International Journal of Advanced Engineering and Technology
ISSN: 2456-7655
Impact Factor: RJIF 5.54
www.newengineeringjournal.com
Volume 1; Issue 4; September 2017; Page No. 21-27

Performance of three different radiators of 8 X 8 Acoustic array antenna for Doppler Sodar

[1] KT Rao, [2] V Naveen Kumar, [3] Ganna Kiran, [4] S Sreedevi, [5] MP Rao
[1, 4, 5] Department of Systems Design, Andhra University, Visakhapatnam, Andhra Pradesh, India
[2] Gudlavalleru Engineering College, BSH Department, Gudlavalleru, Andhra Pradesh, India
[3] KL University, Vaddaswaram, Vijayawada, Andhra Pradesh, India

Abstract
The need for quality measurements of the wind profilers in the first 200m of the atmosphere for wind energy and other emerging areas applications demands new antenna for enhanced echo-signal intensity. This forces antenna designers to look for transducer systems with better conversion efficiencies and to seek for more versatile configurations. In the present experiment, an array antenna of size 8 x 8 with three different transducers is designed and fabricated for an operation frequency of 2 kHz. Basically, two types of transducers made with piezoelectric and neodymium materials are used. The models of Philips 1X9101 and Ahuja APT-165 belong to piezoelectric category and MA Audio MA588 to neodymium. The spacing between any two successive elements 0.5λ. The six elements at each corner of the planar array are removed as part of the optimization of the side lobe levels and the beam width of the main lobe. The antenna was systematically characterized, in an acoustic anechoic chamber, with respect to its axial and also studies transmit, receive conversion efficiencies and directional response. These measurements should be performed in free field conditions. The anechoic chamber at Naval Science and Technological Laboratories (DRDO), Visakhpatnam was used to conduct the measurements. A maximum intensity of 113 dB, 86.4 dB and 92.5 dB is observed at zenith angle at 2 kHz with a beam width of 16^0, 18^0 and 15^0 for Philips, Ahuja and M.A audio array antenna respectively. Among three antenna the MA588 antenna is suitable for profilers up to 500 meters of the boundary layer and capable of high power handling. Before installing the elements in the array, each element was individually characterized for its forward and reverse conversion efficiencies.

Keywords: radiators, acoustic array antenna, Doppler Sodar

1. Introduction
Various researchers did pioneering in the field of antenna design (Singal, S.P *et al.*, 1974; Mousley, T.J *et al.*, 1978) [5]. Phased array antennas were developed and systematically characterized (Khanna R.M *et al.*, 1994; Khanna R.M and Sharam O., 1996) [2, 3]. Among various designs of acoustic antenna the array antenna are reported to give better performance in terms of either lobe gain improvements and/or sidelobe suppression. Moreover, the array antenna are capable of obtaining weak signals and better data availability even at higher altitudes. Therefore, in order to further optimize the array antenna designs to obtain improved performance, we have planned at investigating different designs of array antenna by varying different radiators.
Accordingly, an 8×8 acoustic array antenna was made in three designs with different radiators, namely Phillips model 1X9101, APT-165 manufactured by Ahuja, and MA588 manufactured by M.A. audio. The performance of each array antenna was evaluated. The measurements of each array antenna (i.e. forward conversion efficiency, reverse conversion efficiency and directional response) were measured.

2. Measuring parameters of the array antenna
The experiments needed to evaluate the performance of the antenna were conducted inside anechoic and reverberation chambers of Naval Science & Technological Laboratory (NSTL). They consist the measurements of:
i) Axial transmit efficiency of the array
ii) Axial receive efficiency of the array
iii) Directional response of the array in three orientations.

The transmit (electrical to acoustic conversion) efficiency of the antenna has been measured by exciting the antenna at a constant input voltage ($1V_{rms}$) but at different frequency steps (1.9 kHz, 2 kHz, 2.1 kHz), while measuring the sound pressure levels generated on the acoustic axis of the antenna. In this case a calibrated microphone (1 kHz - 5 kHz) was kept at a distance of 1 meter (R.M. Khanna *et al.*, 1999) [4]. The Bruel & Kjare 4189 microphone was used which gives a constant response within the range from 1 to 5 kHz.
The receive (acoustic to electrical conversation) efficiency of the antenna was also measured, using a single speaker kept at a distance of 1 meter (closer because of limitation of maximum voltage that could be fed to single element for generation of uniform acoustic pressure). The speaker was fed with varying voltages at different frequency steps (1.9 kHz, 2 kHz, and 2.1 kHz) in order to generate a constant acoustic pressure at the antenna aperture. The open circuit r.m.s voltage produced was recorded, corresponding to each frequency step, at the antenna terminals.
The directional response of the array was studied in four

different orientations. Measurements were made for only three orientations because two of the orientations are symmetrical. In each orientation, the iron rod was moved to the diagonal of the antenna inside the anechoic chamber. The output of the microphone, which was positioned at a distance of 1 meter from the acoustic center of the antenna on the axis, was measured by recording the generated sound pressure level.

