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ELECTRONIC FOCUSING OF THE ULTRASONIC BEAM BY MEANS OF AN ANNULAR ARRAY SYSTEM

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In conventional mechanical contact scanners the lateral resolution is inferior to the axial one. Improving the lateral resolution over a wide range of depth requires the use of a variable focusing system. We choose the phase annular array system which may be used in obstetrics and gynaecology.

Calculations of the acoustical pressure were performed assuming pulse excited transducers. For the transmission the range of examination was divided into five focal zones. During reception the system permits dynamic focusing. Measurements of the ultrasonic beam were carried out. These results are in good agreement with calculations and indicate a considerable increase in the lateral resolution.

1. Introduction

In order to obtain the maximum amount of information about the tissues under examination by the *B*-mode ultrasonograph, it is necessary to have as good resolution of the ultrasonograph as possible.

In the present state of ultrasonic technology the most negative effect on the resolution is exerted by the lateral resolution of the ultrasonic system. The lateral resolution is determined by the transmitted beam and receiver directivity pattern.

The aim of this work is to indicate the possibilities of decreasing the width of the ultrasonic beam, i.e. improvement in the lateral resolution.

2. Method

The well known method to narrow the ultrasonic beam uses a transducer with a superimposed lens or a transducer which has a special concave aperture [1]. This kind of focusing is efficient only in a short range.

It is possible to focus over the whole observation range when a multi-element ultrasonic probe, controlled by an appropriate electronic system is used [2, 3, 6]. A multi-element annular array consists of coaxial elements: a disc and surrounding rings. The disc and the rings are excited to vibration. The moment of excitation of a successive element in the probe is related to the wave front as required for focusing at a proper distance on the axis of the transducer. At transmission the beams can be focused successively at discrete distances. This corresponds to several foci over the investigated range.

During reception it is possible to achieve continuous focusing, by continuous change of the delay of the signals received, with the velocity equal to the ultrasonic wave propagation velocity. This is so-called dynamic focusing (Fig. 1).

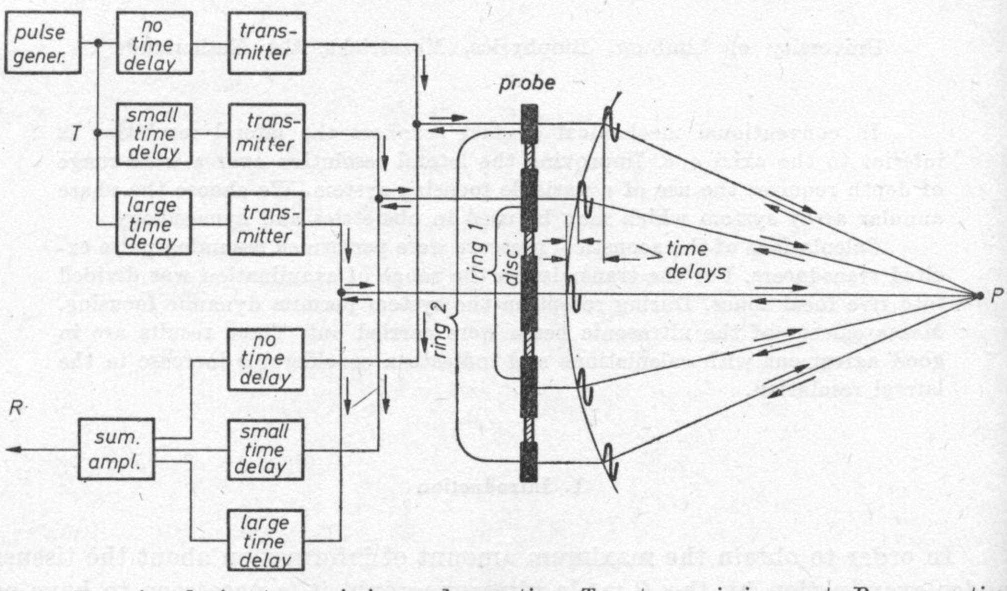

Fig. 1. Focusing during transmission and reception. T – transmission part, R – reception part

In our case we expect such an ultrasonic beam focusing system to be used in obstetrics and gynaecology, that is why 2.5 MHz frequency was chosen for the transducer with depth of range 0-24 cm; the surface of the transducer is in touch with the surface of the body. On the basis of theoretical analysis of the lateral resolution for an annular array excited by continuous wave and short pulses, depending on the size, configuration and the excitation method, the ultrasonic probe was built. This probe consists of seven coaxial elements of piezoelectric ceramic: a disc and six rings [5]. The diameter of the disc is about 10 mm and the external diameter of the outside ring is about 40 mm. All the elements have the same surface area. This permitted the achievement of:

a) the same electric impedance of all elements, i.e. the same electric loading of all transmitters,

b) practically the same distance of the transition point between the near and far fields, for the disc and all the rings [6, 8].

