MULTI FREQUENCY ARRAYS

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1. Introduction

Table 1 lists a few of the operating parameters of a 300 kHz sector scanner[1] which utilises thickness mode resonant ceramic transducer elements, whose dimensions and certain material constants are given in Fig.1. The receiver electronics are assumed to be of the modulation type, although the multi-frequency concepts we shall discuss are by no means exclusively applicable to this type of processor. The parts of such a system which are frequency dependent are the transmitter and receiver transducer arrays and their corresponding electronics.

The operation of this system at a different frequency would normally require a separate set of transducer arrays, considerable modifications to the receiver electronics and possibly some small changes in the transmitter electronics. Operation *simultaneously* at two different frequencies requires two complete sets of equipment. This presents merely the problem of cost as far as the electronics are concerned: twice the equipment at (roughly) twice the price; but when the problems of stabilising and training two sets of arrays of comparable dimensions are considered it is clear that more than the cost of an additional set of arrays is involved, though that is no small consideration in itself.

These difficulties may largely be resolved if the transducer arrays may be operated at two or more different frequencies *with reasonable overall efficiency*. As a result of the use of an efficient element mounting technique[2], it has been found that an array intended for use at high frequency in the thickness resonant mode of element excitation may, with slight modification, also operate quite acceptably in the length and width modes of element vibration, the frequencies of which are indicated in Table 1.

In this paper we shall present results which demonstrate the operation of a particular transducer at various frequencies, then we shall discuss the potential applications of a sector scanner operating at three frequencies and also indicate the preliminary results from a single frequency system which utilises the width resonant frequency, in order to avoid the use of elements of sandwich construction.

2. Piezo-electric Transducer Elements and Array Construction

To be of use in a sonar system, a particular mode of element vibration must possess at least two characteristics: firstly, the efficiency of electro-acoustic energy conversion must be acceptably high, and secondly, the beam patterns obtained from single elements should conform reasonably well to those expected theoretically. The first condition (reasonable efficiency) ensures that the transmitter electronics need not be large and that excessive heat is not generated in the transmitting transducer, as well as keeping the signal to noise ratio in the receiver high.

The efficiency of an element may be estimated in several ways. One convenient way is to measure the resistive component of the impedance at the operating frequency when the element is air loaded, when it is mounted and air loaded and when it is mounted and water loaded. This enables estimates of the mechanical (internal) and the mounting losses to be made. The results of these tests for a crystal of the dimensions shown in Fig.1 are shown in Fig.2. In Fig.2c the thickness, width and length modes are identified, though other modes are present also. Fig.3 shows the vertical beam patterns for several of these frequencies. The beam patterns are of the sin(x)/x form expected of radiation from a flat rectangular plate. These beam patterns were obtained from single elements mounted so that the electroded faces of the thickness resonant mode radiated directly into water. Thus the aperture size for beam pattern calculation is determined by the dimensions of this face.

One of the major problems in the design of multi-channel receiver arrays is the minimisation of inter-element cross-talk, which may be achieved in the case of width mode resonance, only by increasing the inter-element spacing. At a spacing of 0.5mm the cross-talk between adjacent elements is less than -30dB (less than -40dB for adjacent-but-one) when the thickness resonant mode is used, but this rises to about -18dB when the width mode is excited, which necessitates an interelement spacing of about 2mm. This causes a rise in grating side lobe levels at the higher two frequencies of operation. The lowest frequency grating side lobe is missing ($n > L/\lambda$ where n = number of elements and L = array length). The effect of element spacing is shown in table 2 for an array of 75 elements 9.5mm wide. The cross-talk figures Table 3 are experimental results, whereas the grating side lobe levels are estimated from some experimental data related to slightly different array geometries. Our experience leads us to the conclusion that, with our method of construction, 2mm is more than sufficient inter-element spacing.

