THE ACTIVE NOISE CONTROL OF PROPELLER NOISE USING A MULTIPOLE SECONDARY SOURCE

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Abstract

The commercial feasibility of active noise control (ANC) is very promising due to its capability beyond passive noise control (PNC) and to some extend becomes a complement of PNC. The active noise reduction is also capable in reducing noise selectively.

Of course, the mentioned above is not without a problem. The active noise reduction using a conventional secondary source can become to be very complicated when required a significant noise level reduction, because it is required a large number of secondary sources. The active noise reduction is also less effective for reducing a high-frequency noise.

For that it has been developed a multipole secondary source enabling to solve with the problem mentioned above. And then the multipole secondary source will be used to conduct a numeric simulation of noise reduction in a free field for propeller noise source.

1. Introduction

So far, the highest frequency limit that can be reduced is a difficult obstacle to overcome in the time of carrying out the active noise reduction. Likewise concerning the distance of secondary source to primary source is also an obstacle that highly inhibiting the affectivity of active noise reduction. It is due to so far the focus of researchers attention is only oriented to the use of monopole secondary source. This is possibly due to the easy in the time of implementation. Thus it is very useful to develop more further the method of multipole secondary source.

The advantage of using the multipole secondary source besides can afford to reduce a higher frequency noise, it can also reduce the number of secondary sources, so that it can make the active noise reducing system to be more compact.

Although the concept of the multipole secondary source has been already known, but the use of multipole secondary source for eliminating the noise still encounters several obstacles, those are that it is impossible to use the multipole secondary source with the infinity order. In order to solve the problem, so we will conduct and optimization of secondary source strength so that it is obtained radiation of minimal sound power of the sound field. With the optimization it will be indicated that with the limited multipole order it still enable to reduce efficiently the sound.

2. The Concept of Sound Reduction with Multipole Source

Kempton firstly develops the concept of sound reduction with a multipole source, i.e. using the Taylor's series use to express the monopole source by the multipole. Each analytic function, g(x), can be expressed in the Taylor's series as follows:

$$g(x+h)=\sum_{n=0}^{\infty}\frac{h^n}{n!}\frac{\partial^n}{\partial x^n}g(x), \qquad (1)$$

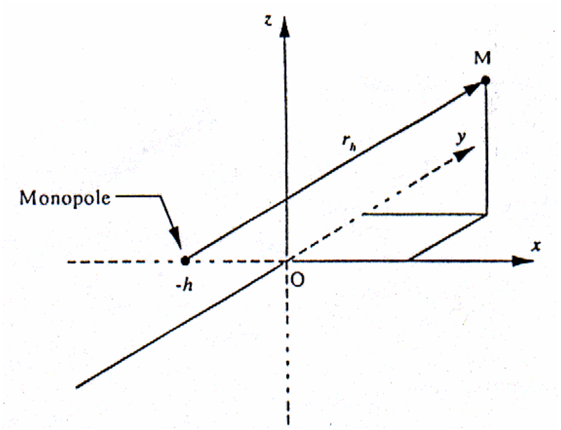


Figure 1. Geometry and coordinate system

Where h is an incremental rise of variable x: in which the formulation above will be convergent to the area $|x| > |h|$. Kempton uses the result to indicate that the sound pressure field of monopole source located in the - h on x-axis can be expressed as a multipole point field of the infinite order situated at the center of coordinate system. Figure 1 indicates the geometry and coordinate system use in this case.

The sound pressure of point M (possessing x, y and z coordinate) as result of the monopole primary source located at –h of x-axis, can be expressed with the equation,

$$P_{pm}(x,y,z) = \frac{j\omega\rho}{4\pi} Q_{pm} \frac{e^{-jkr_h}}{r_h} \qquad (2)$$

Where Q_{pm} is strength of monopole primary source, $r_h = \sqrt{(x+h)^2 + y^2 + z^2}$, ρ is an air density, $\omega = 2\pi f$ where f is a frequency, $k = \omega / c$ where c is sound velocity, and $j = \sqrt{-1}$. The convention of mark $e^{+j\omega t}$ must be determined previously. If the right of equation (2) is expanded in Taylor's series, then it will become,

$$P_{pm}(x,y,z) = \frac{j\omega\rho}{4\pi} \sum_{n=0}^{\infty} Q_{pm} \frac{h^n}{n!} \frac{\partial^n}{\partial x^n} \left(\frac{e^{-jkr}}{r} \right) \qquad (3)$$