The annular array works with an electronic system which was built with a large application of the TTL integrated circuits and the PROM memories [8]. A block diagram of such electronic system is shown in Fig. 2. The seven trans-

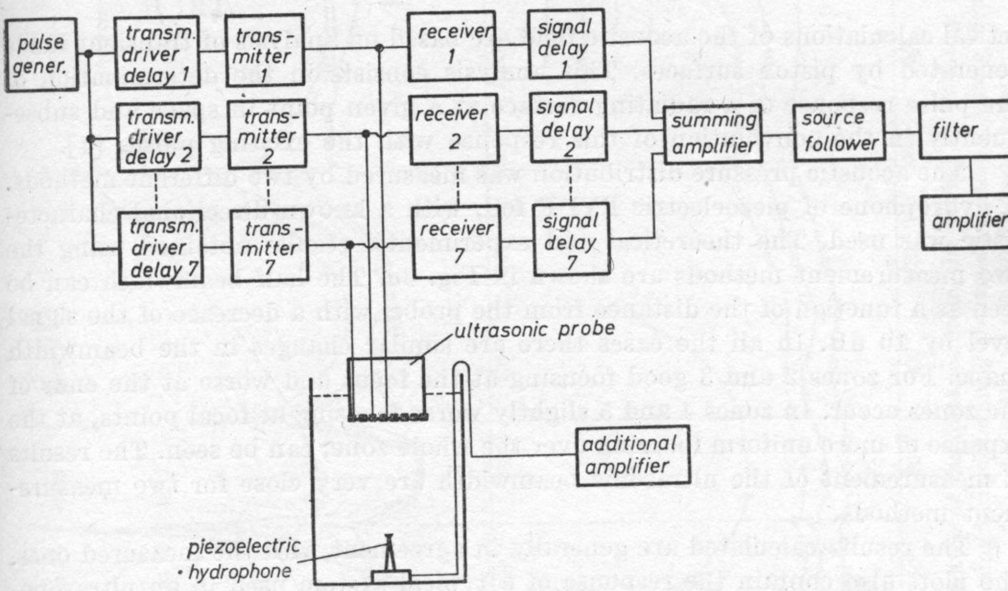

Fig. 2. Block diagram of the system for electronic focusing of the ultrasonic beam

mitter drivers in which the proper delays are programmed, steer the seven transmitters. Each transmitter excites the proper element of the annular array. A hydrophone measures the ultrasonic pressure distribution. The hydrophone can be replaced by a reflector and then the signals reflected after amplification are delayed continuously in the signal delay circuits, and added in the summing amplifier. On the basis of the earlier analysis and measurements [7], the whole range $0 \div 24$ cm was divided into five zones.

Zone 1 : from 0 to 50 mm, with only the disc transmitting.

Zone 2 : from 50 to 70 mm, focal point 60 mm, three elements: the disc and two internal rings transmit.

Zone 3 : from 70 to 90 mm, focal point 80 mm.
Zone 4 : from 90 to 140 mm, focal point 110 mm.
Zone 5 : from 140 to 240 mm, focal point 180 mm.
In zones 3, 4, 5 all the seven elements of the probe transmit.

3. Results

The theoretical calculations and experimental measurements of the acoustic pressure distribution were carried out only during transmission. In the calculations a pulse shape closest to one in practice was assumed. This pulse contains five sinusoidal high frequency periods with the envelope $\sin^2\left(\frac{\pi}{2}t\right)$. The theoretical calculations of the acoustic field are based on analysis of transient fields generated by piston surfaces. This analysis consists in the determination of the pulse response of a radiating surface at a given point in space and subsequently in the convolution of this response with the exciting pulses [4].

