Design of a High Efficiency Acoustic Phased Array Antenna for an Acoustic Wind Profiler

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With 3 Figures

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Summary

Improvements to the performance of acoustic wind profilers necessitate designing efficient acoustic antennas for the profilers, so that weak echoes can be received to enhance data availability.

An efficient acoustic antenna needs to optimize electrical to acoustic and acoustic to electrical conversion efficiency as measured at the antenna axis. It also needs to provide a good directional response, and be able to handle increased electrical power. Phased array antennas, designed using piezo-electric transducers, should provide better characteristics in this regard.

In the present study several different transducer elements were characterized with respect to their relative efficiencies. On the basis of this characterization, measurement of acoustic background noise at the expected site of antenna location and comparative study of atmospheric molecular absorption at the element peak efficiency frequencies, it is concluded that Motorola KSN 1025 A transducer is the best speaker element for the array antennas for profilers up to around 500 meters.

The present array antenna has been designed using 104 KSN 1025 A piezo-electric transducer elements. The corner elements were removed from a 16 × 8 element speaker matrix, yielding an irregular octagonal pattern. Before installing the elements in the array, each element was individually characterized for its transmit and receive conversion efficiencies and variations in the product of these efficiencies (conversion gain) amongst the different elements, has been usefully employed to taper the array gain from centre to periphery.

The antenna was systematically characterized, in an acoustic anechoic chamber, with respect to its axial transmit and receive conversion efficiencies and directional response.

1. Introduction

In a research study, conducted in early seventies (Hall, F. F. and Wescott, J. H., 1973) at WPL, Boulder, the authors suggested that the future acoustic radar design improvements, in order to obtain weak echoes and better data availability from higher altitudes, would need efficient antenna designs, in respect of main lobe gain improvements and suppression of side lobes. They designed conical horn type as well as parabolic dish type antennas, and studied their performance. In the following years, various researchers did pioneering work in the field of antenna design (Singal, S. P. et al., 1974; Mousley, T. J. et al., 1978). They designed and studied the conical horn, dish, as well as, phased array type of antennas. Later, with the availability of high efficiency piezo-electric tweeters, higher efficiency phased array antennas started to be designed and used in acoustic radars (Coulter, R. L. and Martin, T. J., 1986; Bradley, S. G. and Roberts, N. L., 1990). Later, phased array antennas were developed and systematically characterized (Khanna, R. M. et al., 1994; Khanna R. M. and Sharma, O., 1996). The present study...
is a continuing effort in the direction of designing better and more efficient antennas.

2. An Efficient Array Antenna

An acoustic antenna is a region of transition between the electrical power and the acoustic waves. An acoustic array antenna is an arrangement of several identical electro-acoustic transducer elements, so spaced and phased that their individual contributions add in preferred direction and cancel in others. The characteristics of an efficient array antenna are:

(a) It should be able to generate high acoustic energy, corresponding to a particular electrical input; which means that its electrical to acoustic conversion gain must be high.

(b) Most of the acoustic energy that is generated, should be radiated along the acoustic axis of the array or the desired direction: and minimal be frittered in unwanted zones.

(c) It should be able to generate maximum possible electrical signal for a particular acoustic energy incident at the array aperture, i.e. its acoustic to electrical conversion gain must be high.

(d) It should have greater acceptance of acoustic energy from the array axis or the desired direction, which would comprise of the signals; and minimal acceptance from unwanted zones (which would constitute noise).

(e) Last, but not the least, the array must be able to handle greater electrical power without much distortion of the signal.

One of the important parameters, for designing an efficient array, is the selection and use of an efficient electro-acoustic element. The element, that is used in the array, should also possess greater electrical to acoustic, as well as, the reverse conversion efficiency. A study, has therefore been conducted to select a suitable element for the array.

3. Selecting an Efficient Element

As piezo-electric transducers are, generally much more efficient than the electro-dynamic transducers; most of the elements selected for the present study are from amongst the former.

Earlier phased array antennas, using piezo-electric tweeters, mostly employed Motorola KSN 1005 A elements. These elements are generally efficient in frequency ranges between 3 kHz to 6 kHz. This part of the frequency span is suitable for low altitude, high resolution mini acoustic profilers. If, however, an acoustic profiler is required to be designed for studies of the meteorological parameters up to reasonably high altitudes inside the boundary layer, it is necessary to use frequencies around 2 kHz or lower, so that signal losses due to atmospheric molecular absorption are contained. A study has, therefore, been conducted to select an efficient transducer for designing antennas in the lower frequency ranges. The elements selected for the present study, are three models of Motorola piezoelectric tweeters that are KSN 1065A, KSN 1025A and KSN 1188A driver (fixed with the KSN 1151A horn). A 5 watt electro-dynamic paging speaker has also been included in the study for comparison.

The study, conducted on these elements, comprised of (1) measurement of their electrical to acoustic or forward conversion efficiency and (2) measurement of their acoustic to electrical or reverse conversion efficiency.

A spectral response of these efficiencies has been taken inside the acoustic anechoic chamber. In the first case, electrical signals are applied to the respective transducers at frequency steps, as close as 100 Hz, within the range of 0.5 kHz to 8 kHz. Sound pressure levels produced at 1 meter distance were measured using a calibrated condenser microphone. The level of the electrical signal in each case, and at every frequency step, is kept constant. This measurement provided spectral response of forward conversion efficiency of each transducer in Newtons per meter square (Pascals) per volt of applied rms signal.

In the case of reverse conversion efficiency (i.e., when the element 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 speaker kept at a distance of one meter from the receiving element. In this case an rms voltage generated at the transducer output corresponding to each measurement is recorded. This measurement provides spectral response of