Where $r = \sqrt{x^2 + y^2 + z^2}$. It can be indicated that for n = 0, $\left(j\omega\rho / 4\pi \right) Q_{pm} \left(e^{-jkr} / r \right)$, is a sound pressure field formed by monopole point located at the center of coordinate system. With the same course, n=l, $\left(j\omega\rho / 4\pi \right) Q_{pm} h \left(\partial / \partial x \right) \left(e^{-jkr} / r \right)$, expresses a sound pressure field formed by a dipole point located at the center and forward to as long as x-axis. Those, the general form $\left(j\omega\rho / 4\pi \right) Q_{pm} \left(h^n / n! \right) \left(\partial^n / \partial x^n \right) \left(e^{-jkr} / r \right)$ expresses an n-the order longitudinal multipole field component forwarding as long as x-axis and located at the center of coordinate system (it is necessarily noted that here monopole is defined as an order-0 source).

It is obviously appeared in the equation (3) that the sound pressure field resulted from the monopole located at –h of x-axis can be resulted with an infinite order multipole point situated at the center of coordinate system. So that if the multipole characterized by equation (3) is located at central point, and then operated with the several phase to the primary source, so the each field point located at the outer ball with the radius h will be eliminated.

Furthermore, a continued step determines the strength of secondary source that can be obtained with two ways: with a direct approach and the optimization of source strength based on the minimal sound power.

3. Secondary Source Strength with Direct Approach.

The monopole primary sound field can be expressed explicitly in the form of multipole source strength:

$$P_{pm}(x,y,z) = \frac{j\omega\rho}{4\pi} \sum_{n=0}^{\infty} Q_{sn} \frac{\partial^n}{\partial x^n} \left(\frac{e^{-jkr}}{r} \right) \qquad (4)$$

The multipole source strength in equation (4), Q_{sn}, can be made by comparing it with equation (3) when the monopole primary source strength, Q_{pm}, and the distance of the secondary source, h, have been determined. It is clearly that the monopole in the series expansion has the same source strength as the primary monopole, i.e., $Q_{s0} = Q_{pm}$. The dipole secondary source has a source strength, $Q_{s1} = hQ_{pm}$, and, in general, the n-the order multipole component has a source strength

$Q_{sn} = h^n Q_{pm} / n!$. This approach is used to define secondary resource strength, and then called as a direct approach.

The Q_{sn} is source strengths required to produce exactly a monopole primary sound pressure field when the Taylor's series expansions of equation (3) and (4) are carried out to an infinite number of term. As occurred in the time of implementation, so it not enables to make the infinite-order multipole, hence it must cut the series. It is start to know that when only a limited number of multipole components can be used, Q_{sn} obtained with the direct approach not result in an optimal possessing to a monopole primary field. For that, it is suggested to select Q_{sn} with a procedure to be exposed in a subsequent section, so that it will be obtained total minimal sound strength obtained from the combination of primary and secondary source radiation.

4 Secondary Source Strength with Optimization Approach

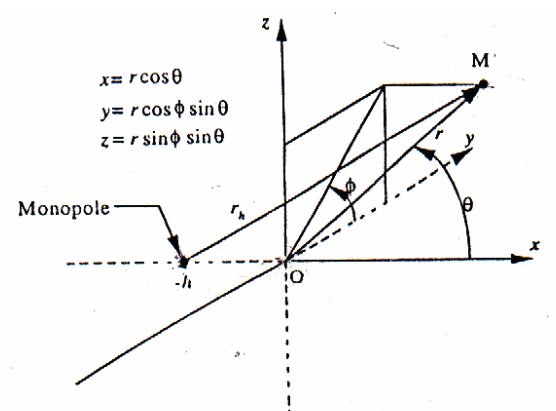


Figure 2. Transformation Coordinate.