3. Design work of three array antenna

3.1 Uniform equispaced 8×8 planar array antenna made with model 1X9101 Philips tweeters

An 8×8 array was designed, fabricated and tested using commercially available Philips piezoelectric tweeters. A wooden square pane of length 22.5 cm covered with polyurethane foam was made as the base for embedding the tweeters. The foam was used for absorption of all the reflected acoustic energy. All the tweeters of each 4Ω impedance were equally placed on this wooden base. Six corner elements on each side of the array were later removed as part of the optimization of beam parameters such as beam width and side lobe suppression. Thus, a total of 24 elements were eliminated from the 8×8 array of 64 elements. The remaining 40 elements are connected in series and parallel fashion to each other so that a total impedance of 4Ω was achieved for the array. The array was operated at 2 kHz and the spacing between centres of adjacent elements was equal to half the wavelength. The design of array structure and outlay were shown in the Figure 1. The Philips tweeter of model IX9101 was chosen for the array, and its technical specifications are as follows:

- Diameter of each tweeter: 2.54 cm
- Sensitivity: 97dB/W/m
- Impedance: 4Ω
- Maximum power of each element: 120 W
- Maximum Sound dispersion: 90°

3.2 Uniform equispaced 8×8 planar array antenna made with APT-165 Ahuja tweeters

The second acoustic planar array antenna was designed with APT-165 piezo tweeters. The array design was similar to the one described in the previous case (using Philips tweeters) but the dimensions of the wooden pane was increased to 84×84 cm^2 due to larger size of the APT-165 piezo tweeters. Accordingly, the array in this case has been designed for 2 kHz and the corresponding spacing between adjacent elements was fixed at 11 cm.

The technical specification of Ahuja tweeters are as follows:

- Model : APT – 165
- Manufacturer : Ahuja
- Material : Piezoelectric
- Diameter : 110mm
- SPl : 93 dB at 2.83 V/m
- Power : 300 W for 4 Ω systems and 150 W for 8 Ω systems
- Frequencies : 1.8 kHz to 20 kHz
- Impedance : 1000 Ω at 1 kHz
- Sound dispersion : 45° in vertical or horizontal position

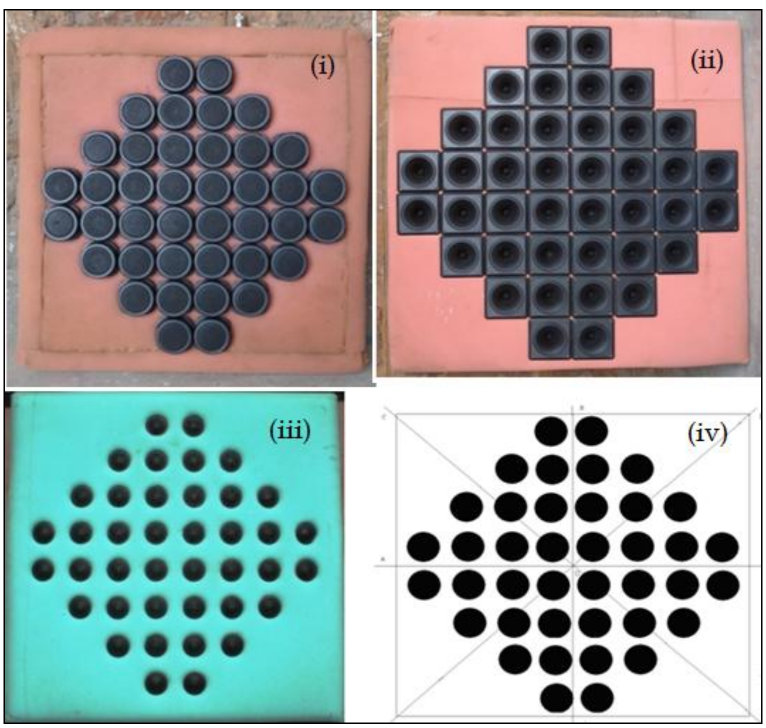

Fig 1: Photograph of the array antenna made 40 elements (i) Philips (ii) Ahuja (iii) MA588 tweeters and (iv) tweeters outlay