3. Multi-frequency Arrays

From the previous results it is clear that singly mounted elements operate at several frequencies quite satisfactorily, but further investigation is required to be sure than an array is operating in an unimpaired manner at all frequencies. Thus, beam patterns, directivity indices and source levels must be measured. These measurements have been performed on a 15 element linear array with the results set out in Table 4 and Fig. 4, together with a comparison of efficiencies obtained by the admittance circle method and as calculated from source level measurements. (These experimental results suggest that a single receiver array, about one metre long and containing up to 90 channels, can be used at three frequencies as a scanning array. The resulting variations in the scanner system parameters are set out in Table 1)

We now turn our attention to the transmitter array, where the problems are slightly different, and the specification differs at each frequency. Fortunately, the power required at a given frequency of operation diminishes as the frequency is reduced, even though the range is increased. The specifications for the transmitters for three frequencies of operation are outlined in Table 5 and are shown diagrammatically in Fig. 5. The transmitter vertical height is increased as the frequency of operation falls to keep the vertical beamwidth constant at about 5°. The 300 kHz transmitter is reduced in size from that of a typical sector scanner and has a reduced power handling capability, as the longer range work may be more readily carried out a lower frequency.

Applications forseen for a three frequency system include sea bed survey and location work, since the area of the scan increases with decreasing frequency approximately as f^{-2}. Once an object of possible interest is located the search vessel may be moved in the indicated direction and the system switched to higher frequency as the range is reduced, thus making use of the greater resolution obtained with the higher frequency modes of operation. Simultaneous operation in all frequency modes is quite feasible, since experience with two independent array systems at two differing operating frequencies indicates that there are no problems with unwanted acoustic interaction. Assuming that the problems of multiplexing the receiver channels to three different receiver electronics with acceptable cross-talk are overcome, then a display of the three frequency system might look like Fig.6, where all three outputs are displayed on one video screen.

An alternative approach would be to retain the same sector size at each operating frequency by combining adjacent elements at the lower frequencies prior to modulation. Since the bandwidth of each receiver channel is then identical at all frequencies and the number of channels required at the lower frequencies is reduced, the increased range achieved may be bought relatively cheaply in terms of additional receiver electronics.

4. Width Mode Sector Scanner

As an illustration of the use of non-thickness-resonant modes of vibration in a sector scanner we shall take a look at a sector scanner built recently at LUT. A requirement arose for a sector scanner operating at 75 kHz for which thickness resonant ceramic elements could not be manufactured because of the high polarisation voltage required (1kV/mm). Previously, a system had been built using elements like those in Fig.1, but with each dimension doubled, thus resulting in a thickness resonant frequency of 150 kHz and a width resonance of 75 kHz. Tests were made on the 150 kHz receiver array to examine the possibility of operation at 75 kHz, with the results described already. The specification of the arrays which have been built to operate at 75 kHz in the width mode are set out in Table 6. The beam patterns of the transmitter and receiver arrays are shown in Fig.7. This system has now been commissioned and works satisfactorily, at its designed frequency, but tests with the 150 kHz receiver electronics show that this set also works much as expected at 150 kHz.

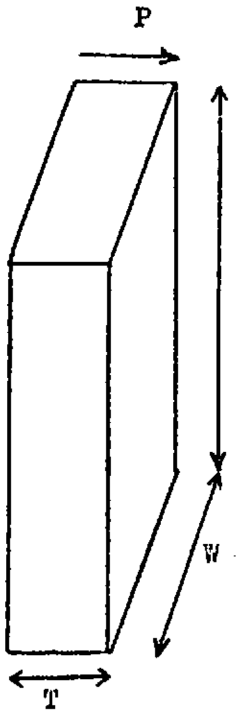
5. Conclusion

It has been demonstrated that, by using low acoustic impedance mounting materials, rectangular piezo-electric elements may be used at any of the three basic resonant frequencies without significant reduction in the operating specifications of the equipments with which they are to be used. Work is in progress to examine other sonar systems, such as side scanners and echo integrators, to determine whether operation at several frequencies, either simultaneously, or as an option, will lead to enhanced capabilities or new applications.

References

1) Holley, M., Mitson, R.B., Pratt, A. R., Recent Advances in Scanning Sonar Systems, "IERE Conf. on Oceanography" Bangor 1975.

2) Pratt, A. R., Stevens, P. J., "High Frequency Deep Water Arrays" I.O.A. Transducer Workshop, December 1976



P. Direction of polarisation.
c. velocity of sound.

c_T = 4000 m/s.

$c_W = c_L$ = 3300 m/s.

Typical element dimensions.

T = 6.7 mm.
W = 9.5 mm.
L = 23 mm.