The optimal secondary source strength is obtained with a way as follow. Firstly we determined a sound power. The sound power, W, radiated by an acoustic source, can be expressed as

$$W = \iint_S I.ndS \qquad (5)$$

Where I is an acoustic intensity vector, vector n is a surface integration exterior normal vector including the source, and dS is an incremental element of the surface. When assuming a harmonically motion the average intensity is given by $I = (1/2)\mathrm{Re}(p * v)$, where p is a sound pressure, v is a velocity vector provided by Euler's equation, $v = -(1/j\omega\rho)\nabla P$, $\mathrm{Re}\{.\}$ expresses an argument real part, superscript * expresses a complex conjugate and ∇ is a gradient operator. If it is conducted an integration of equation (5) as overall ball surface, then the sound strength can be expresses as;

$$W = \int_0^{2\pi}\int_0^{2\pi} I_r r^2 \sin\theta d\theta d\phi$$

here $I_r = (1/2)\mathrm{Re}\{P * V_r\}$ is a radial component of the sound intensity, V_r is a radial component of particle velocity, and angular θ and ϕ are shown in figure 2. For the various cases discussed in this paper, the distribution of sound pressure is circular symmetric to the x-axis, so that there is no pressure variation to ϕ. In the case the equation (6) is reduced to become,

$$W = 2\pi r^2 \int_0^{\pi} I_r \sin\theta d\theta \qquad (7)$$

Prior to conduct the use of equation (7) for calculating the sound power, as a result of the combination of monopole primary source and multipole secondary source, then it is fairly comfort to express the field of multipole component variation on a spherical coordinate. As noted previously, the sound field produced by a monopole primary source having source strength Q_{pm} and located at $-h$ on x-axis, that is;

$$P_{pm}(r,\theta) = \frac{j\omega\rho}{4\pi} Q_{pm} \frac{e^{-jkr_h}}{r_h} \qquad (8)$$

where r_h is distance of monopole primary source to the field point, and now expresses Figure 2. Transformation coordinate.

as $r_h = \sqrt{r^2 + h^2 + 2rh\cos\theta}$. The expression of sound field formed by monopole secondary, dipole, quadrupole longitudinal and octopole longitudinal sources are successively as follows;

$$P_{sm}(r,\theta) = \frac{j\omega\rho}{4\pi} Q_{sm} \frac{e^{-jkr}}{r} \quad (9)$$

$$P_{sd}(r,\theta) = \frac{\omega\rho}{4\pi} k\cos\theta \left(1 + \frac{1}{jkr}\right) Q_{sd} \frac{e^{-jkr}}{r} \quad (10)$$

$$P_{sq}(r,\theta) = -\frac{j\omega\rho}{4\pi} k^2 \left[\left(1 + \frac{3}{jkr} + \frac{3}{(jkr)^2}\right)\cos^2\theta - \left(\frac{1}{jkr} + \frac{1}{(jkr)^2}\right)\right] Q_{sq} \frac{e^{-jkr}}{r} \quad (11)$$

$$P_{so}(r,\theta) = -\frac{\omega\rho}{4\pi} k^3 \cos\theta \left[\left(1 + \frac{6}{jkr} + \frac{15}{(jkr)^2} + \frac{15}{(jkr)^3}\right)\cos^2\theta - \left(\frac{3}{jkr} + \frac{9}{(jkr)^2} + \frac{9}{(jkr)^3}\right)\right] Q_{so} \frac{e^{-jkr}}{r} \quad (12)$$

