Acoustic Yagi–Uda Antenna Using Resonance Tubes

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ABSTRACT

A Yagi–Uda antenna gets high directivity by applying current phase shift between elements due to resonance phenomena. It has some directors and reflectors, which are elements without electric supply. The length of directors is shorter than half-wave and that of reflectors is longer than half-wave. We proposed an acoustic Yagi–Uda antenna which elements are resonance tubes and a loudspeaker. The aim of this research is to improve directivity in a specific frequency. This can be applied to Radio Acoustic Sounding System (RASS), which is a kind of radar for weather observation, or to a parametric loudspeaker. The phase shift of sound waves was observed in the condition with a resonance tube and without the tube at the same position. That shift changes suddenly around the resonance frequency of the tube. Our acoustic antenna has resonance tubes that have different length as directors and reflectors to apply this phenomenon. Moreover, the distances between a loudspeaker and tubes were concerned by some experiments and by numerical analysis. The acoustic antenna showed directivity in an appropriate condition of the distances and the frequency of the sound source. It will be also added the consideration about the effective frequency band of this acoustic antenna.

Keywords: Resonance phenomena, phase shift, director, reflector, RASS, parametric loudspeaker

1. INTRODUCTION

A Yagi–Uda antenna is a very common type of electromagnetic antenna which is widely used in telecommunication. Its directivity is based on the phase difference of directors, reflectors and a driven element. The phase difference is caused by the difference of the length of each element (1).

In the previous research, E. Meyer and E. G. Neumann investigated the acoustic Yagi–Uda microphone (2). It has composed of metallic principal axis and disk–shaped elements. Similar to elements of a Yagi–Uda antenna reducing the phase velocity of electromagnetic surface wave, disk–shaped waveguides of the acoustic Yagi–Uda microphone reduce the phase velocity of sound wave. This principal utilizes the difference of sound velocities in the metal and in the air. The distance between the disk-shaped waveguides is $\lambda/12$ and the spaces between those waveguides act as a resonator.

In this paper, we applied the structure of a Yagi–Uda antenna to sound waves not using the metallic disk-shaped waveguides but acrylic resonance tubes. For the resonator, we chose resonance tubes for the elements as directors and reflectors. The driven element is a loudspeaker. First we investigated the phase shift of sound waves by resonance using tubes experimentally. Then, we measured the directivity of the acoustic Yagi–Uda antenna that confirmed the effectiveness of resonance tubes acting as a reflector and directors. An application of the acoustic Yagi–Uda antenna includes Radio Acoustic Sounding System (RASS), which is a kind of radar for weather observation (3). This system applies the change of reflecting scattering ratio of radar by the density variation of air which is occurred by sound waves. Thus both sound and radar are radiated in the air. The frequency of the sound source is determined by the wavelength of the radar, for example 100 Hz, 1 kHz and 3 kHz. The sound is audible and its amplitude is very high.

Following this introduction, Section 2 introduces the structure and the principle of a Yagi–Uda antenna. After that, the phase shift by resonance phenomena in a resonance tube is investigated in Section 3. Section 4 shows the structure of an proposed acoustic Yagi–Uda antenna. The research is concluded in the Section 5.

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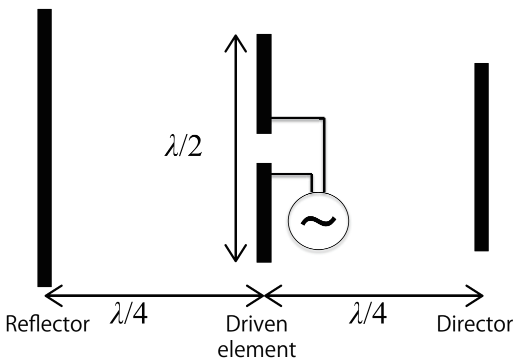
2. THE PRINCIPLE OF A YAGI–UDA ANTENNA

Figure 1(a) shows the structure of a Yagi–Uda antenna. There are three kinds of elements, a driven element, directors and reflectors. The driven element is a dipole antenna, which is only supplied electricity in the elements. Its length is half of the wavelength of electric current and it generates a standing wave by resonance. Directors and reflectors are arranged parallel to the driven element, but these have no electric supply. However, electricity occurs through these elements because a magnetic field around the driven element causes electromagnetic induction (1). Moreover, the phase of current at each element shifts by resonance (4). The phase shift of each element affects the electromagnetic field. According to these phenomena, the directivity pattern of the electromagnetic field can be controlled by determining the distance between each element so that the electromagnetic waves match in phase.