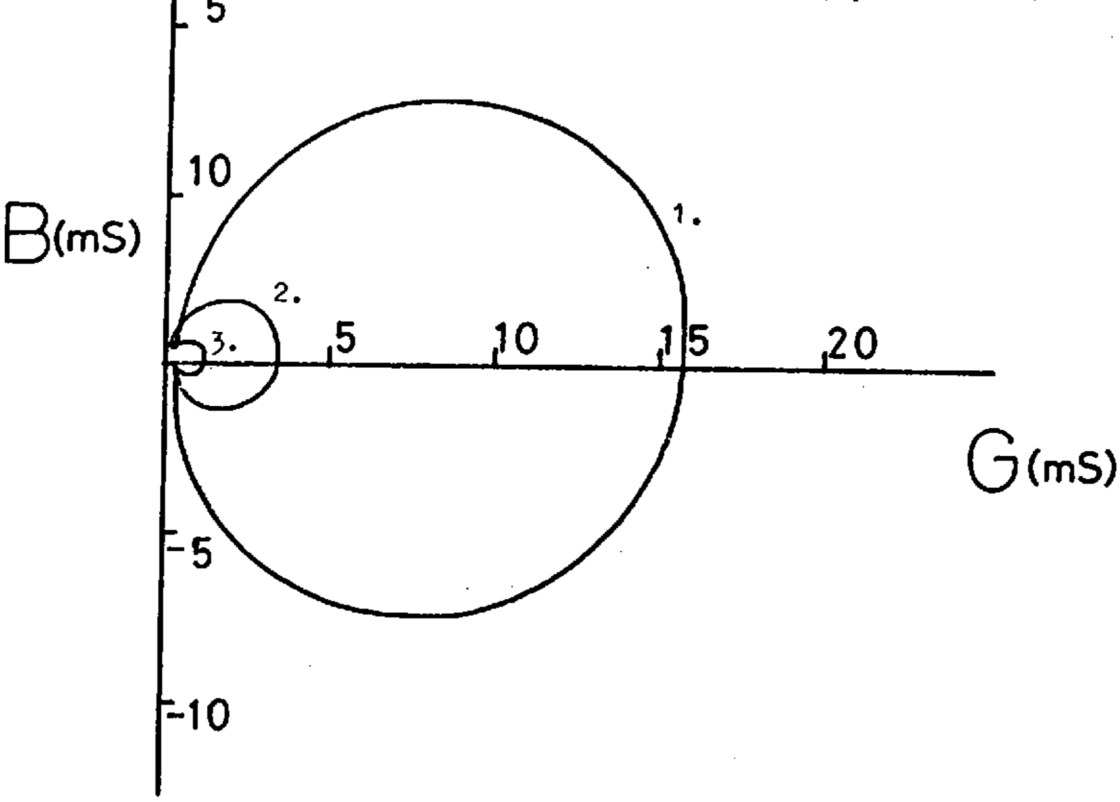
Figure 1. Typical high frequency ceramic element.

Frequency. f.	KHz.	300	150	75
θ_H	degrees	0.3	0.6	1.2
θ_{HE} / θ_s	degrees	30	60	120
R	metres	0.15	0.30	0.60
Δf & f_s	KHz.	8	4	2

Receiver Array length	d (1 m)
Element Width	W (10 mm)
Number of channels	N = d/W (100).
Mechanical Quality of elements in water	Q (27.5)
Horizontal angular resolution	$\theta_H = c/df$ rads.
Horizontal beamwidth of single element	$\theta_{HE} = c/Wf$ rads.
Scanned sector	$\theta_s = \theta_{HE}$ rads.
Range resolution	$R = cQ/f$ metres.
Scan frequency	$f_s = f/Q$ KHz.
Channel frequency separation	$\Delta f = f_s$

Table 1. Typical Sector Scanner Parameters.

Figure 2a. Typical admittance circles. (length mode)
1. In air, 2. mounted, 3. in water.



Frequency KHz.	300	150	75
In air.	18Ω	14	68
Mounted.	120	84	330
Water loaded.	850	400	1940

Figure 2b. Typical resistive components of impedance for each of resonances of the element shown in figure 1.

