

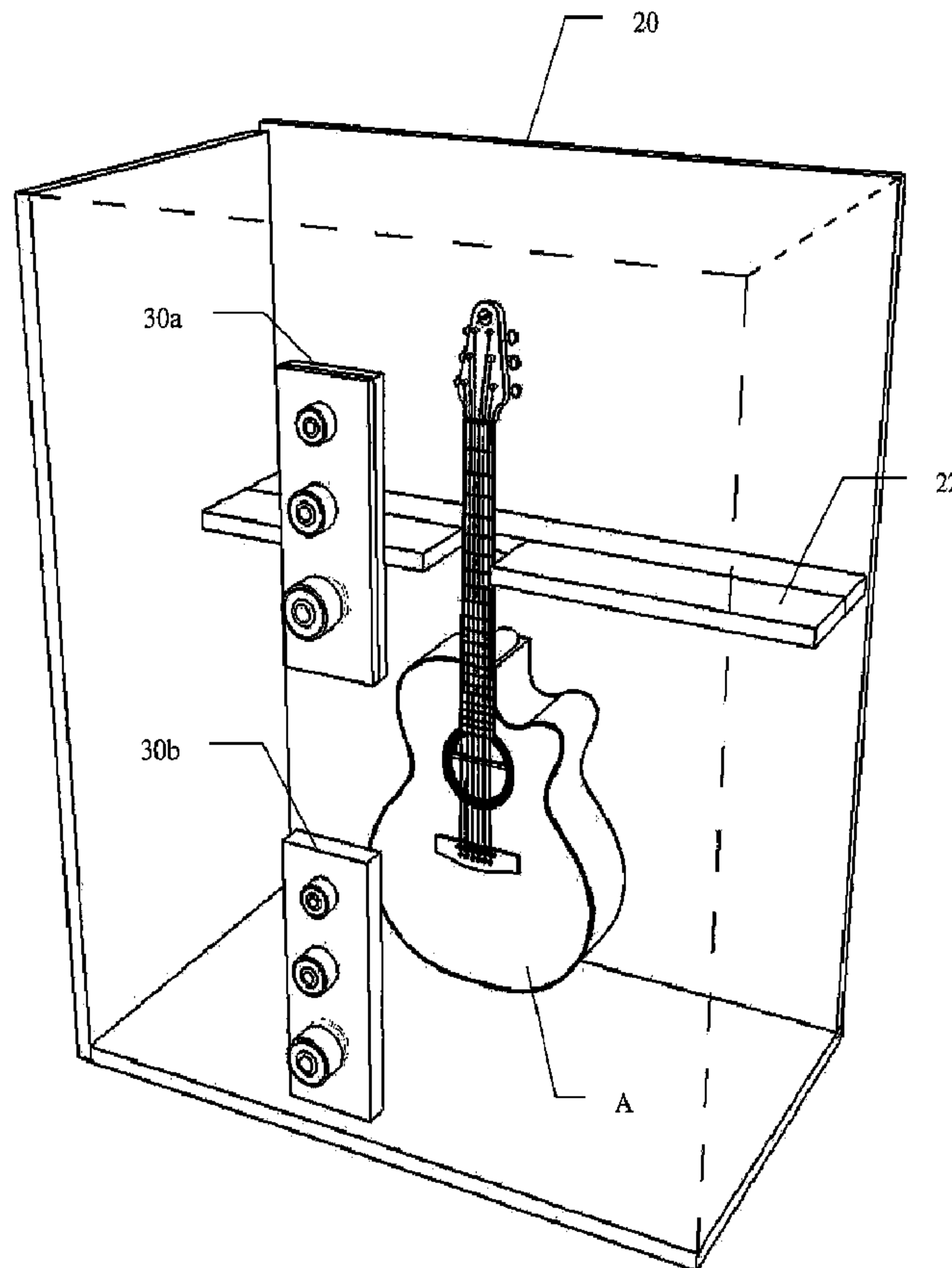


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(54) Titre : PROCÉDE DE MODIFICATION DE LA REPONSE FREQUENTIELLE D'UN ARTICLE EN BOIS  
 (54) Title: METHOD OF MODIFYING THE FREQUENCY RESPONSE OF A WOODEN ARTICLE