3.3 Uniform equispaced 8×8 planar array antenna made with MA588 tweeters

The third acoustic array, which was made with MA588 tweeters manufactured by M.A. Audio. The dimensions of the array are 75×75 cm^2. The array was operated at 2 kHz and spacing between centers of adjacent elements is equal to half the wavelength. The features of MA588 tweeters are:

- Neodymium Magnet
- 1” super dome tweeter
- continuous input power 30 watts per driver

- Peak input power 50 watts per driver
- Sensitivity @ 1W/1M 90.2dB

4. Experimental chambers for measurements

4.1 Experimental setup in anechoic chamber

The basic method of measuring the normalized power of any acoustic antenna is to measure its transmitting intensity by varying its elevation angle (θ) and keep the azimuth angle (Φ) constant.

These measurements should be performed in free field conditions. The anechoic chamber at Naval Science and Technological Laboratories (DRDO), Visakhapatnam, described with the block diagram in Figure 2, was used to conduct the measurements. An anechoic chamber is a closed room in which there are no echoes. In a well designed acoustic anechoic chamber, the equipment under test will only receive signals which were emitted directly from the signal source, and not reflected from any other part of the chamber.

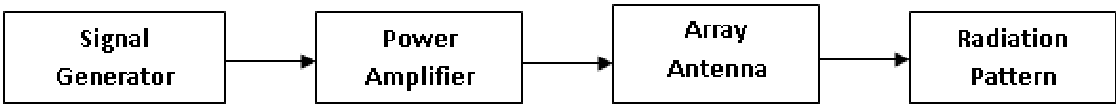

Fig 2: Block diagram representation of the experimental setup in the anechoic chamber

The array was fed with an amplified voltage input from an audio power amplifier. The power amplifier is driven by a frequency generator. A sensor receives the transmitted sound energy emitted by the array by placing the microphone (1 kHz - 5 kHz) at different angles of elevation from 0 to 180^0 in the intervals of 5^0.

An iron rod of semi-circle shape with a diameter of 1m was marked with elevation angles from 0° to 180° for this purpose.

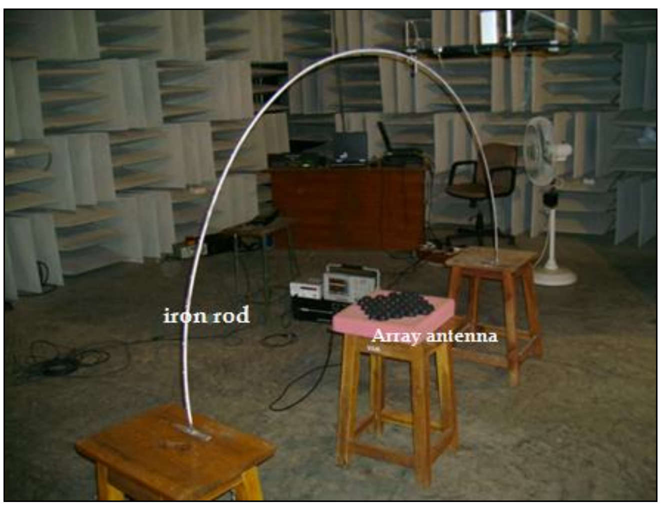

Fig 3: The experimental setup of Philips array antenna in the anechoic chamber

The sensor was placed manually at each angle and the relative intensity of array at that position was measured using Type 2250 Investigator Sound Level Meter (SLM) connected to the microphone. Experimental setup of Philips array antenna in the anechoic chamber was shown in Figure 3. It can be seen from the figure that the antenna array was exactly positioned at the middle of the semi circle (i.e., at 90^0) so as to minimize or eliminate the errors in the measured pattern.

4.2 Experimental setup in reverberation chamber

The reverse conversion efficiency of array antenna was measured in reverberation chamber again at the N.S.T.L, Visakhapatnam. During the experiment, the acoustic source and the array were kept at a standard distance of 1 m. The received power of the array was measured when a certain frequency from the source was being transmitted. The source is fed by a frequency generator through an audio power amplifier, as shown in Figure 4.