The antenna showed in Fig. 1(a) has only three elements, but commonly used Yagi–Uda antennas have more elements. The frequency band of a Yagi-Uda antenna is basically narrow, but that can be widen if various length elements are combined.



(a) The basic structure of a three–elements Yagi–Uda antenna.

(b) An example of an actual Yagi–Uda antenna.

Figure 1 – The structure of a Yagi–Uda antenna. A driven element is a half-wavelength dipole antenna. A reflector and a director have no electric supply. The degree of phase shift by resonance is depend on the length of them.

3. THE PHASE SHIFT CAUSED BY RESONANCE PHENOMENA

The main principle of a Yagi–Uda antenna is the phase shift of electric current by resonance. The phase of an acoustic wave should also be changed by resonance. Therefore, we did an experiment to observe the phase shift of standing waves generated in a resonance tube.

Figure 2 shows a picture of a resonance tube. This tube is a closed pipe. The side is square, whose size is 44 mm × 44 mm. The length of the tubes we chose is 3 types, 246 mm, 254 mm and 260 mm, whose resonance frequency is 694 Hz, 676 Hz and 658 Hz, respectively. They have a 40 mm × 50 mm rectangle hole at the middle of the side. Figure 3 shows the schematic depiction of the experiment. The resonance tube was placed in front of the loudspeaker, and the microphone was put in the hole of the tube. The measurement frequency was increased from 620 Hz to 740 Hz by 0.5 Hz step. We measured in 2 conditions: with a tube and without a tube. Table 1 shows the equipment used in this experiment.

Figure 2 – A resonance tube (inside: 40 mm × 40 mm × 250 mm, outside: 44 mm × 44 mm × 254 mm). It has a 40 mm × 50 mm hole at the middle of the side.

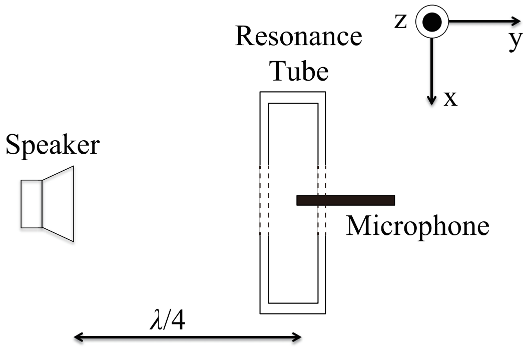


Figure 3 – The schematic depiction of the experiment about a resonance tube. We measured sound pressure at the center of 3 tubes whose length is 246 mm, 254 mm and 260 mm. We also measured sound pressure at the same point without a tube to compare the phase of sound wave.

Table 1 – The condition of experiment.

Place	Anechoic chamber in Waseda university Nishi-Waseda campus
Instruments	Power amplifier (YAMAHA P4050) Microphone（G.R.A.S. Type 46BE） Audio interface（M-Audio Fast Track Ultra 8R）
Sound source	Sine waves (from 620 Hz to 740 Hz at the intervals of 0.5 Hz)

Figure 4 shows an example of the measured waveform with and without the tube whose length is 254 mm. The frequency of sound emitted from the speaker was 680 Hz, the resonance frequency of the tube. The green line is the result with a tube and the blue line is that of with no tube. Although the measuring point was same for two conditions, the magnitude and phase of the sound wave were different. Figure 5(a) shows the level difference at each frequency and Fig. 5(b) shows the phase difference at each frequency. The phase differences at the resonance frequencies were about 65 degree, and it suddenly changed around those frequencies.