**FIG. 1**



(57) **Abrégé/Abstract:**

A method for modifying the frequency response of a wooden article by exciting the article with acoustic energy. Frequency response is the measure of a system's spectrum response at the output to a signal of varying frequency but constant amplitude at

(57) **Abrégé(suite)/Abstract(continued):**

its input. The acoustic energy includes at least one excitation frequency which is preferably in the audible spectrum (20 to 20,000Hz). The use of acoustic energy from the remote source provides non-contact excitation of the wooden article. In one embodiment, the acoustic energy is at least one sound wave that includes at least one resonant frequency of the wooden article, at least one acoustic mode of the wooden article, at least one discrete broadband frequency, and a composite frequency including any combination of multiple broadband frequencies, white noise and pink noise.

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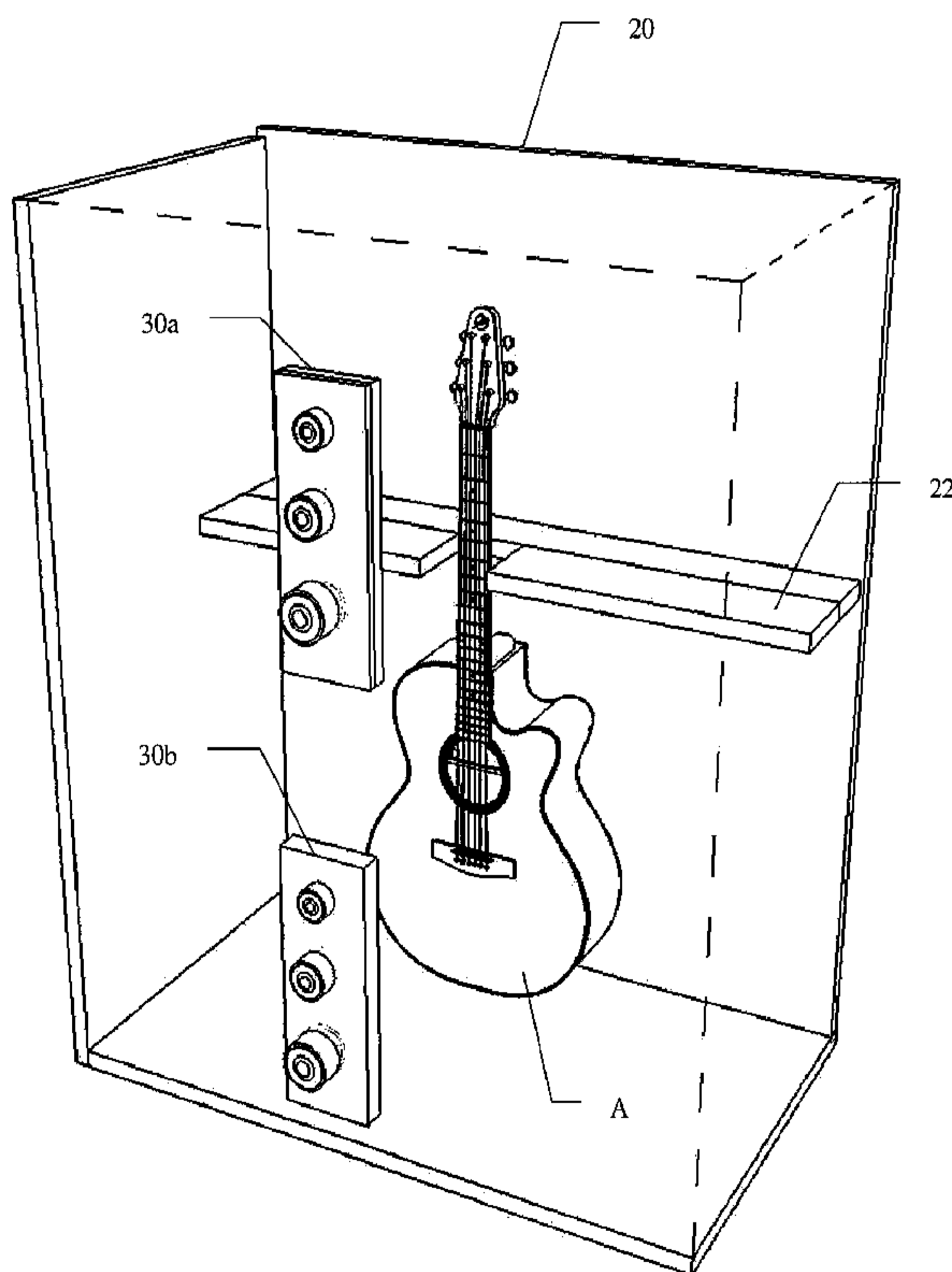
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[Continued on next page]