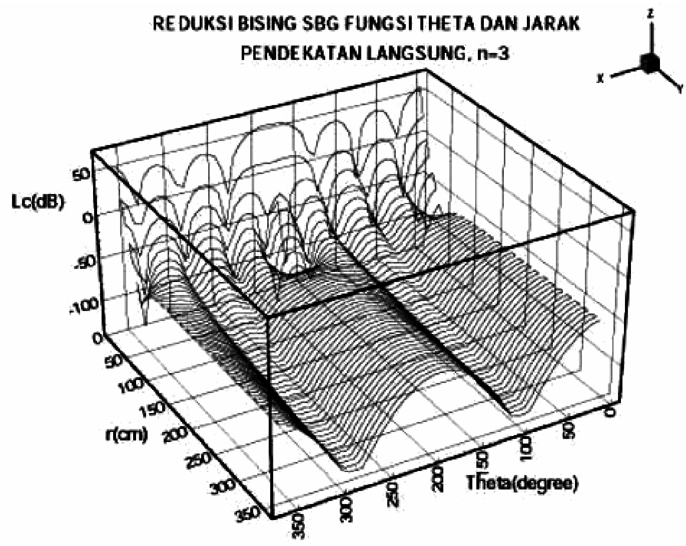
From equation 9, 10, 11, and 12 it will be obtained the total sound power of primary and secondary source consisting of monopole, dipole, quadrupole, and octopole secondary sources. And then the secondary source power is optimized so that obtained the total minimal sound power.

5. Applications

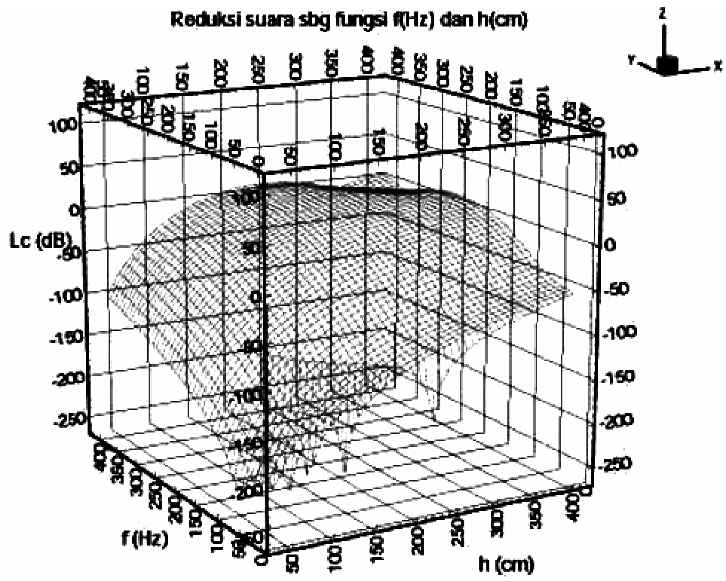
The section describes a simulation of noise reduction in several cases occurred in the vicinity of our environment. The first case uses a simple-plural frequency primary source issued by blower at aircraft airconditioning,TL-lamp, transformator, etc. The second case uses a primary source in the form of noise issued by an aircraft propeller. The third case uses a broadband primary source in the form of white noise.

5.1. The Case of Simple-Plural Frequency Noise Reduction of aircraft air-conditioning blower.

The sub-section exposes the results of the reduction of noise pressure consisting of several single frequencies. This noise sound is in the form of droning sound. This droning sound is occurred in the aircraft electronic instruments, for example: noise sound of TL lamp, transformator, cooling machine, etc.



a)Noise reduction as function of position (radius and theta)



b) Noise reduction Vs frequency variation and distance between primary to secondary source
Figure 3. The picture of the result of droning sound reduction is consisting a single sound frequency.

In the figure it has been seen that the multipole method can reduce successfully the droning noise, because usually the droning sound consists of several single fairly low frequencies.

5.2. The Case of Noise Reduction of Aircraft propeller Cessna 150

The section describes the result of noise reduction derived from the aircraft engine Cessna 150. The aircraft Cessna 150 belongs to a small aircraft category using propeller engine.

Figure 4 is graph of sound pressure in the time domain obtained by measuring the aircraft noise. The measurement is conducted in the aircraft condition being in

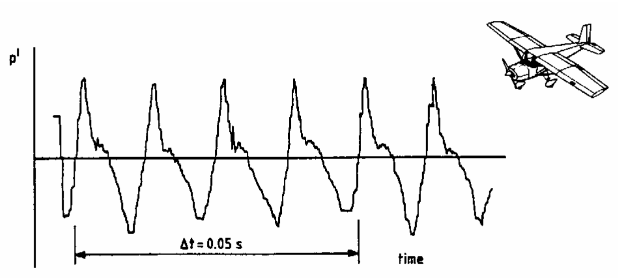


Figure 4. Picture of C-150 aircraft and diagram of time response of aircraft noise

the land. Figure 5 shows the response of noise frequency of the aircraft engine.