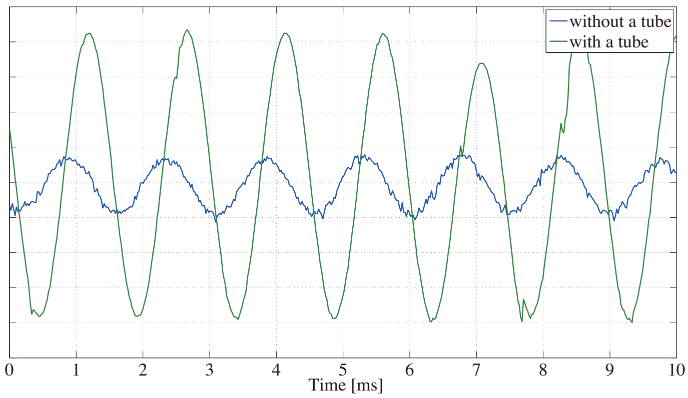
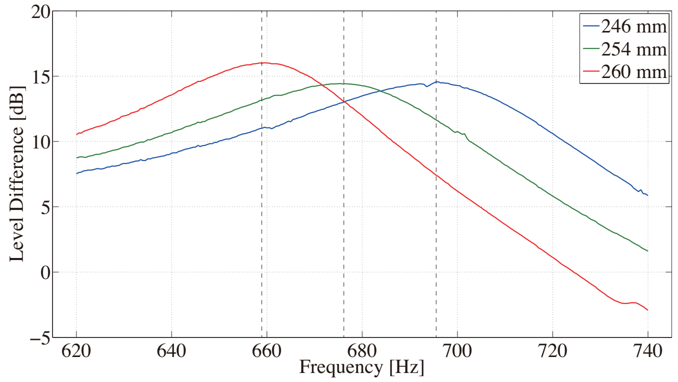
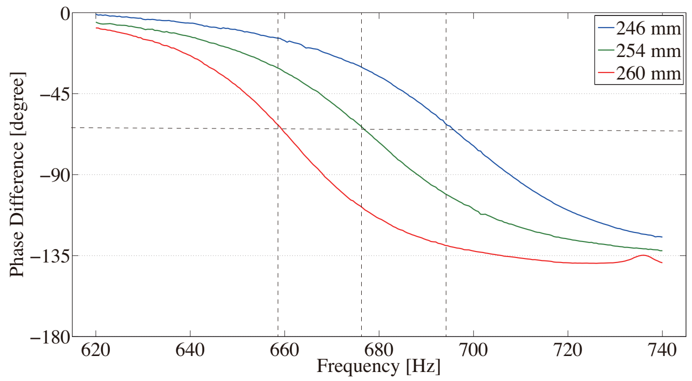


Figure 4 – An example of the wave forms (the frequency of the sound source was 680 Hz). These were observed at the same position with and without a tube, but their magnitude and phase is different.



(a) Level difference



(b) Phase difference

Figure 5 – Phase difference and level difference caused by resonance. Phase difference indicates how much the phase of the sound with the tubes delays from that without the tubes. The phase difference suddenly changed around the resonance frequencies.

4. DIRECTIVITY PATTERN OF AN ACOUSTIC YAGI–UDA ANTENNA

Since the tube that has different length yields the phase shift at different frequency, the shorter tube should act as a director and the longer tube should act as a reflector. Hence, we can use several different tubes to construct an acoustic Yagi-Uda antenna. Figure 6 shows an acoustic Yagi–Uda antenna we proposed. The speaker, which is placed at the middle of this instrument and works as a driven element, was made of two loudspeaker units faced each other. The resonance tubes have the same shape that in Fig. 2 and their length is same as that of the previous experiment, 246 mm as a director and 260 mm as a reflector.

We measured the directivity pattern of the acoustic Yagi-Uda antenna. The schematic depiction of the experiment is shown in Fig. 7. We measured sound pressure level (SPL) at 24 points equally segmenting the circle centered at the sound source whose radius was 0.5 m. The frequency of the sound source was 680 Hz.

