Folded planar resonator-based sonic Crystal scatterer: Part I. Shifting from split tube resonator design

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Abstract. A split tube resonator (STR) is one of the typical base structures in many previous acoustic metamaterial structures. This paper introduces a brand new approach to designing the tunable concentric wall resonating structure to look like a similar shape but with a different response and performance to STR. The central concept is a planar resonator folded outward and inward direction. We found that the proposing approach gives the possibility for a single geometrical dimension tunable sonic crystal element that could not occur in a single degree of freedom conventional STR. The test model made of stiff paper and the sound absorption performance test conducted experimentally with impedance tube refers to ASTM E-150-98 standard.

1. Introduction
Control of sound waves propagation attracts strong interest in many scientific applications and technology nowadays. Researchers proposed various approaches to solve many different problems. The most recent solution is artificial materials such as metamaterials, including artificial crystals, namely sonic crystals (SCs). SCs are structurally similar to the idea of crystals in solid-state physics. It is a periodic distribution of scatterers or elements whose mechanical properties differ from the surrounding medium. It is also possible for tunability in the local resonant frequency.

The use of acoustic metamaterials and SCs have been discussed in the literature [1-5]. The applications ranging from low-frequency noise controls [6-8], noise mitigation [9,10], and sound transmission control purposes [11,12]. Regarding the scatterer element, the structure of SCs commonly constructed by Helmholtz resonators. It brings advantages to local resonance tuning ability and also broadband absorption performance [13,14]. The other consideration is according to the practical aspect of the SCs elements production. The split tube resonator (STR) and split ring resonator (SRR) is the most used for this purpose [15-17]. However, since the thickness of the inner splitting wall is too small compared to the wavelength of sound waves, the connecting slit between the two cavities of STR does not contribute to the resonator reactance changes. The element works as a single degree of freedom structure, and the resonant frequency depends on the coupled cavity volume. This limitation is the disadvantage to the tuning resonant frequency ability. To get the scatterer with a different resonant frequency, a multi-layered STR is applying [18,19]. However, it does not solve the limitation, especially when the researcher needs to work with a single geometrical dimension scatterer.
In this paper, we are introducing a novel tunable scatterer to solve the limitation of STR and SSR based SCs. The proposed element is a circular folded coplanar resonator-based (FCR) element suitable for a single geometrical dimension scatterer-based SCs structure. The novel, FCR, brings two significant advantages. First, the tuning ability of the resonant frequency and the high flexibility in scatterer shape design. Second, possibility for development of a single geometrical dimension scatterer SCs.

2. Method
The schematic comparison of STR and the two types of FCR presented in Figure (1). In Figure 1 (a), the STR is constructed by two concentric tubes with a slit type orifice placed oppositely. FCR is illustrated in Figure 1(b) while the test model in Figure 1 (c). When the slit type orifice coplanar resonator folded inward, it becomes a type one FCR coupled-cavity Helmholtz resonator. However, when the same coplanar resonator folded outward in the opposite direction, the type two FCR structure has resulted. It works as an array of two independent Helmholtz resonators. Theoretical prediction of the resonance is given by classical equation,

\[
f_{1,2} = \frac{c^2 S_{1,2}}{V_{1,2} L_{eff,1,2}}
\]

where \( c \) represents the speed of sound, \( S_{1,2} \) denote the cross sectional areas of the two resonator necks, \( V_1 \) and \( V_2 \) represent the volume of the two resonant cavities, and \( L_{eff,1,2} \) denote the effective lengths of the two resonator necks [20].

![Figure 1](image_url)

Figure 1. Schematic illustration of an STR, the two types of FCR and test models.

The laboratory test conducted by using transfer function based impedance tube method refer to ASTM E-1050 standard. The B&K 4206 impedance tube and Pulse LAN-Xi are used in the entire experiment, while data acquisition and analysis using dedicated B&K Material Testing software. The laboratory test scatterer model is a square-shaped element made of 2 mm thickness stiff paper. The model geometrical dimension is 50 mm and 99 mm in width and height, respectively. It has curve-shaped at the top and bottom section to fit the impedance tube apparatus. All models, STR and FCR, have the same slit type orifice 2 mm width and 65 mm height.

3. Results and Discussions
The sound absorption coefficient of the basic STR, folded inward FCR, and folded outward FCR is presented in Figure (2). The highest absorption coefficient of the STR was achieved at a frequency of 400 Hz with an alpha of 0.7. The much better result is shown on the type one FCR curve where the highest sound absorption is 0.9 occurred at a lower frequency of 350 Hz. Shifting of sound absorption
to the lower frequency band as occurred on the type one FCR is associated with the coplanar resonator’s depth. As the coplanar resonator folded, the two edges form a parallel wall separated in the distance equal to the size of orifice width. It works as a short narrow channel or neck of Helmholtz resonator. It changes the FCR reactance and can induce a resonance mechanism that does not occur in the basic STR.

![Graph showing sound absorption coefficient of STR and the two types of FCR](image)

**Figure 2.** The sound absorption coefficient of STR and the two type of FCR

An interesting result occurred on the type two FCR model. The two peaks curve shows that the structure works as a dual Helmholtz resonator. Theoretical explanation of this kind or Helmholtz resonator also provided by Xu et al. [21] in a similar form to equation (1). Similar to Xu et al., as the sound waves propagate through the scatterer model, the two cavities and slit-type orifices on the opposite position work as two independent Helmholtz resonators. The inner cavity connected with the short narrow channel happened in type one FCR but with a smaller cavity volume. The sound absorption coefficient is 0,93 occurred on a frequency of 600 Hz. Simultaneously, the outer cavity of type two FCR also works as a cavity resonator as occurred in STR. Since the cavity volume is small, the resonant occurred on a higher frequency. The second peak of the sound absorption curve occurred at a frequency of 850 Hz, with an alpha value of 0.78.

The two peak curve on the sound absorption performance indicates that the FCR element is potential for tonal noise control applications. The freedom and flexibility on modification of coplanar resonator bring the extensive opportunity for tuning the scatterer resonant frequency. This important finding shows that the proposed FCR concept is a suitable solution for developing a single geometrical dimension scatterer based tunable SCs structure.

4. **Conclusion**

The concept of proposed FCR is novel with unique properties that not occurred on basic STR structure. The dual peaks curve on the sound absorption performance indicates the FCR applicable for tonal noise control applications.

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