Practical realization and analysis of shotgun microphone prototype

Marko Janković[1], Dejan Ćirić[2] and Marko Stamenković[3]

Abstract –**Directivity of a microphone plays an important role in the microphone selection for a specific application. For adequate suppression of ambient noise and reflected sound in applications such as news gathering, wildlife recording or recording a dialog on movie and television sets, directivity of a standard microphone is not enough. For that purpose, highly directive microphone such as microphone with a waveguide, called shotgun, interference or rifle microphone is preferred. In this paper, a practical realization of a low-cost shotgun microphone prototype is presented. Its features are analyzed with focus on directivity characteristics that are measured in pseudo-anechoic conditions. Special attention is paid to the effects of the interference tube and its slots.**

Keywords – **Shotgun microphone, Directional response, Polar pattern, Interference tube.**

I. Introduction

Ability of a microphone to respond to sounds coming from different directions around the microphone, called polar pattern, is of extreme importance in the microphone selection. Specific applications require adequate suppression of ambient noise and reflected sound and for that purpose highly directive microphone is preferred. There are three main types of these microphones [1-3], and a number of commercial microphones can be found on the market. They have different constructions that greatly affect their features.

From an acoustical point of view, one of basic types of highly directive microphones is a microphone with waveguide representing a tube with slots connected to a chamber where a microphone is positioned [4,5]. Sounds arriving from the sides enter trough a number of slots in the interference tube. In this way, sounds travelling through different paths have different phases. Some frequencies tend to be canceled, partly or completely, while some others tend to be amplified._Crucial factor for attenuation (or amplification) is the source position relative to the microphone axis.

Construction of the interfence tube and its slots is of special importance for microphone directivity [4]. This has been a motive to analyze the function of a shotgun microphone presented in this paper. For that purpose, a low-cost shotgun microphone prototype is realized. Its directivity characteristics are measured in pseudo-anechoic conditions. Special attention is paid to the effects of the interference tube and its slots.

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II. Highly directive microphones

For many applications, it is necessary to use a microphone with directional properties exceeding those of the first-order cardioid family. For example, in video industry, dialog pick-up on the shooting set is usually done by an overhead boom microphone, which must be clearly out of the scene. Sport events and other activities with high ambient noise levels may require highly directional microphones for noise immunity. Recording in reverberant spaces may require such microphones to enhance music clarity. Furthermore, field recording of natural events such as bird calls may call for operation at great distances. In such applications, usage of highly directional microphones is essential in order to ensure both speech intelligibility and a subjective sense of intimacy.

Highly directional microphones represent microphones with directivity patterns the main characteristic of which is frontal lobe that is significantly narrower than any other conventional microphone type [1]. These microphones typically have a total angle of pick-up of ±20°. There are basically three principal methods of achieving such a pattern: microphone with a waveguide (interference tube), parabolic reflector and microphone array [1-3,6].

The microphone with interference tube [4-8] is schematically shown in Fig. 1. Sounds that come off the tube axis and enter the slots arrive at the microphone diaphragm at different times, depending on which part of the tube they entered [1]. As a consequence, sound could be cancelled because of phase cancellation. The amount of cancelation depends on the angle of incidence and the wavelength. A significant degree of cancellation appears only if the sound wavelength is less than the acoustic length of the tube. This is why majority of interference tubes are of an effective length of about 50 cm. These microphones are not particularly directional below about 500 Hz. A certain improvement in the directivity characteristics can be obtained if the basic microphone capsule is made to have a cardioid directivity, as shown in Fig. 1.

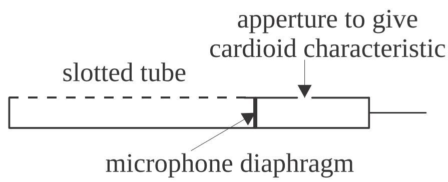


Fig. 1. An interference tube microphone

Parabolic reflector microphone is a specific configuration where a microphone is placed at the focus of a parabolic reflector [3]. In this way, very narrow-angle lobes can be obtained (e.g. ±3°), but only when the sound wavelengths are significantly smaller than the diameter of the parabolic dish [1]. The maximum diameter of such a dish is likely to be about 50 cm for most practical applications. In this case, the system is omnidirectional below about 150 Hz, and highly directional only above about 2 kHz.

The third method for achieving high directivity is based on an array of microphones [2]. Such an array (electronically steerable) can provide multiple beams from different directions simultaneously. Furthermore, it can be designed with a much better directivity than what is attainable with the best shotgun microphone [2]. The accompanied signal processing can be often very complex.