(54) Title: METHOD OF MODIFYING THE FREQUENCY RESPONSE OF A WOODEN ARTICLE

FIG. 1



(57) Abstract: A method for modifying the frequency response of a wooden article by exciting the article with acoustic energy. Frequency response is the measure of a system's spectrum response at the output to a signal of varying frequency but constant amplitude at its input. The acoustic energy includes at least one excitation frequency which is preferably in the audible spectrum (20 to 20,000Hz). The use of acoustic energy from the remote source provides non-contact excitation of the wooden article. In one embodiment, the acoustic energy is at least one sound wave that includes at least one resonant frequency of the wooden article, at least one acoustic mode of the wooden article, at least one discrete broadband frequency, and a composite frequency including any combination of multiple broadband frequencies, white noise and pink noise.

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5                   **METHOD OF MODIFYING THE FREQUENCY  
                          RESPONSE  
                          OF A WOODEN ARTICLE**

**CROSS REFERENCE TO RELATED APPLICATIONS**

10       This application is a continuation of copending U.S. Patent Application 12/185,906, filed August 5, 2008, which claims priority to copending U.S. Patent Application 11/668,031, filed January 29, 2007, which application claims priority to U.S. Provisional Application 60/763,021 filed on January 27, 2006, which is incorporated herein by reference.

**BACKGROUND OF THE INVENTION**

15       The acoustic properties of wood are well documented. The selection of wood as a construction material, particularly for acoustic applications such as instruments and concert halls, is important because the sound is produced by the vibrations of the material itself. The characteristics which determine the acoustic performance of a material are density, Young's modulus and loss coefficient (see Wegst, U. 2006. Wood for sound. *American Journal of*  
20       *Botany* 93: 1439–1448). Wegst has shown that Young's modulus (measurement of a material's stiffness) for a given species of wood is almost linearly correlated to density.

Pitch, loudness and timbre represent the three auditory attributes of sound. The term pitch represents the perceived fundamental frequency of a sound, which can be precisely determined through physical measurement. The intensity of a sound is a function (the square  
25       of the amplitude) of the vibration of the originating source. In addition to a pitch associated with a sound, an acoustic body also has a pitch which is expressed by the spectrum of frequencies it creates when vibrated. The acoustics of a given body depend on shape as well as the material from which the body is made (Wegst).

It is known that stringed instruments are enhanced with age, specifically from actual playing-  
30       time (or use). The wood used to construct the instruments provides a more pleasing result as the instrument is played. It is for this reason that such a high value is placed on vintage instruments.

The vibration associated with use of the instrument causes subtle changes in the pliability of the wood. Vibration has equal effects on the natural resins within the wood. Moreover,  
35       finishes such as lacquer, commonly applied to wooden stringed instruments, are affected by vibration resulting in the loss of plasticizers. These changes usually take many years.

5 Others have sought to shorten the time needed to gain the desired effects of aging. For  
example, U.S. Patent No. 2,911,872 describes a motor powered apparatus which  
mechanically bows the strings of a violin. The system can be set up such that the strings can  
be played at any selected position and bowed in succession. U.S. Patent No. 5,031,501  
10 describes a device comprising a small shaker board which is attached to the sound board of  
a stringed instrument. The shaker is then driven by a musical signal to simulate what the  
sound board experiences as it is being played. These approaches both provide automatic  
means to simulate playing the instrument, thus allowing the instrument to be aged without the  
expenditure of time or effort by a real musician. However, both approaches take a prolonged  
period of time to age a new instrument because they basically simulate playing the  
15 instrument; aging occurs in real time.

U.S. Patent No. 5,537,908 developed a process for wooden stringed instruments that utilizes  
broadband vibration from a large electromagnetic shaker and controller. The instrument is  
attached to a specially designed shaker fixture and then subjected to broadband vibration  
excitation. The broadband input provides excitation over the frequency range of 20 to  
20 2,000Hz, providing accelerated aging compared to single tone inputs from earlier methods.  
Experienced musicians attested to hearing improvement in sound producing ability after  
application of this method. In addition, simple vibration measurements showed an increase in  
instrument response. The process, however, requires direct contact or coupling with a large  
electromagnetic shaker which can and result in damage to the instruments processed. In  
25 addition, the upper frequency limit of such shakers is about 2,000Hz.