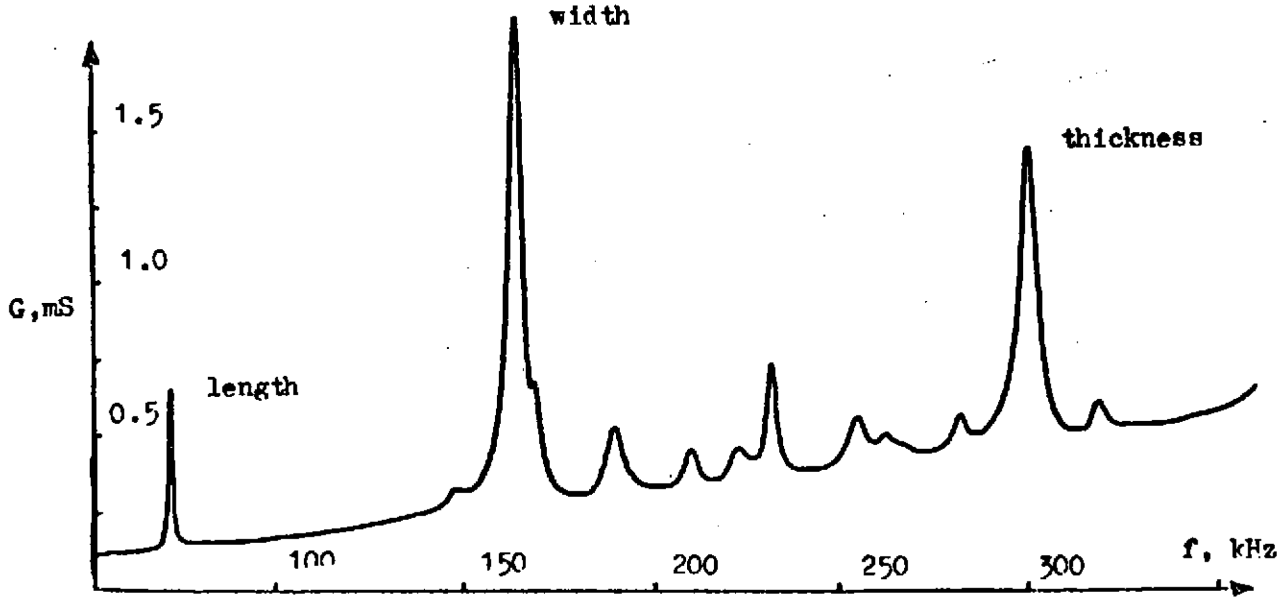


Figure 2c. Graph of conductance / frequency for the element shown in figure 1.

Spacing	Frequency (kHz)	1st side lobe position	Theoretical level	Actual level	2nd side lobe position	Theoretical level
0.5mm	300	±30.0°	-25.6dB	-18dB	none	
1.0mm	300	28.5	-19.8	-15	±72.5°	-20.2dB
1.5mm	300	27.1	-16.4	-12	65.6	-17.2
2.0	300	25.8	-14.1	-10	60.6	-15.4
0.5	150	none				
1.0	150	72.5	-19.8	-15		
1.5	150	65.6	-16.4	-12		
2.0	150	60.6	-14.1	-10		
0.5 to 2.0	75	nene				

Table 2. Grating side lobe levels for an array of 75 elements each 9.5mm wide.

Spacing	Frequency	Resonant Mode	Cross-talk
0.5mm	300kHz	thickness	-35dB
0.5	150	width	- 8
0.5	75	length	-16
1.0	75	width	-18
2.0	75	width	-32

Table 3. Cross-talk between neighbouring elements. Different elements used for the last two tests.