III. Realization of a shotgun microphone prototype

In spite of some advantages that microphone arrays posses, when the goal is to achieve the highest possible directivity and signal-to-noise ratio with high signal fidelity, shotgun microphones are still state-of-the-art [7]. On the contrary to microphone arrays, when shotgun microphones are properly designed, they do not suffer greatly from inconsistencies and sound color artifacts. There is a general rule in shotgun microphones, the higher the frequency the narrower the beam formed by the pipe (interference tube). In the frequency region where the pipe is shorter than the wavelength, a shogun microphone achieves merely a super-cardioid directivity.

Function of a shotgun microphone can be analyzed by simulations. A traditional way to model the directional response of a shotgun microphone is to assume plane waves travelling in the tube as it is in the free field. Such an approach is implemented in Matlab in order to get a picture of a microphone behavior. Unfortunately, the frequency response and directivity predicted by this traveling wave model can differ drastically from practical measurements, as shown here and in the recently published paper [4]. Nevertheless, the results from the simulation together with the results published in the literature are used as the approximations of the microphone working principles.

For realization of a shotgun microphone prototype, it is decided to develop an adaptable configuration with a case where different microphones can be built in, and where different tubes can be attached to. The microphone case is realized from aluminum enabling lightweight construction. The case is used for placing the microphone, associated electronics and power supply (battery of 1.5 V), see Fig. 2.

The waveguide (interference tube) is also made of aluminum. It is attached to the microphone case by the threads made on both the microphone case and the tube. In this way, the tube is simply screwed on the case. Different tubes can be attached to the case. In this initial phase, only one tube is made. Its length is 173 mm, the diameter is 21 mm and distance between the first and last slot is 153 mm (see Fig 3). The slot width as well as the distance between two adjacent slots is 3 mm. On the front side of the tube, there is a mesh whose function is to prevent foreign object entering the tube. The mesh can be replaced by the lid which could completely close the tube from the front side. Commercial shotgun microphones with similar dimensions can be found on the market, where directivity is dominantly achieved at middle and high frequencies.

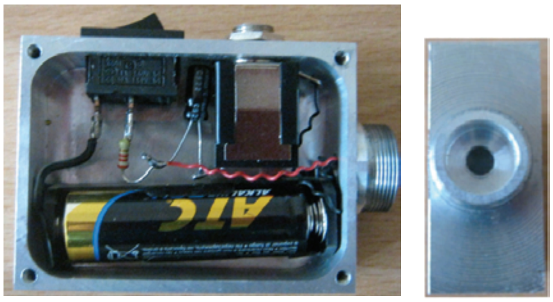


Fig. 2. Case of the shotgun microphone (left) with position of the condenser (electret) microphone in the case (right)

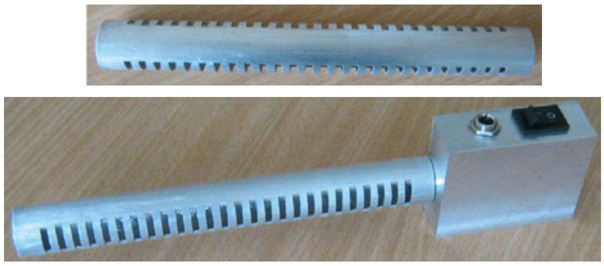


Fig. 3. Realized shotgun microphone prototype (the interference tube (above) and the whole microphone of length of 242 mm (below))

Since the aim was to realize the low-cost highly directional microphone system, the microphone itself is a low-cost electret microphone of relatively high sensitivity of -38 dBV (high for this type of microphone). Its diameter is approximately 5 mm, and it is coupled to the tube by a hole of only somewhat smaller dimension.

IV. Directivity measurements

Since one of the main properties of shotgun microphones is the directivity, it is measured here for the realized prototype. In this initial phase, only the directivity in horizontal plane of the microphone with only one attached tube was measured. Generally speaking, measurements of directional response of microphones are carried out in an anechoic chamber. However, since small anechoic chamber realized at the Faculty of Electronic Engineering in Niš has not been qualified yet, the directivity of the shotgun microphone was measured in pseudo-anechoic conditions. All obstacles from the central part of a laboratory similar to a classroom were removed. In this central area, an omnidirectional (dodecahedral) sound source and the microphone prototype were placed, see Fig. 4. Distance between the sound source and microphone was about 1.5 m, and the distance to the first obstacles including floor and ceiling was also approximately 1.5 m.