In addition to its use in the construction of instrument, wood is an important component in the  
acoustic makeup of structures. Concert halls, in particular, are meticulously constructed to  
maximize acoustic effect. To this end, great care goes into the selection and placement of  
construction materials. Two important factors, with regard to room acoustics, are  
30 reverberation time as well as the level of reverberant sound. Wood is often used to maximize  
acoustic effect through the placement of wooden panels which act as reflectors and  
resonators, and the use of wood flooring and stage construction are necessary for the  
optimization of the sound field and reverberation time (Wegst. 2006).

An acoustic system, such as a musical instrument or concert hall, possesses an acoustic  
35 resonance. Resonance refers to the tendency of a system to oscillate at maximum amplitude  
at certain frequencies, known as the system's resonance frequencies (or resonant  
frequencies). At these frequencies, even small periodic driving forces produce large amplitude  
vibrations, because the system stores vibrational energy.

5 Acoustic resonance is the tendency of the acoustic system to absorb more energy when the frequency of its oscillations matches the system's natural frequency of vibration (its resonance or resonant frequency) than it does at other frequencies. Most objects have more than one resonance frequency, especially at harmonics of the strongest resonance. An acoustic system will easily vibrate at the strongest frequencies, and vibrate to a lesser degree  
10 at other frequencies. Materials, such as wood, possess the ability to react to its particular resonance frequency even when it is part of a complex excitation, such as an impulse or a wideband noise excitation. The net effect is a filtering-out of all frequencies other than its resonance.

#### **SUMMARY OF INVENTION**

15 In one embodiment, the invention includes a method of modifying the frequency response of a wooden article by applying acoustical energy from the acoustical energy source to the wooden article. The article can be any wooden article for use in an acoustical system such as musical instruments, unfinished wood, finished wood, wood panels and flooring. In one embodiment, the article is suspended in an enclosure which allows free vibration and  
20 prevents dampening from contact with a support surface.

The acoustical energy has a predetermined frequency selected from the group consisting of at least one resonant frequency of the wooden article, at least one discrete broadband frequency, a composite broadband frequency and a combination thereof. In one embodiment, the excitation frequency is substantially maintained for a predetermined time (i.e. one week or  
25 168 hours). Results of the treatment can be modified by altering the treatment time and/or intensity. In an illustrative embodiment, the article is treated between about 90 and 134 dB. The acoustic energy can be applied perpendicularly to the longitudinal axis of the article or in parallel.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

30 For a fuller understanding of the nature and objects of the invention, reference should be made to the following detailed description, taken in connection with the accompanying drawings, in which:

FIG. 1 is a perspective view of an illustrative device for implementing the inventive method.

FIG. 2 is a side view of the illustrative device of FIG. 1.

35 FIG. 3A is the formula for calculating the average power and cross spectra.

FIG. 3B is the formula for computing frequency response.

FIG. 3C is the formula for calculating coherence  $\gamma^2(f)$  as a function of frequency.

5 FIG. 4A is a graph showing representative initial and final (i.e., before and after) frequency response data (Example I).

FIG. 4B is a graph showing the difference in magnitude after the aging treatment (Example I).

FIG. 5 shows graphs of the initial frequency response measured versus the final response for test violins (Example I).

10 FIG. 6 shows graphs of the initial frequency response measured versus the final response for guitars (Example II).

FIG. 7 shows graphs of the initial frequency response measured versus the final response for the first guitar, left position, before and after treatment for one week (Example III).

15 FIG. 8 shows graphs of the initial frequency response measured versus the final response for the first guitar, center position, before and after treatment for one week (Example III).

FIG. 9 shows graphs of the initial frequency response measured versus the final response for the second guitar, left position, before and after treatment for one week (Example III).

FIG. 10 shows graphs of the initial frequency response measured versus the final response for the second guitar, center position, before and after treatment for one week (Example III).

## 20 **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT**

In the following detailed description of the preferred embodiments, reference is made to the accompanying drawings, which form a part hereof, and within which are shown by way of illustration specific embodiments by which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural changes may be made  
25 without departing from the scope of the invention.