The received power of the array in watts is converted into sound intensity (dB) by the following relationship:

$$dB = 10 \log (P_2 / P_1) \text{ ---------(1)}$$

Where P_1 is the reference power = 0.001W and P_2 is the received power of array.

Fig 4: Experimental set-up in reverberation chamber for three different radiators array antenna

5. Results and discussion

5.1 Axial transmit efficiencies of three antenna

5.1.1 Axial efficiencies of 8×8 Ahuja array antenna with 40 radiators

The transmit efficiency response has been measured by positioning the microphone at a point one meter form the acoustic center of the array, along its axis. The different positions of the microphone and its corresponding sound pressure level reading at three different frequency steps at 1.9

kHz, 2 kHz, 2.1 kHz. As expected, the SPL meter reading in dB has been the highest for all the three frequencies at 90^0. The normalized power was deduced by subtracting the SPL meter reading of the highest intensity from the SPL meter reading at each elevation angle.

The variations of normalized power as a function of elevation angle were further drawn in Figure 5 to demonstrate the trends of Normalized polar radiation patterns of Ahuja array antenna with 40 radiators for three different frequency steps of 1.9 kHz, 2 kHz and 2.1 kHz. The 1.9 kHz pattern has the beam width of 20^0 and the side lobe level of -6dB. The 2 kHz pattern on the other hand was marked by relatively narrow beam width of 16^0 and larger suppression in the side lobe level of -15dB, which were highly desirable. And, the 2.1 kHz pattern has a beam width of 20^0 and side lobe level of -5dB.

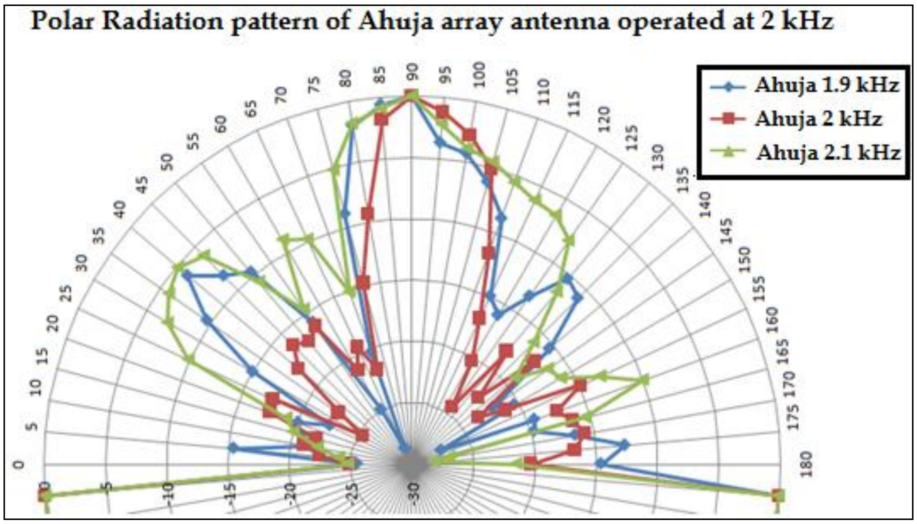

Fig 5: Normalized polar radiation pattern of the uniform 8 x 8 Ahuja array antenna at three frequency steps 1.9 kHz, 2 kHz and 2.1 kHz.

It can be clearly seen from the figure 5 that the radiation power for 2 kHz pattern is directed toward 90^0 elevation angle while greatly suppressing the radiation at all the side lobes resulting in high gain and narrow beam width. On the other hand, the radiation powers for the remaining two frequencies were also high in the elevation angles between 25 and 50^0 apart from the 90^0 leading to larger beam widths and higher side lobe levels for these frequencies.

5.1.2 Axial efficiencies of 8 x 8 Philips array antenna with 40 radiators

The figure 6 shows the radiation pattern of Philips array antenna with 40 radiators in three different frequency steps i.e 1.9 kHz, 2 kHz and 2.1 kHz. The pattern of 1.9 kHz has beam width of 16^0 and the side lobe level of --19dB, and the 2 kHz pattern has a beam width of 14^0 and side lobe level of -18dB whereas 2.1 kHz pattern displays a beam width of 16^0 and side lobe level -12dB.