Fig. 4. Setup for directivity measurements of the realized gunshot microphone prototype

The directivity is determined by measuring broadband impulse responses applying the swept sine technique. As an excitation signal, the exponential swept sine of duration of 20 s and frequency range from 20 Hz to 22 kHz was used. The measurement system consisted of a computer, external sound board (M-Audio Fast Track Pro audio interface), audio amplifier (Sony TA-FE510R) and dodecahedral sound source.

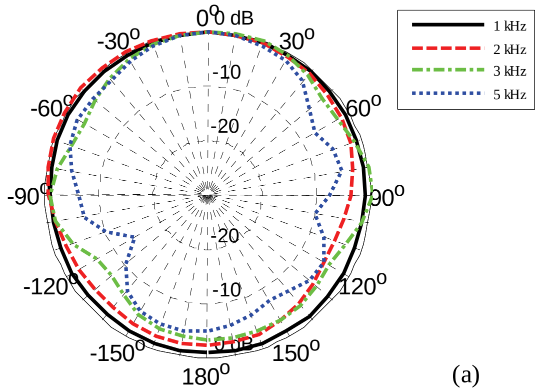
The source was fixed, and the microphone was rotated around its axis in the horizontal plane. The resolution was 10°, so 36 impulse responses were measured (from 0° to 350°) plus one additional control response (for 360°). Since there were no obstacles closer than 1.5 m, the first reflections were shifted away from the direct sound for approximately 10 ms in the measured impulse responses. The part of the response with direct sound and without reflections was windowed out and transformed to the frequency domain. The directivity pattern was determined at different frequencies based on these frequency responses. The frequency resolution was approximately 100 Hz.

The directivity was measured for several microphone configurations: I) only for the microphone in the microphone case (without interference tube), II) for the microphone with the tube closed on the front end (covered with the reflective lid), and with the mesh on the tube front end, where the slots of the tube were in III) horizontal and IV) vertical plane.

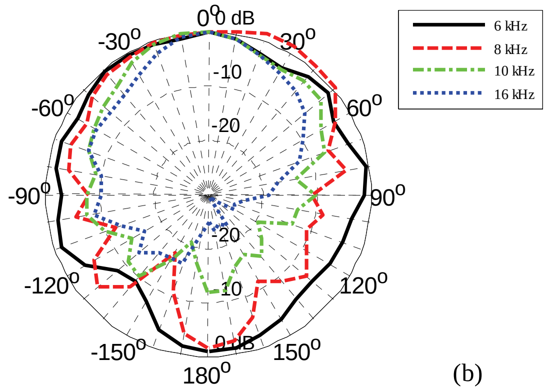
V. Directivity of the Shotgun Microphone Prototype

Repeatability of the measurements was tested by repeating the measurements under the same conditions. The results confirm that very small deviations (smaller than 0.5 dB) are obtained among these impulse, that is, frequency responses. Somewhat greater deviations appear between the results for the first (done for 0°) and last (done for 360°) measurement. They are caused by inability to place the microphone in completely the same position.

Some characteristic directivity patterns for the configuration I (microphone with the case, but without the tube) are shown in Fig. 5. It can be noticed that the microphone itself (with the case) is omnidirectional at low and mid frequencies. It becomes somewhat directional (with specific directivity) in the range above 4 or 5 kHz. At the highest frequencies (above 10 kHz), it is almost one-directional, but with relatively wide lobe, as shown in Fig. 5(b).



(a)



(b)

Fig. 5. Directivities in horizontal plane for configuration I (only the microphone in the microphone case (without interference tube))

The shotgun microphone with the tube closed on the front end (configuration II) is also omnidirectional up to approximately 4 or 5 kHz, see Fig. 6(a). Above that frequency, the microphone becomes one-directional. In that regard, the higher the frequency, the narrower the directivity lobe (see Fig. 6(b)). The pick-up angle is smaller than about 30° at frequencies above 10 kHz. Almost the same directivity is obtained for the microphone with the mesh on the tube front end and slots in the horizontal plane (configuration III). These results are not shown here due to lack of the space.

Similar trends in directivities are also obtained for the slots in vertical plane (configuration IV), but the shapes of directivity patterns are somewhat different, as shown in Fig. 7. The frontal lobes (Fig. 7(b)) are somewhat wider in the region close to the reference axis.

The frequency responses for all four configurations measured on the microphone axis are presented in Fig. 8. The levels for configurations II, III and IV (shotgun microphone with the tube) become to be greater than the levels for the configuration I (microphone without the tube) at frequencies already above 1 kHz. The differences between these levels yield the transfer characteristic of the interference tube itself. The shape of these responses is also affected by the response of the source, which is not supposed to be an effective radiator at the highest frequencies.