The aircraft Cessna 150 possesses a single engine and has a propeller with two blades are drivered by the four-cylinder piston engine. The peaks in the figure of frequency response (figure 5) are in relation with the frequency as a result of the rotation of propeller's blades and the combustion frequency in the piston engine. The

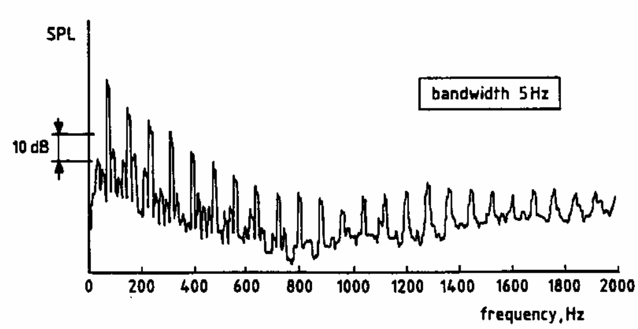


Figure 5. Spectrum of Frequencies of Cessna 150 Aircraft Noise

magnitude of frequency as a result of propeller blade rotation, f_1, is expressed with :

$$f_1 = B\frac{n_p}{60}, \text{Hz} \qquad (13)$$

where B is the number of propeller blades and n_p is rotational velocity of propeller in rpm. In the aircraft reviewed B=2 and n_p = 2400 rpm, so that,

$$f_1 = 2\frac{2400}{60} = 80\,\text{Hz}$$

Since the aircraft machine belongs to the machine 4 TAK, so the frequency as a result of combustion, f_e, is expressed by:

$$f_e = N\frac{n/2}{60}, \text{Hz} \qquad (14)$$

where N is the number of cylinders and n is a velocity of machine rotation in rpm. With N=4 and $n = n_p = 2400$ rpm, then it is obtained $f_e = f_1$. Since $f_e = f_1$, then the contribution of propeller noise and machines noise can't be separated in the frequency spectra.

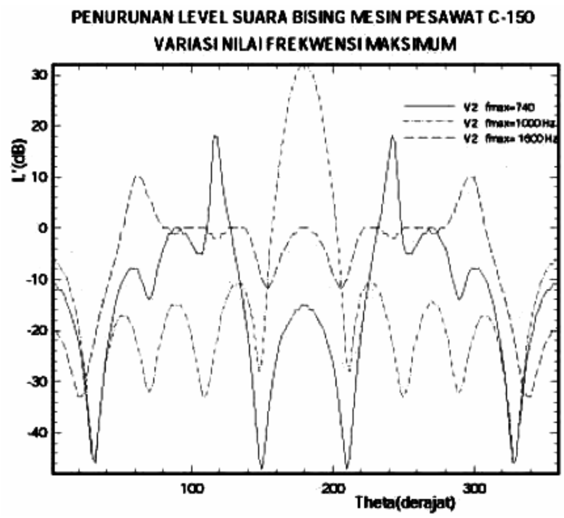


Figure 6. The result of reduction of C-150 aircraft propeller noise

5.3. The Case of Noise Reduction of Broadband White Noise

The section describes the result of noise reduction being in the form of broadband white noise. There are three kinds of variation conducted in the review of this broadband noise. The first is the variation of the distance of primary to secondary sources. It can be seen in the figure 7 that the farer the distance of primary and secondary sources the more difficult to reduce the broadband noise (1-20.000 Hz)

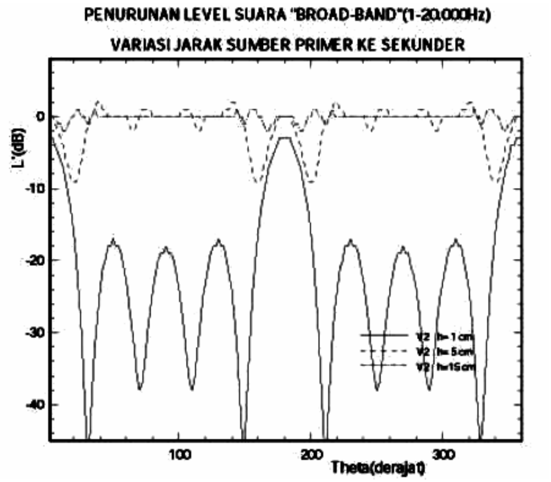


Figure 7. The variation of the distance of primary to secondary sources.

