k-Wave toolbox is designed to make photoacoustic modeling easy and fast. The next examples show how the nonlinear beam pattern from an ultrasound transducer can be modeled. It built on the defining an ultrasound transducer and simulating transducer field patterns examples.

The k-wave toolbox is used in this paper to demonstrate a heat distribution pattern which shows that the maximum temperature is located at a certain point or a region. All the next programs will show the area such that the temperature is the highest compared with the surrounding area and this which we hope to reach to it so the area at which the malignant tumor is exposure to maximum temperature and the other cells doesn't effected.

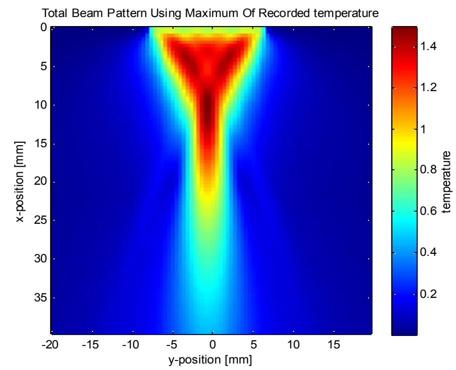


Figure 15: The transducer field pattern from above position demonstrates that the maximum temperature region located at x= [8:13] and y= [-1.5:1.5].

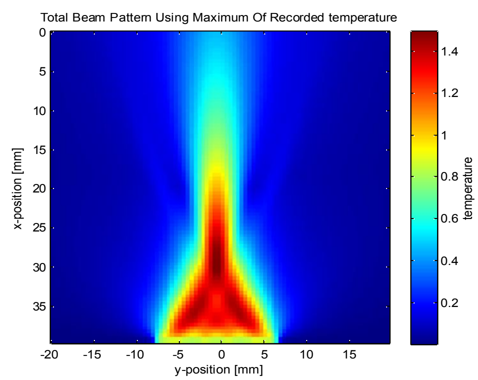


Figure 16: The transducer field pattern from bottom position demonstrates that the maximum temperature region located at x= [27:32] and y= [-1.5:1.5].

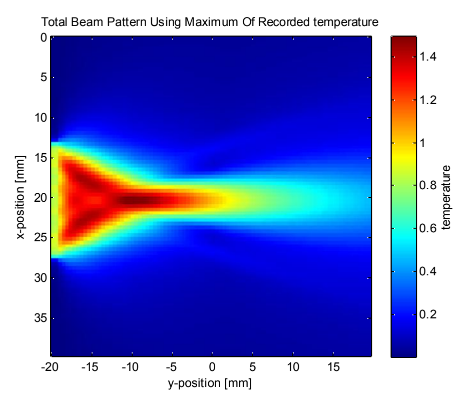


Figure 17: The transducer field pattern from left position demonstrates that the maximum temperature region located at x= [18.5:21.5] and y= [-12:-7].

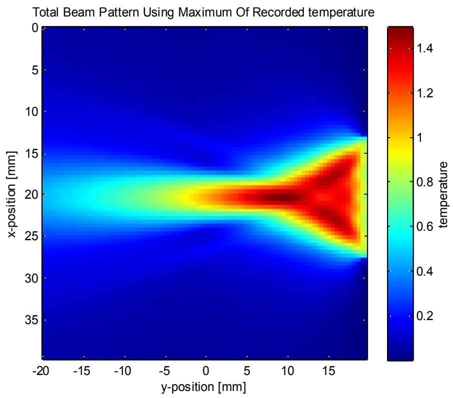


Figure 18: The transducer field pattern from right position demonstrates that the maximum temperature region located at x= [18.5:21.5] and y= [7:12].

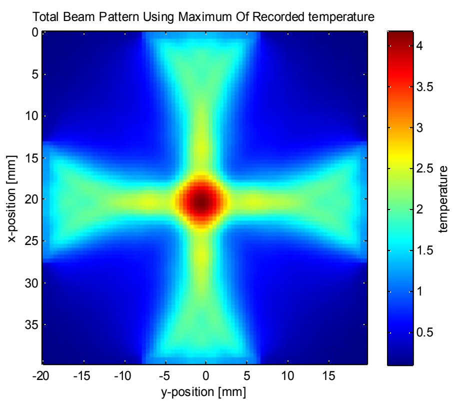


Figure 19: This field pattern is produced from summation of four ultrasound transducers from all positions to make a cylindrical array as shown, it demonstrates that the maximum temperature point located at x= [18:22] and y= [-2:2] and we will take this output as the **reference** for all the following programs.