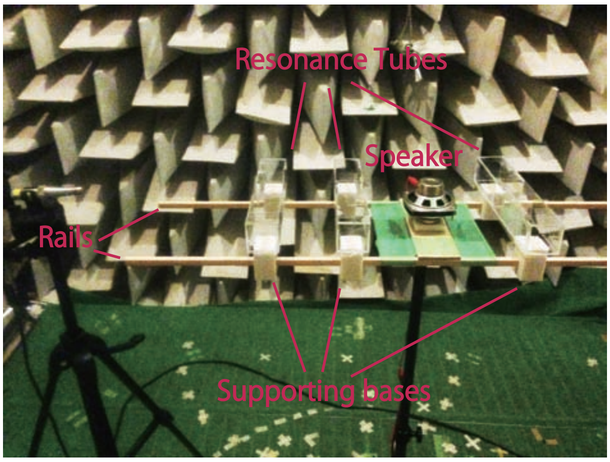


Figure 6 – A system of a proposed Yagi-Uda antenna. All elements are placed on two wooden rails. A speaker which act as a driven element is fixed at the center. Resonance tubes are set on supporting bases and their location can be changed by sliding the bases.

Table 2 – The condition of experiment.

Place	Anechoic chamber in Waseda university Nishi-Waseda campus
Instruments	Sound level meter（RION NL-32） Power amplifier（YAMAHA P4050） Audio interface（M-Audio Fast Track Ultra 8R）
Sound source	sine wave（680 Hz）

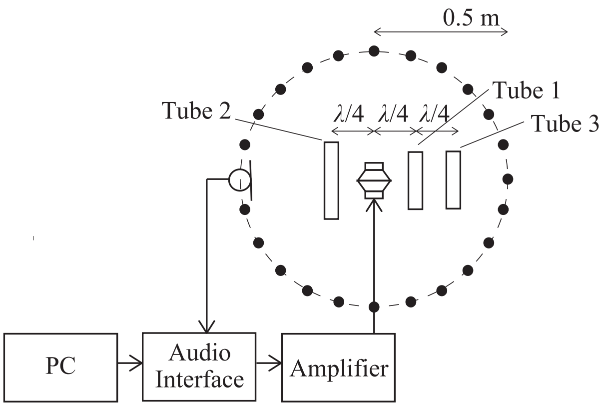
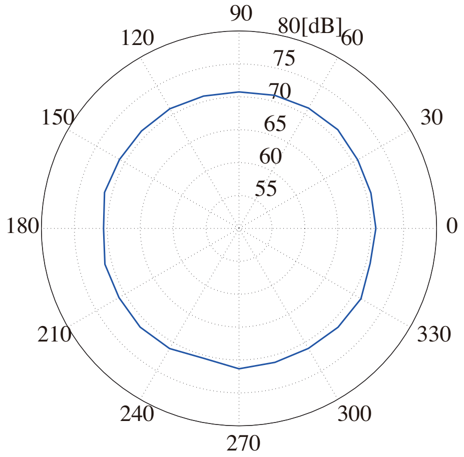


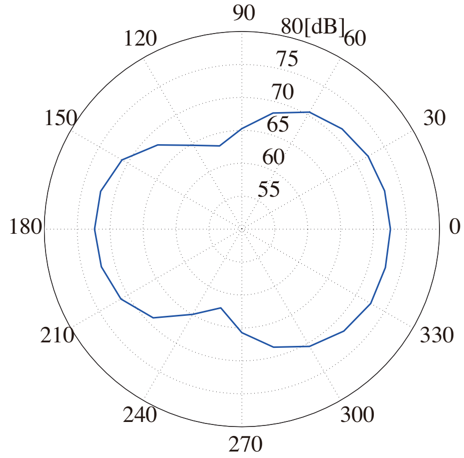
Figure 7 – The schematic depiction of the experiment about an acoustic Yagi–Uda antenna. The sound was recorded at 24 points that were marked around the circle.

A director (246 mm) was located at the position of Tube 1 in Fig. 7 and a reflector (260 mm) was located at the position of Tube 2. The second director was located at the position of Tube 3, the interval of $\lambda/4$ from the first director.