And then the second is the variation of number of frequency contents. It can been seen in figure (8), that the number of frequency content not influence the magnitude of the noise reduction.

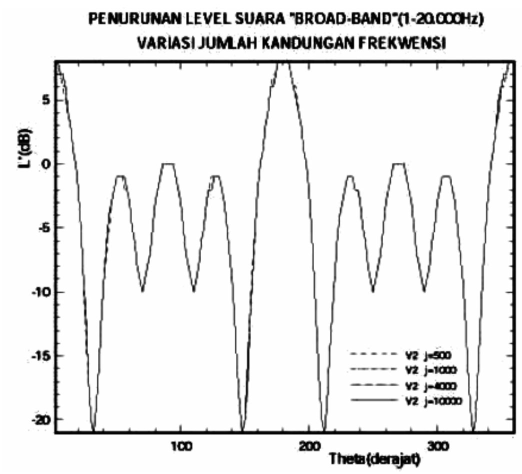


Figure 8.The result of the reduction of broadband white noise.
The variation of number of frequency contains.

Furthermore, the third is really not a white noise, because the maximum frequency used is limited in value(below 20.000 Hz)

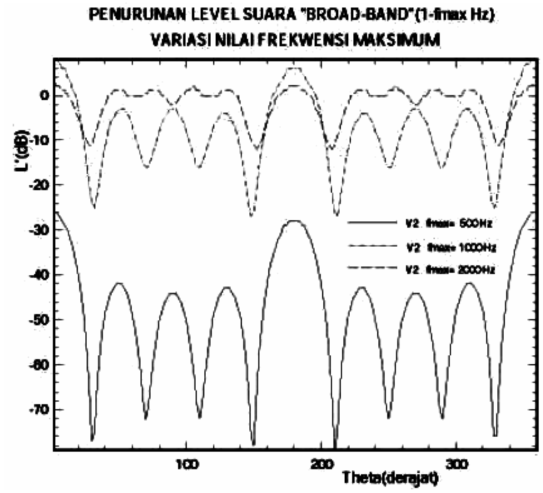


Figure 9. The result of the reduction of broadband white noise.
The variation of maximum f values

6. Implementation

On line implementation of active noise control of aircraft noise using multipole secondary sources still far to be implemented. This paper only presents a projection of implementation.

Implementation of active noise reduction at C-150 noise aircraft has advantages, because the noise is periodic, so we are not need a close lope.

Here are steps to implementation active noise reduction using multipole secondary source.

6.1. Prepare Multipole Secondary Sources

Monopole source radiated using monopole speaker. Dipole sources produced using two monopole source which be taken nearly. The phase between the firs and the second speaker different 180 degree. Quadrapole source is produced by using two-dipole sources. Figure 10 shows the schema to implementation the active noise control using multipole secondary source.

Noise is monitored using microphone or accelerometer. The advantage of using accelerometer that we can direct knows the source noise. If using microphone we must invert to get noise source.

Figure 11 shows the reconstruction of C-150 noise. That data is taken at t=0.00 until t=1.65 second. The comparison between reconstruction results and measurement result show that the result is same.