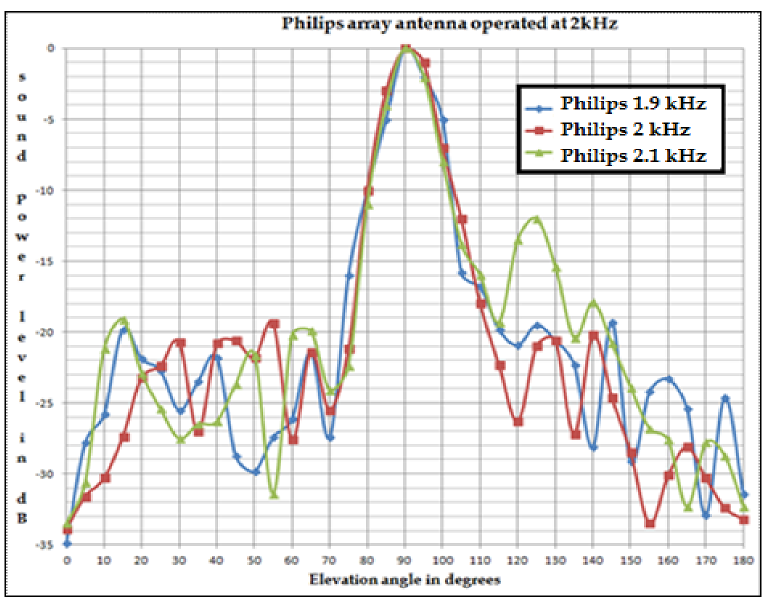

Fig 6: Normalized Radiation pattern of the uniform 8 x 8 Philips array antenna at three frequency steps 1.9 kHz, 2 kHz, 2.1 kHz.

5.1.3 Axial efficiencies of 8×8 MA588 array antenna with 40 radiators

The Figure 7 shows the polar radiation pattern of MA588 array antenna with 40 radiators in three different frequency steps i.e 1.9 kHz, 2 kHz and 2.1 kHz. As evident from the figure that the 2 kHz pattern shows the narrow beam width of 15^0 and better side lobe suppression of -16dB. Whereas, the beam width and side lobe suppressions for the lower and upper frequencies of 1.9 and 2.1 kHz are observed at 20^0 and -14dB, and 18^0 and -16dB, respectively.

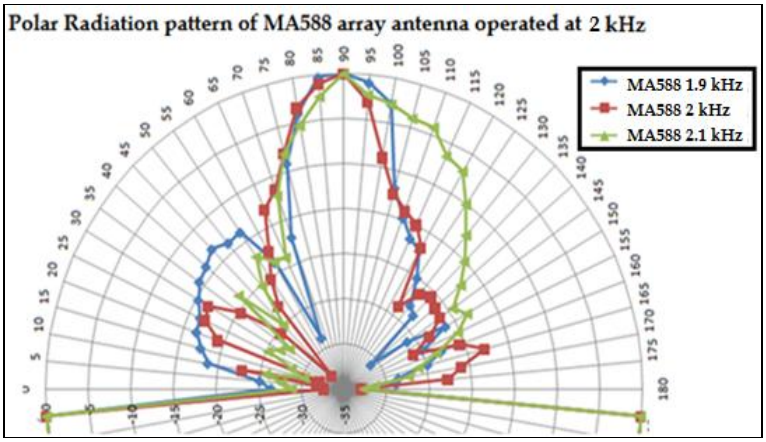

Fig 7: Normalized polar Radiation pattern of the uniform 8 × 8 MA588 array antenna at three frequency steps 1.9 kHz, 2 kHz, 2.1 kHz.

5.2 Reverse conversion efficiency of three antenna

In the case of reverse conversion efficiency (i.e. when the array acts as a microphone), a constant sound field is generated at the same frequency steps, in the case of each transducer, at the element aperture. This is done by exciting a single antenna kept at a distance of one meter from the receiving elements. In this case, an R.M.S voltage generated at the transducer output corresponding to each measurement is recorded. This measurement provides spectral response of reverse conversion efficiency of each transducer in Volts per Pascal of acoustic pressure.