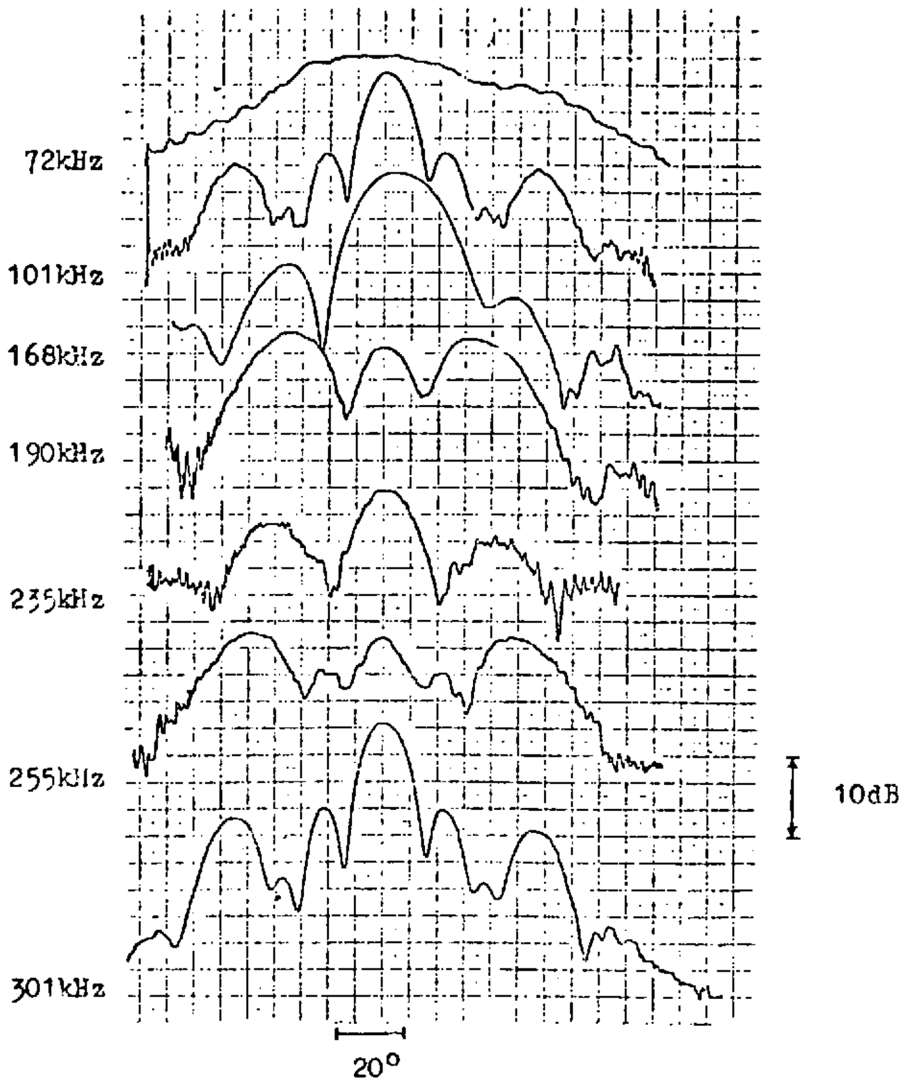


Figure 3. Vertical beam patterns for single element as shown in fig. 1.