The invention includes a method for modifying the frequency response of a wooden article by exciting the article with acoustic energy. Frequency response is the measure of a system's spectrum response at the output to a signal of varying frequency (but constant amplitude) at its input. In the audible range it is usually referred to in connection with acoustic systems.

30 The acoustic energy comprises at least one excitation frequency, which is preferably in the audible spectrum (20 to 20,000Hz). The use of acoustic energy from a remote source provides non-contact excitation of the wooden article. In one embodiment, the acoustic energy is at least one sound wave which comprises at least one resonant frequency of the wooden article, at least one acoustic mode of the wooden article, at least one discrete  
35 broadband frequency, a composite frequency (including multiple broadband frequencies, white noise and pink noise) or any combination thereof.



5 The acoustic energy source of one embodiment is an electromechanical transducer, or any device that converts one type of energy to another (such as converting electricity into sound waves). In an illustrative embodiment, the acoustic energy source is a three-way speaker comprising three drivers: large for the bass, midsize for the midrange frequencies, and small for the high frequencies.

10 An illustrative device for employing the inventive method is shown in FIGS. 1 and 2. Wooden article **A**, here a guitar, is suspended in enclosure **20**. Suspension of the article prevents dampening due to the articles contact with a solid surface. The enclosure can be mobile, resembling a box or case, or can be room specifically adapted for the accelerated aging of multiple instruments or large instruments such as a piano. In Fig. 1, the enclosure (**20**) is a

15 box (with most of sides omitted for ease of viewing). Wooden article **A** is suspended in enclosure **20** at the neck by support **22**. Padding can be used to isolate instrument **A** from support **22** and to protect its surface. Enclosure **20** can be constructed from any suitable material, including inexpensive materials such as medium density fiberboard. Acoustic energy source, here speakers **30a** and **30b**, are positioned to apply acoustic energy to the

20 surface of article **A**. In one embodiment, a pair of speakers is utilized with one speaker **30a** facing the front body of instrument **A** and the second speaker **30b** facing the instrument's neck. In an alternate embodiment, speaker **30a** faces the front body of instrument **A** and the second speaker **30b** faces the back or side of the article. The acoustic energy emanating from the acoustic energy source can be amplified through a power amplifier (not shown). In

25 one embodiment, the acoustic energy is applied between about 100 and 140dB. The acoustic energy source is adapted to run continuously for days or weeks at a time.

Test instruments were assessed before and after receiving an acoustic treatment as described above. Experienced musicians provided subjective input on test instruments and found significant improvement with respect to response, playability, and ease of tuning. In

30 addition, frequency response data computed from impact testing using a miniature soft tipped impact hammer and a miniature accelerometer revealed significant improvements in measured response.

Frequency response,  $FR(f)$ , was determined with the impact force  $F$  (in units of Newtons, N) to the article as the input and the resulting vibratory acceleration  $A$  (in units of g) of the article

35 sound board as the output. It was calculated using a two-channel dynamic signal analyzer. Time trace measurements of the dynamic input and output were obtained, these measurements were windowed, and the fast Fourier transforms of these windowed time traces computed. This was repeated at least 8 times, and the average power and cross spectra are computed as using equation (1) in FIG. 3A. The frequency response was then

40 computed using equation (2) in FIG. 3B.

5 The magnitude of the response function is presented graphically in FIGS. 4A through 6 as g/N  
versus frequency. Coherence was also computed to assess the validity of the measurement.  
Coherence provides a measure of the power in the test instrument vibration that is caused by  
the power in the impact force. A coherence of 1 indicates that all of the vibratory acceleration  
is caused by the impact force, whereas a coherence of 0 indicates that none of the vibration is  
10 caused by the force. The coherence  $\gamma^2(f)$  is a function of frequency and is computed equation  
(3) (FIG. 3C).

#### Example I

Tests with several violins and guitars were performed. The instruments were subjected to the  
acoustic treatment, as describe above, continuously for several weeks using pink noise (1/f)  
15 broadband input. The instruments were assessed both before and after the treatment by  
experienced musicians and through frequency response measurements.

The musicians noticed a vast improvement in the tonal quality (warmer), responsiveness  
(increased response), and ease of tuning. The improved ease in tuning is of special interest  
because new instruments (especially lower end string instruments) are very difficult to get and  
20 keep in tune.