The acoustic pressure distribution was measured by two different methods. A hydrophone of piezoelectric PVDF foil, with a known directional characteristic was used. The theoretical and experimental results obtained using the two measurement methods are shown in Fig. 3*a*. The half beamwidth can be seen as a function of the distance from the probe, with a decrease of the signal level by 10 dB. In all the cases there are similar changes in the beamwidth shape. For zones 2 and 3 good focusing at the focus and worse at the ends of the zones occur. In zones 4 and 5 slightly worse focusing at focal points, at the expense of more uniform focusing over the whole zone, can be seen. The results of measurement of the ultrasonic beamwidth are very close for two measurement methods.

The results calculated are generally in agreement with the measured ones. The plots also contain the response of a typical system used in an ultrasonograph for examination of the abdominal structures (frequency 2.5 MHz, diameter of transducer 20 mm). The ultrasonic beam radiated by the annular array system is narrower and much more regular over the whole range under study.

The distribution of the measured signal amplitudes over the whole range is shown in Fig. 4*A*. Greater amplitudes occur in zones 3, 4, 5, it should be mentioned, however, that all the elements transmit to these zones. At the ends of zones 2 and 3 there is a distinct effect of the side lobes. The amplitude distribution is rather regular over the whole range under study.

The second part of measurements was made with focusing in zones during transmission and dynamic focusing during reception. The hydrophone was replaced by a small reflector (platinium ball with 0.3 mm diameter). In zone 1