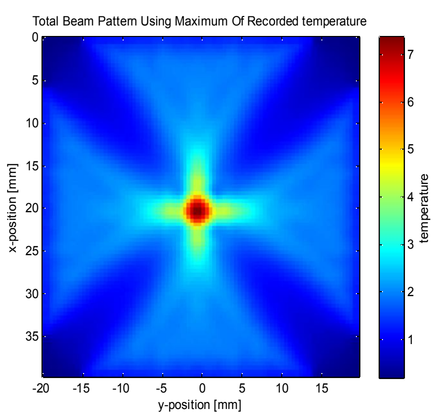


Figure 20: The transducer number elements are increased to 64 which demonstrate that the maximum temperature point located at x= [19:21] and y= [-1:1].

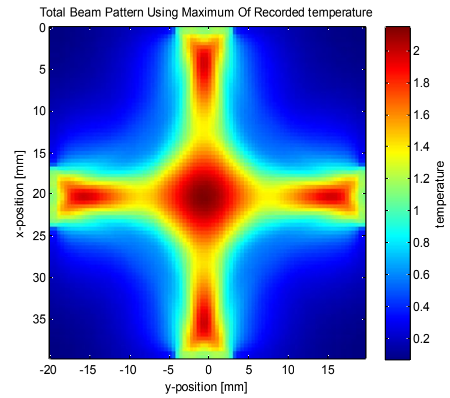


Figure 21: The transducer number elements are decreased to 16 which demonstrate that the maximum temperature point located at x= [17:23] and y= [-3:3] and there are unpreferable four regions at the face of transducers.

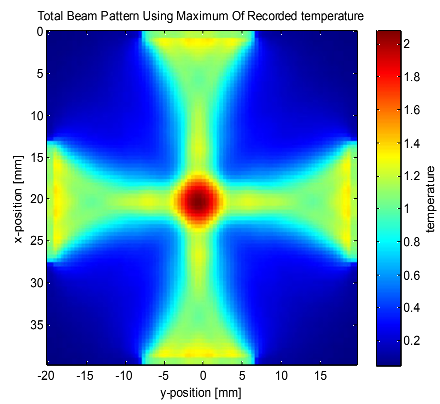


Figure 22: The transducer element length is decreased which demonstrate that the maximum temperature point located at x= [18:22] and y= [-2:2] and the heat distribution starts very close to the face surface of transducer.

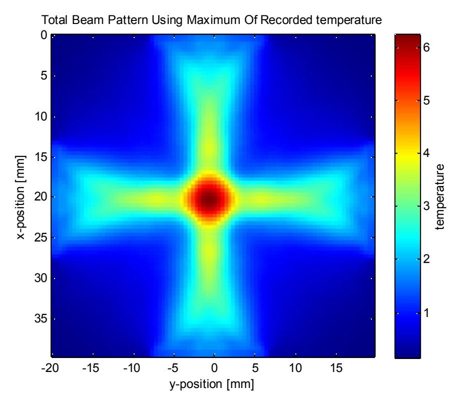


Figure 23: The transducer element length is increased which demonstrate that the maximum temperature point located at x= [18:22] and y= [-2:2] and the heat distribution starts far from the face surface of transducer.

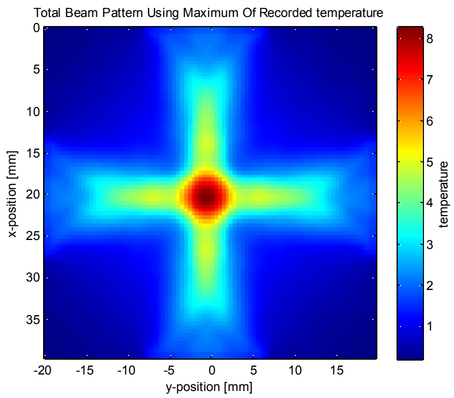


Figure 24: The transducer element length is more increased which demonstrate that the maximum temperature point located at x= [18:22] and y= [-2:2] and the heat distribution starts more far from the face surface of transducer.