FIG. 4A shows representative initial and final (i.e., before and after) frequency response data.  
The coherence shows that most of the response is due to the input over most of the  
frequency range assessed. The magnitude is notably higher following the aging treatment.  
This is highlighted in FIG. 4B which shows the difference in magnitude. This data clearly  
25 shows that the instrument yields more vibratory response (g) per unit input (N) over most of  
the frequency range. This is consistent with one of the findings observed independently from  
experienced musicians.

#### Example II

Additional tests were performed on four violins and three guitars. The repeatability of the  
30 process is shown consistently between the ranges of 500 – 600 Hz and 800 -900 Hz for the  
violins. The magnitude of change ranged from 5 to 20. A positive magnitude change means  
that the instruments produce more sound, or responds more for the same energy input; a  
significant aspect of this process. The violins used for testing ranged in quality from very  
cheap (\$150.00) to moderately priced (\$1200.00) with the building quality commensurate with  
35 the price paid. FIG. 5 shows the initial frequency response measured versus the final  
response for the violins.

The repeatability of the process is consistent between the ranges of 700 – 900 Hz for the  
guitars (FIG. 6). The magnitude of change ranged from 0 to 1. Even though the magnitude  
change is significantly less than the results found for the violin, this is still significant.

5

**Example III**

Two guitars were treated for a period of one week (168 hours) with the method as described above. The guitars were suspended at the neck as shown in FIG. 1. Padding was used to protect their surfaces. The acoustic energy was non-contact, broadband audio at a sound level of 110dB.

10 The vibratory response of the guitars was assessed before and after the treatment using impact testing. For this test, the guitars were suspended on elastic bands under the nut and at the end pin. The impact was applied on the bass side of the bridge with a PCB model 086D80 hammer with a vinyl tip and a sensitivity of 59.5 N/V, which provides fairly uniform excitation up to 1,000 Hz. A spring and a positioning guide were used to provide repeatable  
15 hammer hits.

The vibration of the guitars was measured with a PCB model 309A accelerometer placed at two different positions: (a) on the bass or left side of the bridge (one inch from the bridge), and (b) at the center (one inch from the bridge). The sensitivity of the accelerometer was 200 g/V. It was attached with bees wax, which is easily removed and does not damage the guitar  
20 finish.

The vibratory response, shown in FIGS. 7 through 10, is presented as the magnitude of the frequency response with units of acceleration output per unit force input, i.e., g/N. This is computed from an average of four impact force and accelerometer measurements using a spectrum analyzer. Measurements were taken every 24 hours to monitor change and each  
25 test was done twice to check repeatability.

The data shows that one week of treatment causes an increase in amplitude in several of the vibratory modes. Physically, this means more response (measured acceleration) for the same input (measured impact force). In addition, the treatment causes a decrease in frequency of several of the resonant frequencies. This indicates increased flexibility (or  
30 decreased stiffness). Treatment at higher sound levels will potentially induce larger changes and/or reduce treatment time.

It will be seen that the advantages set forth above, and those made apparent from the foregoing description, are efficiently attained and since certain changes may be made in the above construction without departing from the scope of the invention, it is intended that all  
35 matters contained in the foregoing description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

It is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention herein described, and all statements of the scope of the invention which, as a matter of language, might be said to fall there between. Now that the  
40 invention has been described,