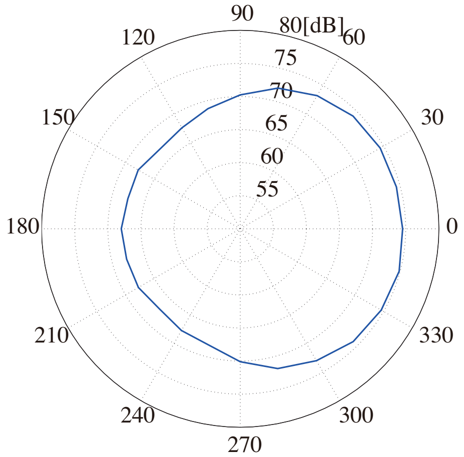
Figure 8 shows the results of the experiment. When there was no resonance tube, the directivity pattern was almost circle. However, the acoustic Yagi–Uda antenna changed that directivity. The result shows the directors increased the level at 0 degree and the reflector decreased the level at the transverse direction. When one director and one reflector were arranged, the level of 0 degree increased 4.7 dB than no tube condition, and the level of 90 degree decreased 6.0 dB. When there was an additional director, the level of 0 degree increased 6.5 dB and that of 90 degree decreased 11.6 dB.



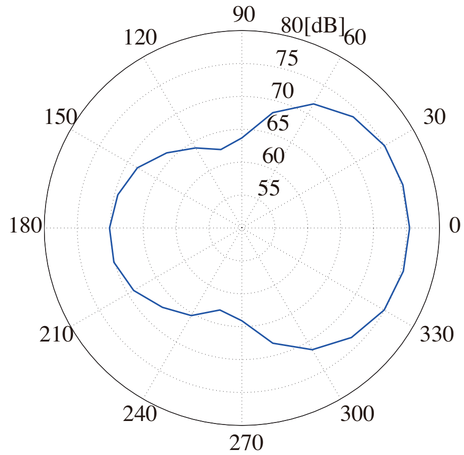
(a) no tubes



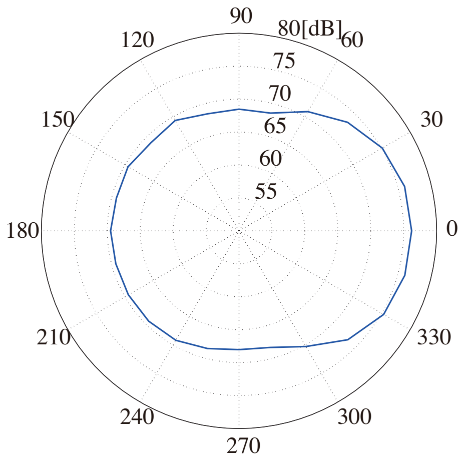
(b) 1 reflector



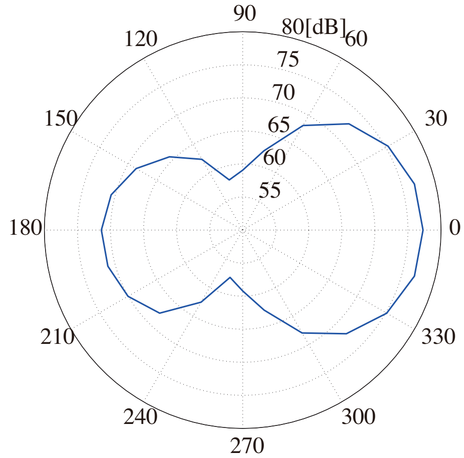
(c) 1 director



(d) 1 director and 1 reflector



(e) 2 directors



(f) 2 directors and 1 reflector

Figure 8 – Directivity pattern of the acoustic Yagi-Uda antenna. The direction of Tube 1 in Fig. 7 is 0 degree. The directors increased the SPL at 0 degree. The reflector decreased the SPL around 90 degree and 270 degree, and it increased the SPL at 0 degree.

5. CONCLUSIONS

In this paper, we observed that the phase of the wave in a resonance tube shifted suddenly around the resonance frequency. In addition, we proposed an acoustic Yagi–Uda antenna combining different length tubes as directors and a reflector. The experiment showed high directivity of the proposed system in the condition that the distance between the elements was $\lambda/4$. Remaining works include examining the geometry of resonance tubes that show appropriate phase shift and investigating a method for widening the frequency band of the acoustic Yagi–Uda antenna.

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