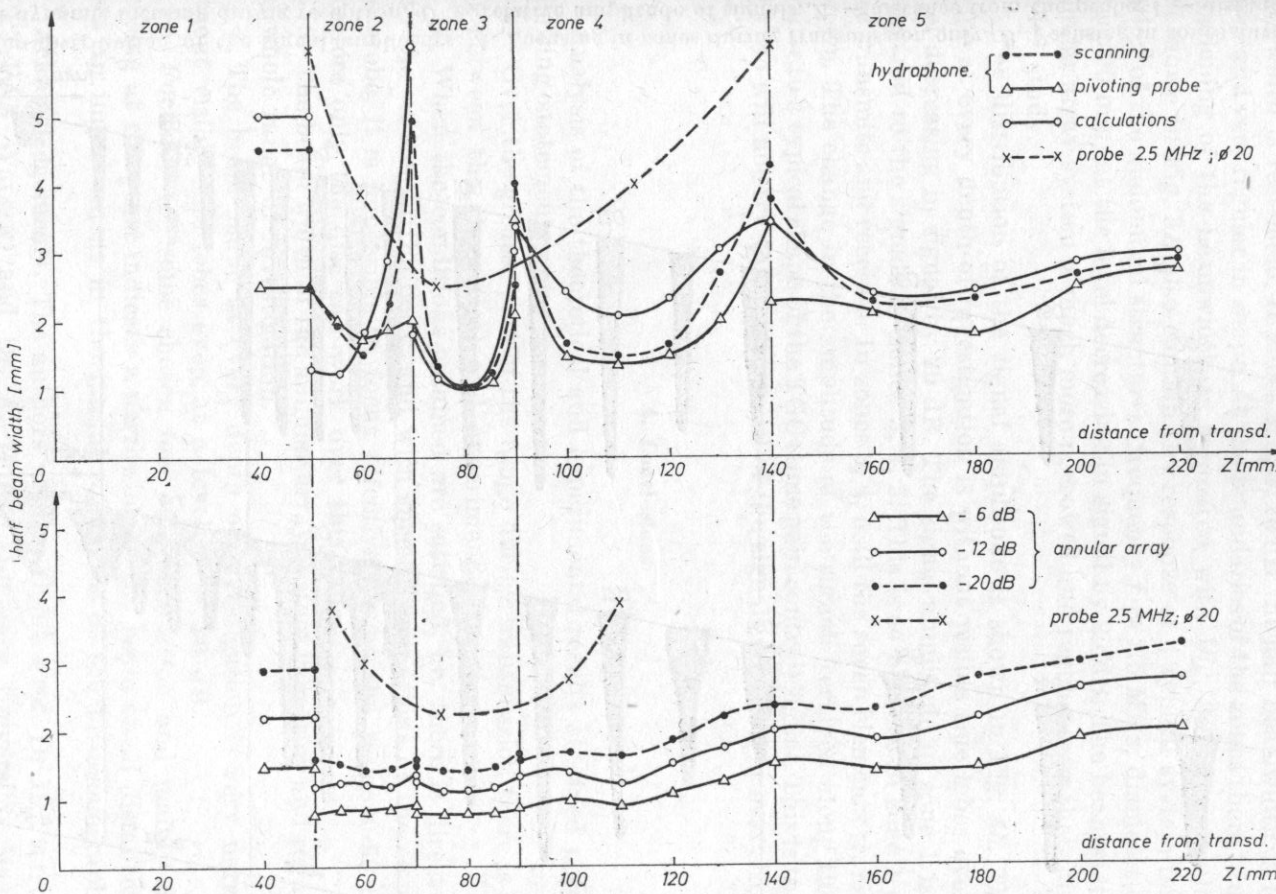

Fig. 3. Half beam width as a function of the distance from the probe. *A*. Focusing in zones during transmission only. Signals drop by 10 dB. *B*. Focusing in zones during transmission and dynamic focusing during reception. Signals drop by 6 dB, 12 dB, 20 dB respectively

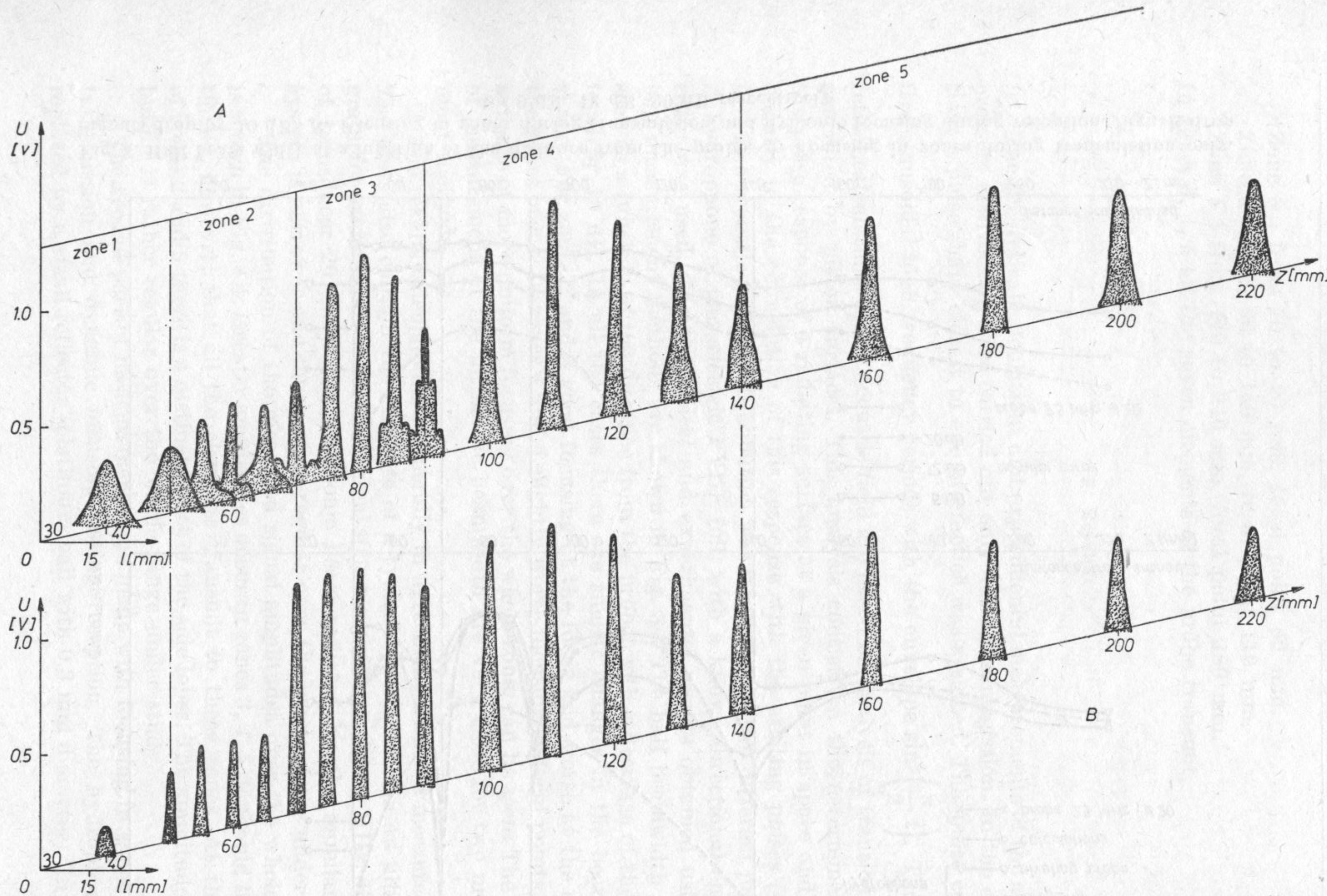

Fig. 4. The distribution of the signal amplitudes. *A*. Focusing in zones during transmission only. *B*. Focusing in zones during transmission and dynamic focusing during reception, U — relative amplitude of signals, Z — distance from the probe, l — distance off axis