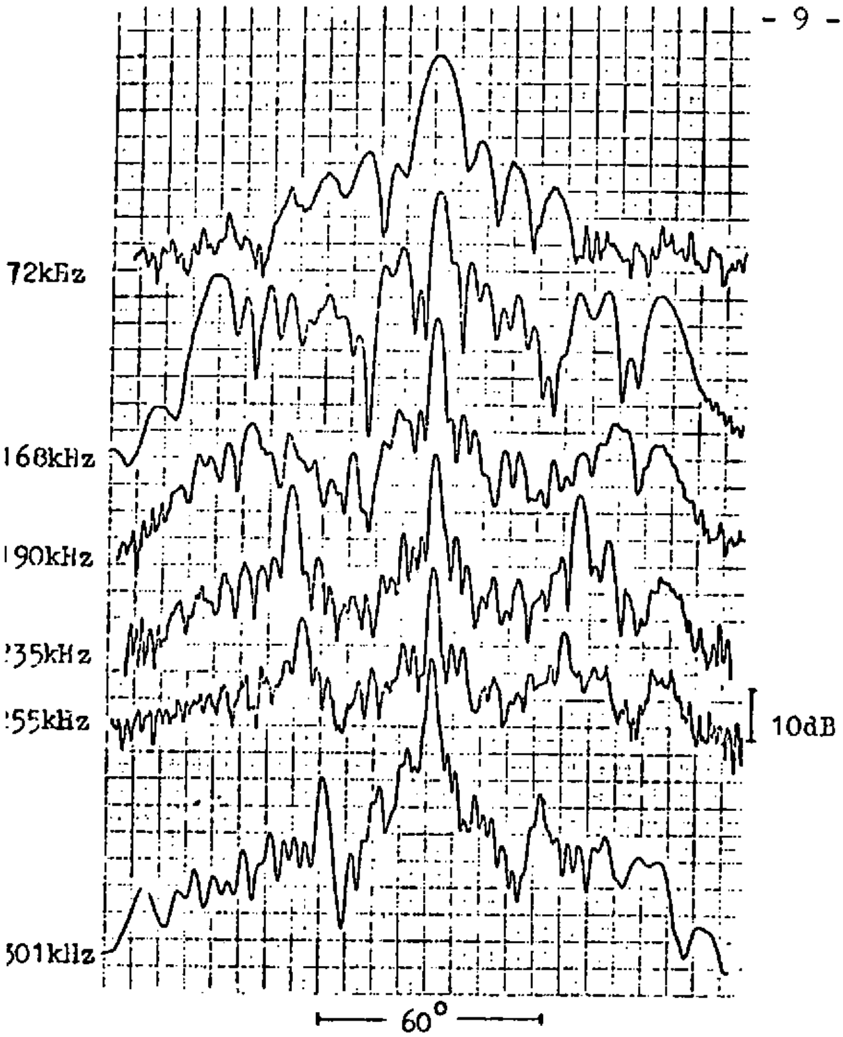


Figure 4. Horizontal beam patterns of 15-element test array.

Frequency (kHz)	301	168	72
Directivity Index in dB	33	28	21
Efficiency from admittance circles	78%	75%	79%
Efficiency from source levels	60%	65%	53%
Source level per volt RMS, re 1μbar @ 1m. in dB	72	71	56
Source level per watt RMS, re 1μbar @ 1m. in dB	102	97	89

Table 4. Results of measurements on a 15-element test array.

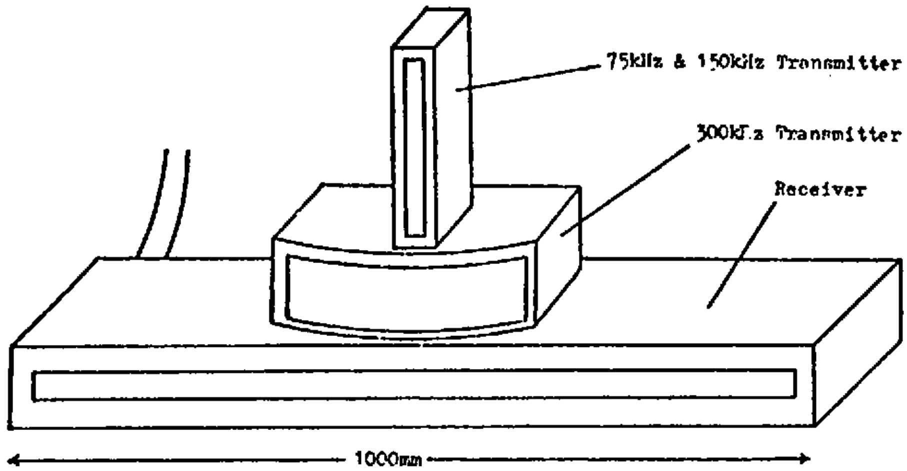


Figure 5. Possible array configuration for three-frequency operation.

Nominal frequency (kHz)	300	150	75
Beam width (vertical x horizontal)	5°x 30°	5°x 60°	5°x 120°
RMS pulse power (kW)	7	1	1
Approximate range	300m	500m	800m
Scanned area (hectares)	2	13	66

1ha. = 10,000m^2

Table 5. Transmitter specification for three-frequency system.