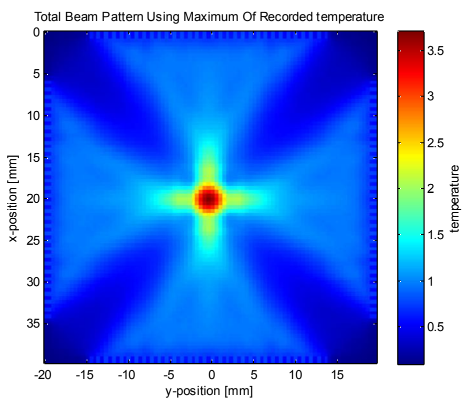


Figure 25: The transducer element spacing (kerf) is increased which demonstrate that the maximum temperature point located at x= [19:21] and y= [-1:1] and this output remember us when increasing the transducer number elements.

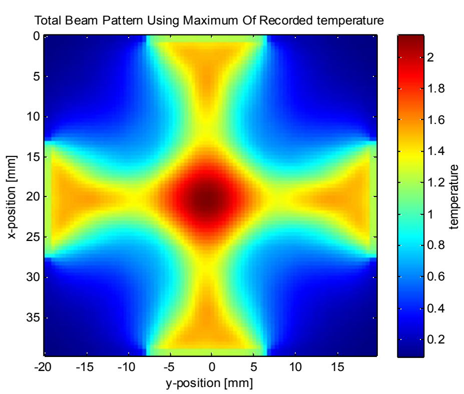


Figure 26: The transducer tone burst frequency is decreased to 0.5 (MHz) which demonstrates that the maximum temperature point located at x= [17:23] and y= [-3:3] and this output remembers us when decreasing the transducer number elements.

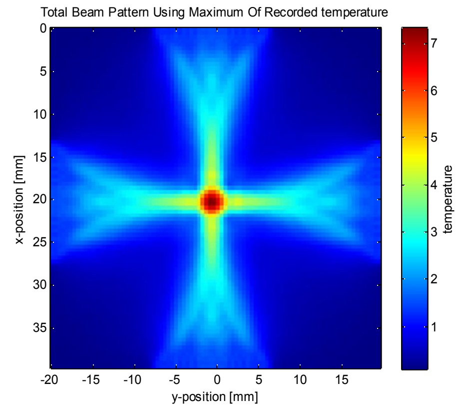


Figure 27: The transducer tone burst frequency is increased to 1 (MHz) which demonstrates that the maximum temperature point located at x= [19:21] and y= [-1:1].

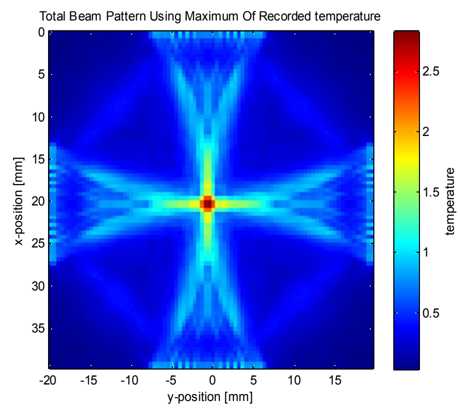


Figure 28: The transducer tone burst frequency is increased to 2 (MHz) which demonstrate that the maximum temperature point located at x= [19.5:20.5] and y= [-0.5: 0.5].

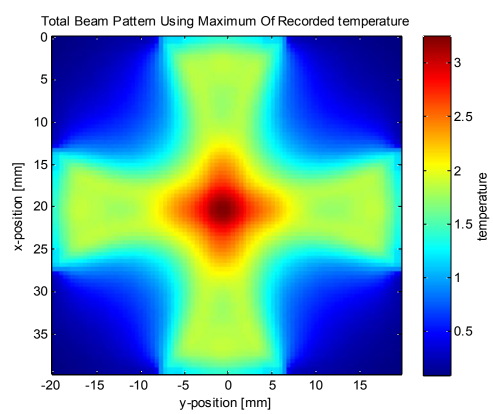


Figure 29: The transducer focus distance is increased which demonstrate that the maximum temperature region located at x= [17.5:22.5] and y= [-2.5: 2.5].