only the disk receives. In the zones 2, 3, 4, 5 all the elements receive. The results of measurements are shown in Fig. 3*B* at three different levels with signal decreases of 6 dB, 12 dB, 20 dB. In zone 1 where only the disk works half the beamwidth is restricted. In zones 2, 3, 4, 20 dB the half beamwidth is less than 2 mm and very regular in shape. At the boundaries of the zones there is no visible broadening of the beamwidth as compared with Fig. 3*A*. The results which are shown in Fig. 3*B* also contain the response of a typical system for examination of the abdominal structures (frequency $f = 2.5$ MHz, diameter of transducer 20 mm) at the level decreasing in signal by 20 dB. The beamwidth of the annular array system is much more narrowed and regular over the whole range under study.

The distribution of the signal amplitude is shown in Fig. 4*b*. The beam shape at every depth of investigation is without visible side lobes even at the level decreasing in signal by 20 dB. The signal amplitude in zone 1 is smaller compared to the signals in zones 3, 4, 5. This is so because in zone 1 only the disc transmits and receives. In zones 3, 4, 5 all the seven elements transmit and receive. The change in the amplitude of the signals received along the axis is similar to a typical shape of the TGC (time gain control) signal. This is the reason why we will not try to equalize level of the signals received in every zone.

4. Conclusions

Analysis of the theoretical and experimental results obtained permits the following statements.

1. Over the greater part of the range during transmission there is agreement between the theoretical and experimental results.

2. When the conditions assumed are satisfied, i.e. there is direct contact with the surface of the body, and with specific dimensions of the elements of the probe, it is impossible to focus effectively over the range 0-50 mm and therefore only the disc can work over this range.

3. The beam width of the annular array system is narrow and regular over the whole range of investigation.

4. The beam shape at every depth of investigation is very narrow and without visible side lobes even at a level of − 20 dB.

5. Focusing for some chosen foci at transmission and mainly dynamic focusing at reception indicate a narrowing of the beam at all distances and it gives an improvement in the lateral resolution of the ultrasonograph.

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References

[1] L. Filipczyński, G. Łypacewicz, J. Sałkowski, T. Waszczuk, *Automatic eye vizualization and ultrasonic intensity determination on focused beams by means of electrodynamic and capacitance methods,* Ultrasonics in Medicine Katzner *et al.* (eds.), Excerpta Medica, Amsterdam, Oxford, 1975.

[2] M. Hubelbank, O. J. Tretiak, *Focused ultrasonic transducer design,* M.I.T. Res. Lab. Elect. Q.P.R. 1971, 169-177.

[3] G. Kossoff *et al., Annular phased arrays in ultrasonic obstetrical examinations,* Advanced Study Institute, Ultrasonic Diagnostics, Milan, June 1974.

[4] T. Kujawska, *Dynamic focusing of an ultrasonic beam by a phased array using the pulse method,* Archives of Acoustics, **8**, 1, (1983).

[5] T. Maruk-Kujawska, *Dynamic focusing of an ultrasonic beam by annular transducers* (in Polish) (doct. diss.), Institute of Fundamental Technological Research, Polish Academy of Sciences, Warsaw 1980.

[6] H. E. Melton, F. L. Thurstone, *Annular array design and logarithmic processing for ultrasonic imaging,* Ultrasound in Biology and Medicine, **4**, 1-12 (1978).

[7] T. Waszczuk, J. C. Somer, *System for dynamic focusing of an ultrasonic beam using annular array, practical implementation,* Proc. XXVII Open Seminar on Acoustics, Warsaw-Puławy, September 1980.

[8] T. Waszczuk, J. C. Somer, T. Kujawska, *Focusing of an ultrasonic beam by means of a piezoelectric annular array,* Archives of Accoustics (in press).