5.2.1 Axial receive efficiency of 8×8 Ahuja array antenna with 40 elements

The Ahuja array antenna was operated at 2 kHz and also at frequency steps of 1.9 kHz and 2.1 kHz. The sound source maintained in reverberation chamber was approximately 100dB. Then reverse conversion efficiency was calculated using equation (1). The received power P_2 was estimated using the expression $P_2 = \frac{V^2}{R}$ where V is the measured r.m.s voltage and R is the impedance of the array, which is taken as 4Ω. The reference power P_1 was equal to 0.001 W. The calculated reverse conversion efficiency values for all frequencies of operation are shown in table 4.4a. As can be seen from the table, the reverse conversion efficiency is higher at the frequency for which the array is designed. It has been observed to decrease for frequencies below and above from the designed frequency of 2 kHz.

Table 1: Reverse conversion efficiency of the Ahuja array antenna

Frequency (kHz)	r.m.s voltage (V)	Source Intensity (dB)	Array Intensity (dB)	Efficiency (%)
1.9	0.32	100	14.082	14.08
2	0.35	99	14.86	15.01
2.1	0.30	99	13.52	13.65

5.2.2 Axial receive efficiency of 8×8 Philips array antenna with 40 elements

The reverse conversion efficiency values for the Philips array antenna were also calculated and listed in table 2. For this array too, the results indicate maximum value of reverse conversion efficiency for the frequency of 2 kHz and decreased values were observed for 1.9 and 2.1 kHz frequencies.

Table 2: Reverse conversion efficiency of the Philips array antenna

Frequency (kHz)	r.m.s voltage (V)	Source Intensity (dB)	Array Intensity (dB)	Efficiency (%)
1.9	0.46	101	17.23	17.05
2	0.46	98	17.23	17.58
2.1	0.44	100	16.84	16.84

5.2.3 Axial receive efficiency of 8x8 MA588 array antenna with 40 elements

The axial reverse conversion efficiency values were calculated for MA588 array antenna operated at three different frequencies of 1.9, 2 and 2.1 kHz, and the results were found similar to the other arrays, as listed in table 3.

Table 3: Reverse conversion efficiency of the MA588 array antenna

Frequency (kHz)	r.m.s voltage (V)	Source Intensity (dB)	Array Intensity (dB)	Efficiency (%)
3.2	0.74	99	21.36	21.57
3.3	0.78	98	21.86	22.31
3.4	0.75	99	21.48	21.69

5.3 Directional response of 8×8 array antenna with 40 radiators

The directional response of the array was measured in three different orientations, as shown in Figure 8. Since the orientations AA[l] and CC[l] are symmetrical to each other, they are considered as one and BB[l] and DD[1] are the other two orientations.

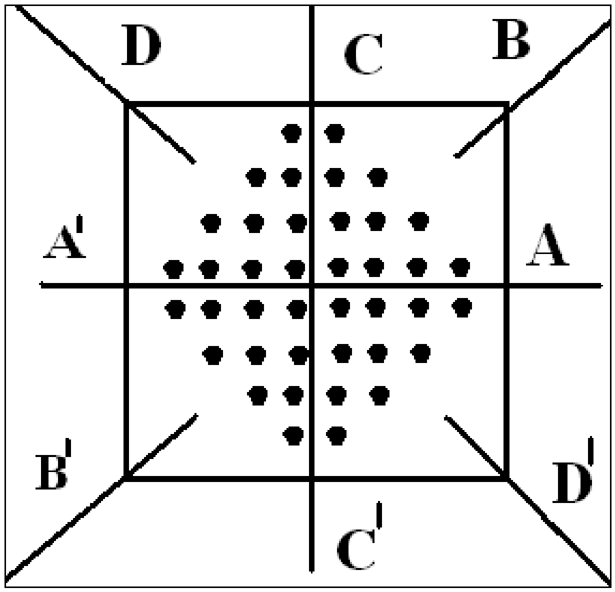

Fig 8: Directional response of the antenna with 40 radiators in three different orientations

The Figure 9 shows the polar radiation pattern of MA 588 array antennas with 40 radiators operated at 2 kHz