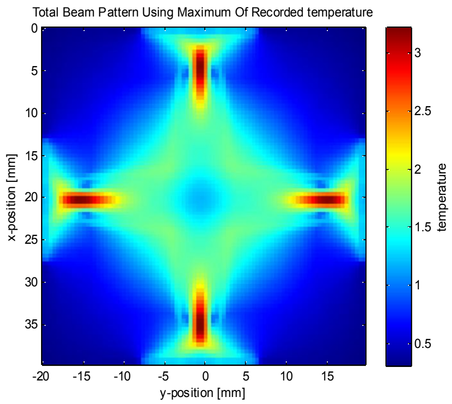


Figure 30: The transducer focus distance is decreased which demonstrate that the maximum temperature point located at four different points, and the output is the worst one compared with all the previous examples.

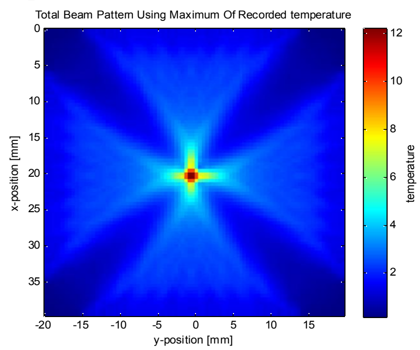


Figure 31: The transducer number elements are increased to 64 and the tone burst frequency is increased to 2(MHz), the maximum temperature point located at x= [19.5:20.5] and y= [-0.5: 0.5], as shown it demonstrates that the output is very good compared with all previous.

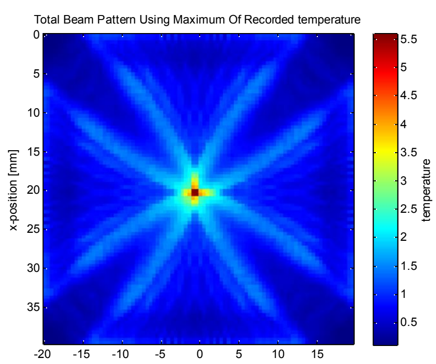


Figure 32: the transducer number elements and more increase the tone burst frequency, the maximum temperature point located at x= [19.6:20.4] and y= [-0.4: 0.4], as shown it demonstrates that the output is very good compared with all previous.

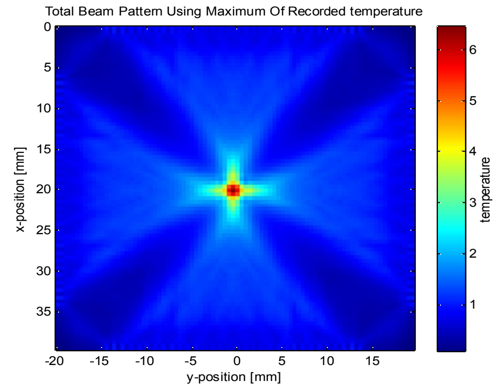


Figure 33: The transducer element spacing is increased and more increase the tone burst frequency, the maximum temperature point located at x= [19.6:20.4] and y= [-0.4: 0.4], as shown it demonstrates that the output is very good.

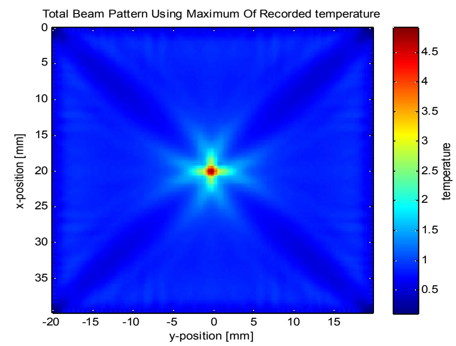


Figure 34: The transducer element spacing is increased and more increase the tone burst frequency and increasing the transducer number elements, the maximum temperature point located at x=[19.9:20.1] and y=[-0.1: 0.1], as shown it demonstrates that the output is the best one but take care when we increase the transducer element spacing and the transducer number elements the dimension of the output go out from the total grid point of the field pattern so we must increase and set total number of grid points from 128 to a number which is sufficient to contain the total grid points ,we use total number of grid points =178.

## 6. Conclusion

Simulations predict that a US cylindrical phased array, can be more focused where the transducer number of elements is increased to 64, the transducer element spacing is increased, and the tone burst frequency is increased to 2(MHz) which gives more concentration at a certain point such that gives the highest temperature at this point (breast cancer region) of breast and gives lower temperatures at the surrounding regions to keep other cells at the normal condition.

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