How can I calculate the size and shape of the focal zone?

The ultrasound pressure field produced by a piezoelectric focused element is typically of ellipsoid shape with varying axis relations depending on transducer geometry, energy settings and characteristics of the medium in which it propagates.

In cases, where the radiation element is similar to the element shown in Fig 1, it can be modelled numerically quite accurately, where e.g. the -6 dB boundaries of pressure intensity distribution can calculated in the XYZ space surrounding the focal zone.

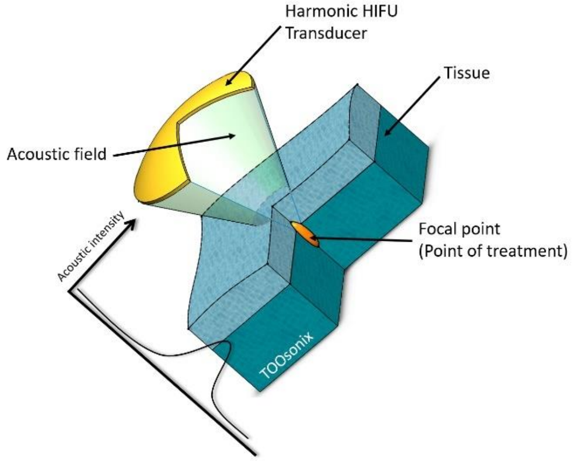

Fig. 1. Ellipsoidal focal zone e.g. defined by a -6 dB pressure zone around the geometrical focal point of the spherically focused piezoelectric element.

From the model, one can derive from that the maximum diameter of the ellipsoid, FD, in the plane perpendicular to the focal axis (i.e. the diameter of the ellipsoid) can be approximated by:

$$FD(6dB) \approx 1.44\left(\frac{R_0}{2a}\right)\lambda = 1.44FN\lambda$$

where a is the aperture of the spherically focused transducer of radius of curvature R0 and λ is the wavelength of the soundwave emitted from the focused element of F-number FN.

Similarly, the maximum length of the ellipsoid, or depth of focus, DoF, of a piezoelectric spherically focused element can be approximated by the following formula:

$$DoF(6dB) \approx 9.68\left(\frac{R_0}{2a}\right)^2\lambda = 9.68FN\lambda$$

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With this model, several key conclusions can be drawn, which are very useful when designing optimal transducers for certain HIFU treatments. The most profound conclusion for TOOsonix, as a producer of systems for accurate treatment of small features, is that the operating frequency need to be high in order to limit the size of the focal zone.

This conclusion can be quantified in the following two calculated examples.

Example 1

A piezoelectric spherically focused element made from a hard PZT material (e.g. Navy type I) is operated in water (c - comparable to speed of sound in tissue) under at 5 MHz and the following conditions:

Parameter	*Symbol*	*Value*	*Unit*
Sound velocity in water	*c*	*1480*	*m/s*
Frequency	*f*	*5*	*MHz*
Element diameter	*D*	*20*	*mm*
Element Focal radius	R_0	*15*	*mm*

One can calculate that the wavelength of acoustic wave in tissue (similar to water) would be 296 µm. This will result in a 6 dB focal zone, characterized by focal diameter of 320 µm with a depth of focus of 1612 µm.

Example 2

A piezoelectric spherically focused element made from a hard PZT material (e.g. Navy type I) is operated in water (c - comparable to speed of sound in tissue) under the same conditions as in Example 4, but at a frequency of 20 MHz:

Parameter	*Symbol*	*Value*	*Unit*
Sound velocity in water	*c*	*1480*	*m/s*
Frequency	*f*	*20.00*	*MHz*
Element diameter	*D*	*20*	*mm*
Element Focal radius	R_0	*15*	*mm*

At this frequency one can calculate the wavelength of an acoustic wave in tissue (similar to water) would be 74 µm. This smaller wavelength, compared with that generated by a 5 MHz element, will result in a smaller 6 dB focal zone characterized by focal diameter of 80 µm and a depth of focus of 403 µm.