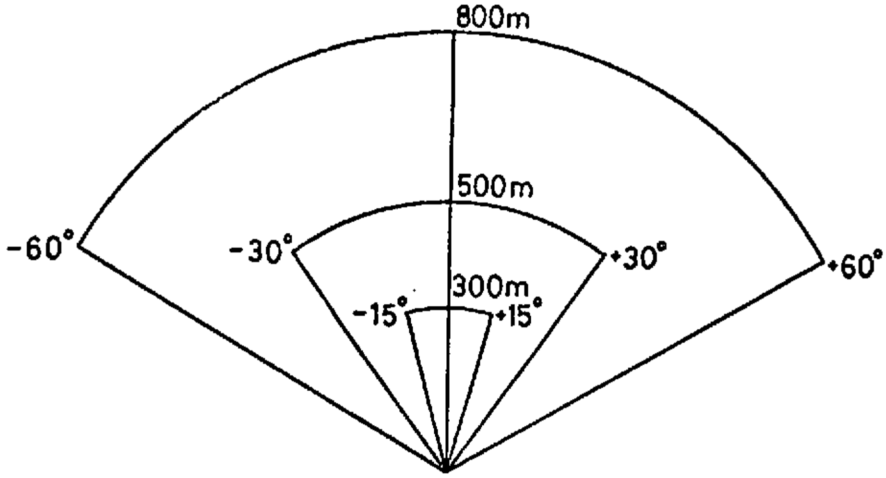
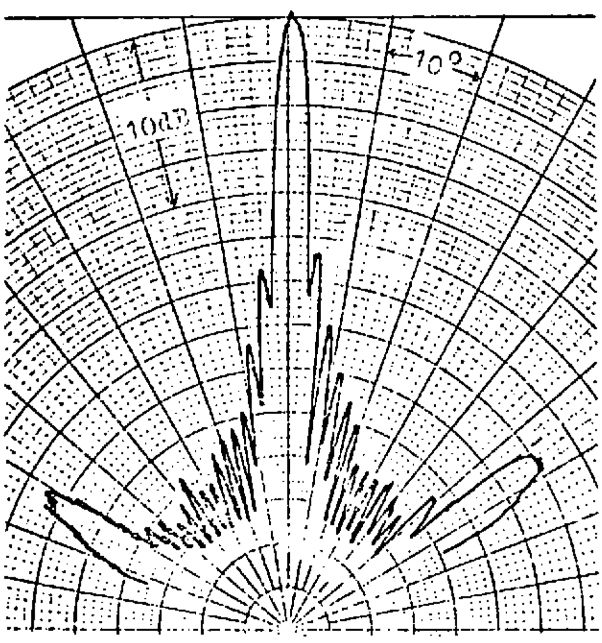


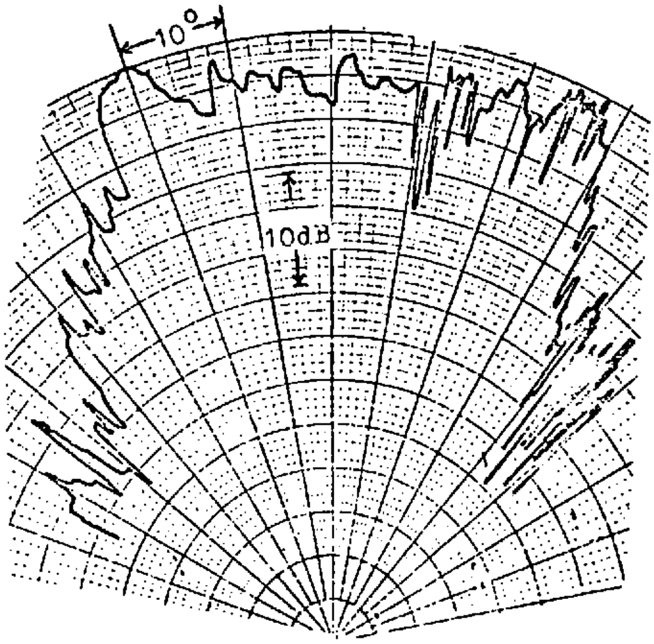
Figure 6. Simultaneous three-frequency display.

	No. of elements	Length	Spacing	Horizontal beamwidth	Conductance @ resonance	Cross-talk	Band-width	Weight in air, no cable
Trans-mitter	45	54° arc 943mm	2mm	54°	80mS	-33dB	2kHz	20kg
Receiver	45	943mm	2mm	1°	1.8mS (one element)	-33dB	2kHz	20kg

Table 6. Specification for a 75kHz width mode sector scanner.



15 element section of receiver



Transmitter

Figure 7. Horizontal beam patterns of 75kHz width mode arrays