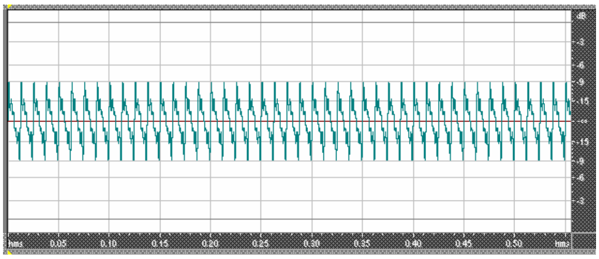


Figure 11. C-150 noise reconstruction, data is taken at t = 0.0 until t = 1.65 s

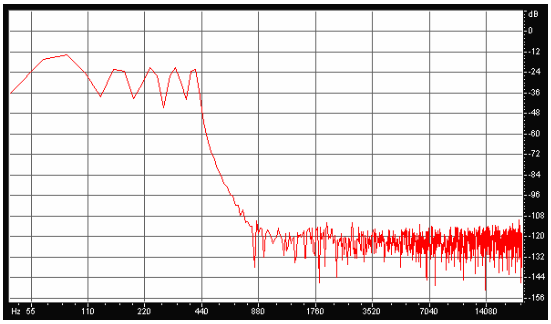
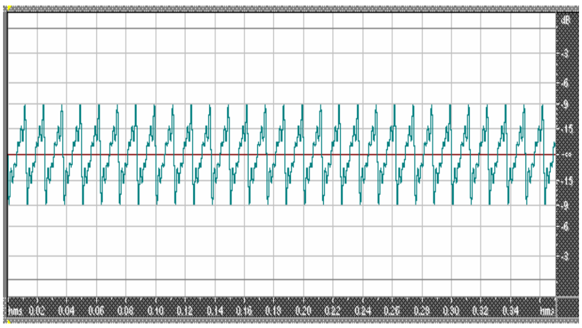


Figure 12 Response Frequency from FFT results from figure 10

The data that show at picture 4 and than reconstructed and showed at figure 10 is taken from distance 20 m which 1.2 m height exactly at the left of C-150 aircraft propeller. Than that data analyze using FFT
analyzer to get frequency response. Response frequency shows at figure 12. That data is inversed to get anti noise source. After that, we can get anti noise signal from the noise source



and than radiated them using multipole speaker.

Figure13 show the anti noise signal

Picture 13 shows anti noise signal that will be radiated by multipole speaker system.

7. Summary

Active noise reduction of aircraft propeller noise using multipole secondary source very promising, although to implemented them at aircraft still need much effort..

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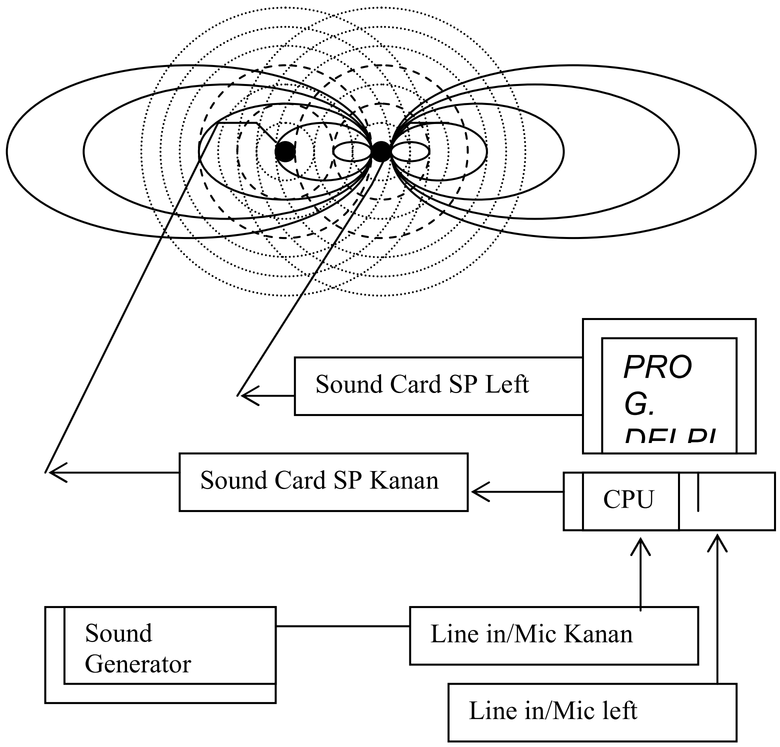

Figure 10 the schema to implementation the active noise control using multipole secondary source.