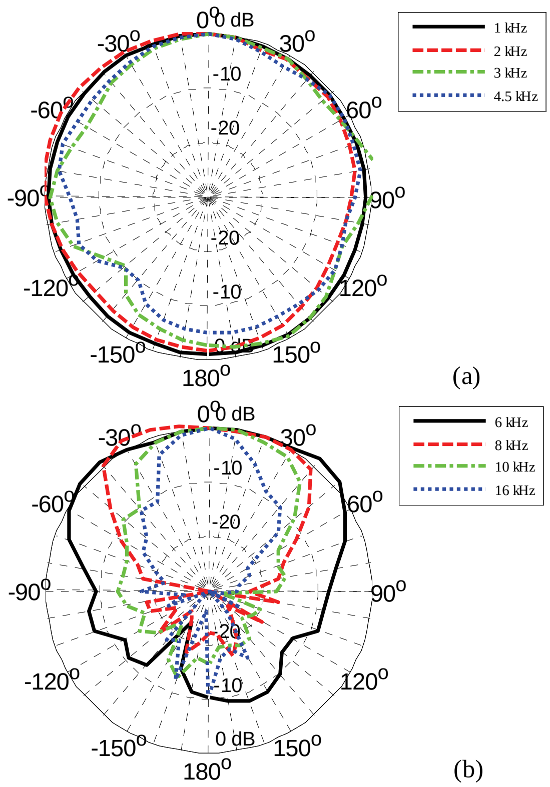


Fig. 6. Directivities in horizontal plane for configuration II (microphone with the tube closed on the front end)

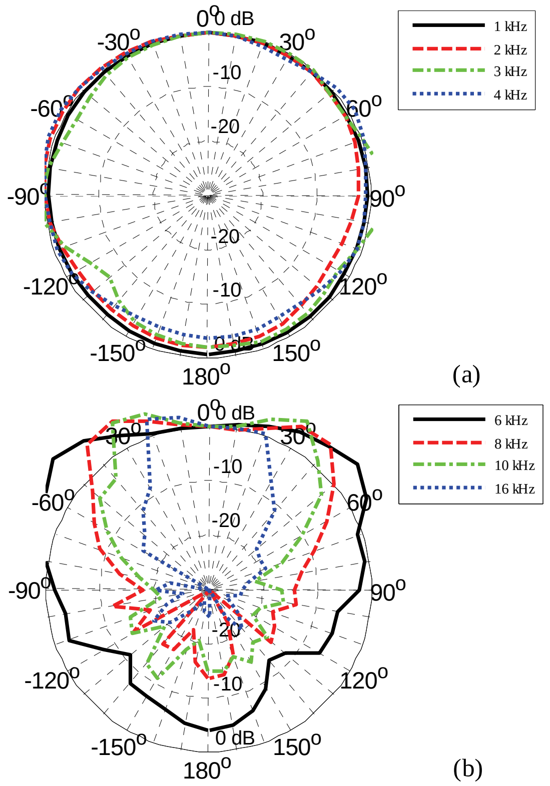


Fig. 7. Directivities in horizontal plane for configuration IV (microphone with the mesh on the tube front end where the tube slots are in vertical plane)

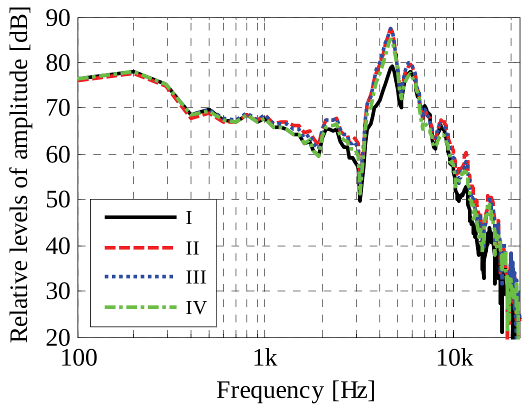


Fig. 8. Frequency responses of four microphone configurations (I to IV) on axis

VI. CONCLUSIONS

The presented shotgun microphone prototype is adaptable in the sense that the microphone and tube can be replaced by other ones. Directivities in the horizontal plane for several microphone configurations are measured. It has been shown that the interference tube enables the microphone to be one-directional at frequencies above approximately 5 kHz. This is somewhat higher frequency than expected. In the next phases of the research, it will be tried to achieve one-directional pattern at lower frequencies by longer tubes, different slots configurations and more sensitive microphones.

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