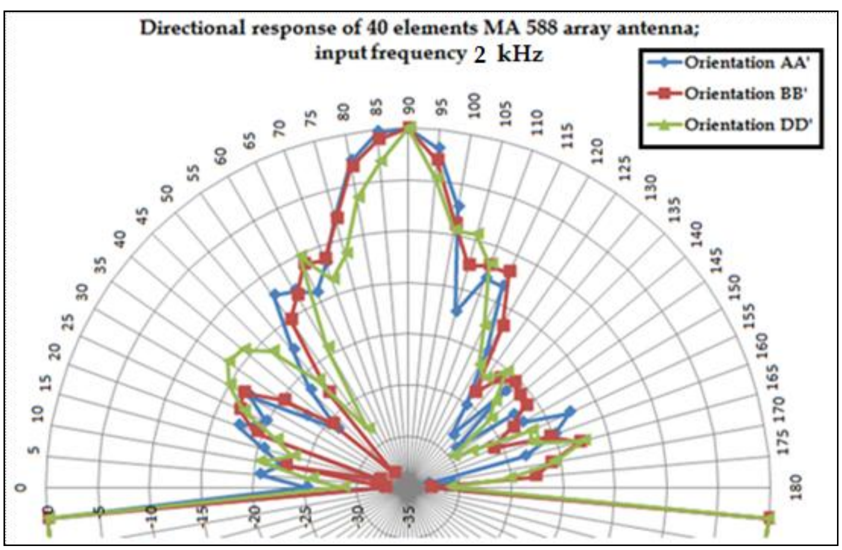

Fig 9: Directional response of MA588 array antenna of 40 elements

The Figure 10 shows the polar radiation pattern of Ahuja array antenna with 40 radiators operated at 2 kHz. The radiation patterns for the orientations AA' and BB' appear more or less similar with weak side lobes, thus indicating larger directivity for these orientations. On the other hand, the DD' orientation resulted in a strong gating lobe in between the elevations angles 15-45^0, but still appears to have shown better directivity.

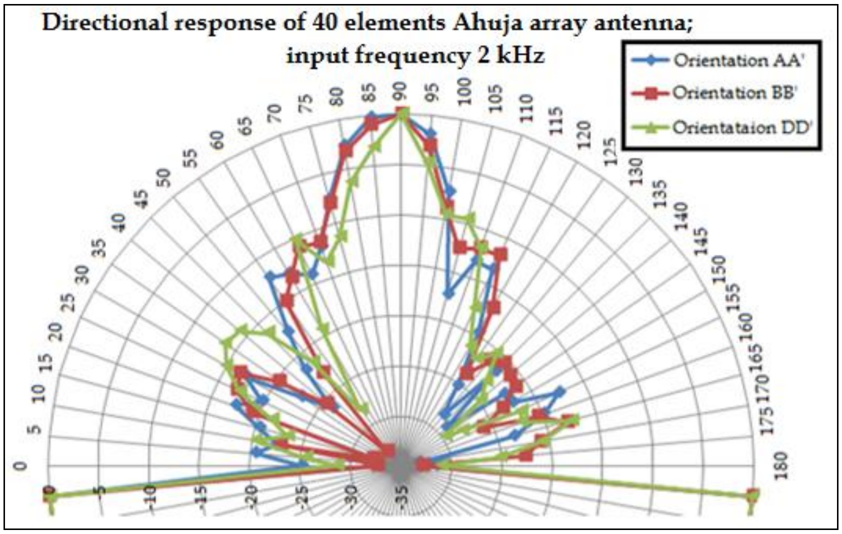

Fig 10: Directional response of Ahuja array antenna of 40 elements

6. Conclusions

A comparative study on the investigations of acoustic antenna parameters on three designs using 40 element Philips, Ahuja and MA588 array antenna at 2 kHz frequencies each determined by 0.5λ spacing indicate that the MA588 array antenna gives better conversion efficiencies and high power handling capable. Thus, MA588 array antenna suitable for profiles up to 500 meter of the boundary layer.

7. Acknowledgment

The authors wish to thank the Director Naval Science and Technological Laboratories (DRDO), Visakhpatnam for providing acoustic test center facilities for carrying out sodar array antenna testing.

8. References

1. Coulter RL, Martin TJ. Results from a high power, high frequency sodar. Atmos. Res. 1986; 20(2-4):257-270.
2. Khanna RM *et al.* Characterizing an array antenna for Doppler Sodar. Proc. 7th ISARS 1994, Boulder, 1994; 3-79-3-83.
3. Khanna RM *et al.* Design and study of an acoustic antenna for a phased array Doppler sodar. Proc. 8th ISARS 1996, Moscow, 1996, 3-67-3-71**.**
4. Khanna RM *et al.* Design of a High Efficiency Acoustic Phased array antenna for an Acoustic Wind Profiler. Meterol. Atmos. Phys, 1999; 71:35-41.
5. Mousley TJ *et al.* Design of arrays for acoustic sodar antennas. J Phys. E Sci. Instrum., 1978; 11:657-662.