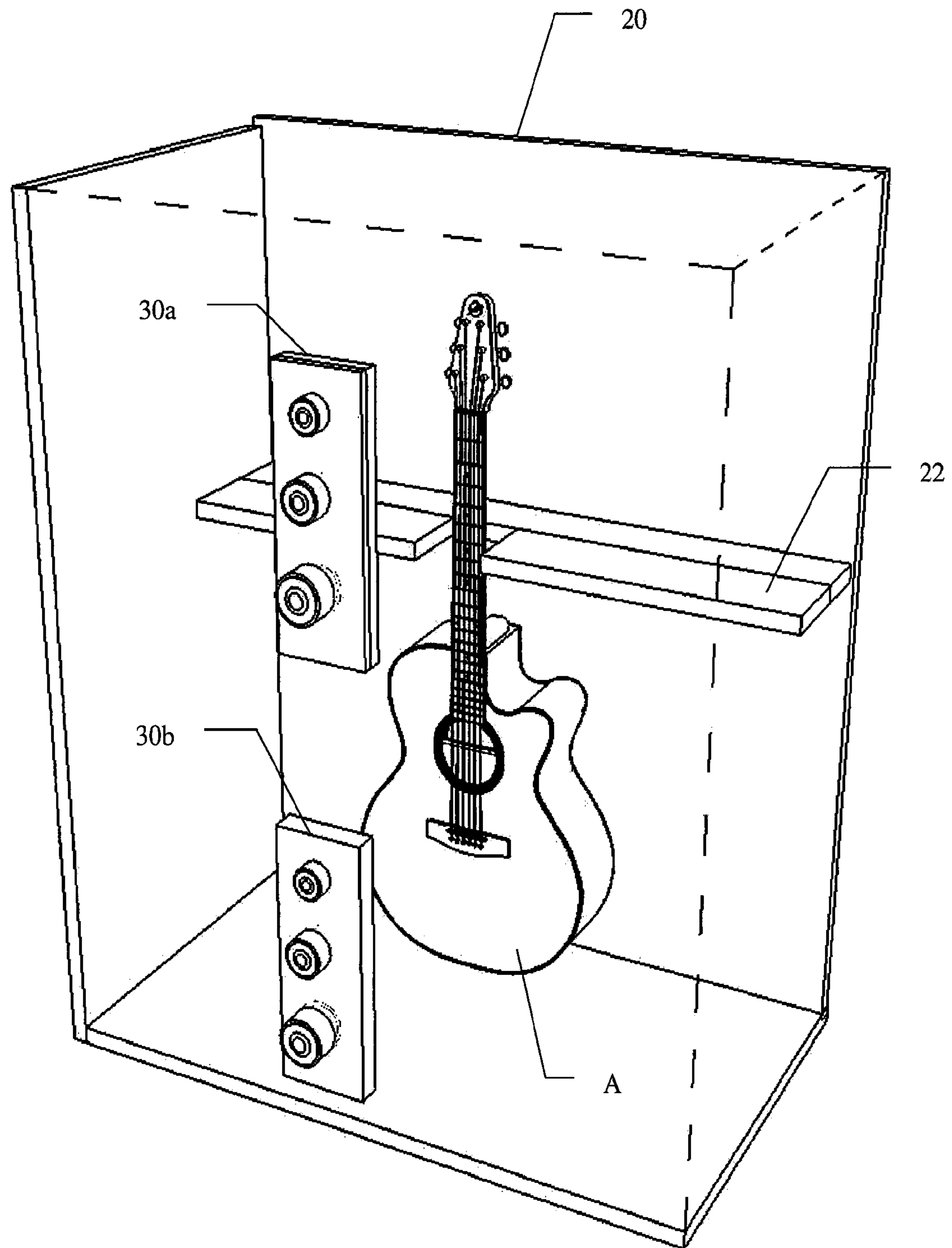
5 What is claimed is:

1. A method of modifying the frequency response of a wooden article, comprising the steps of:
  - placing the article in an enclosure having at least one acoustical energy source;
  - 10 applying acoustical energy from the acoustical energy source to the wooden article.
2. The method of claim 1, wherein the acoustical energy has a predetermined frequency selected from the group consisting of at least one resonant frequency of the wooden article, at least one discrete broadband frequency, a composite broadband frequency  
15 and a combination thereof.
3. The method of claim 2, wherein at least one predetermined frequency is substantially maintained.
4. The method of claim 1, wherein the acoustical energy is applied to the wooden for a predetermined time.
- 20 5. The method of claim 1, wherein the acoustical energy has a sound pressure level greater than about 100dB.
6. The method of claim 1, wherein the acoustical energy has a sound pressure less than about 140dB.
7. The method of claim 1, wherein the acoustical energy is applied to the article for  
25 about 168 hours.
8. The method of claim 1, wherein the article is selected from the group consisting of musical instruments, unfinished wood, finished wood, wood panels and flooring.
9. The method of claim 1, wherein at least on portion of the article is suspended in the enclosure.
- 30 10. The method of claim 1, wherein the acoustic energy source is substantially perpendicular to the surface of the article.
11. The method of claim 1, wherein the acoustic energy source is substantially parallel to the surface of the article.

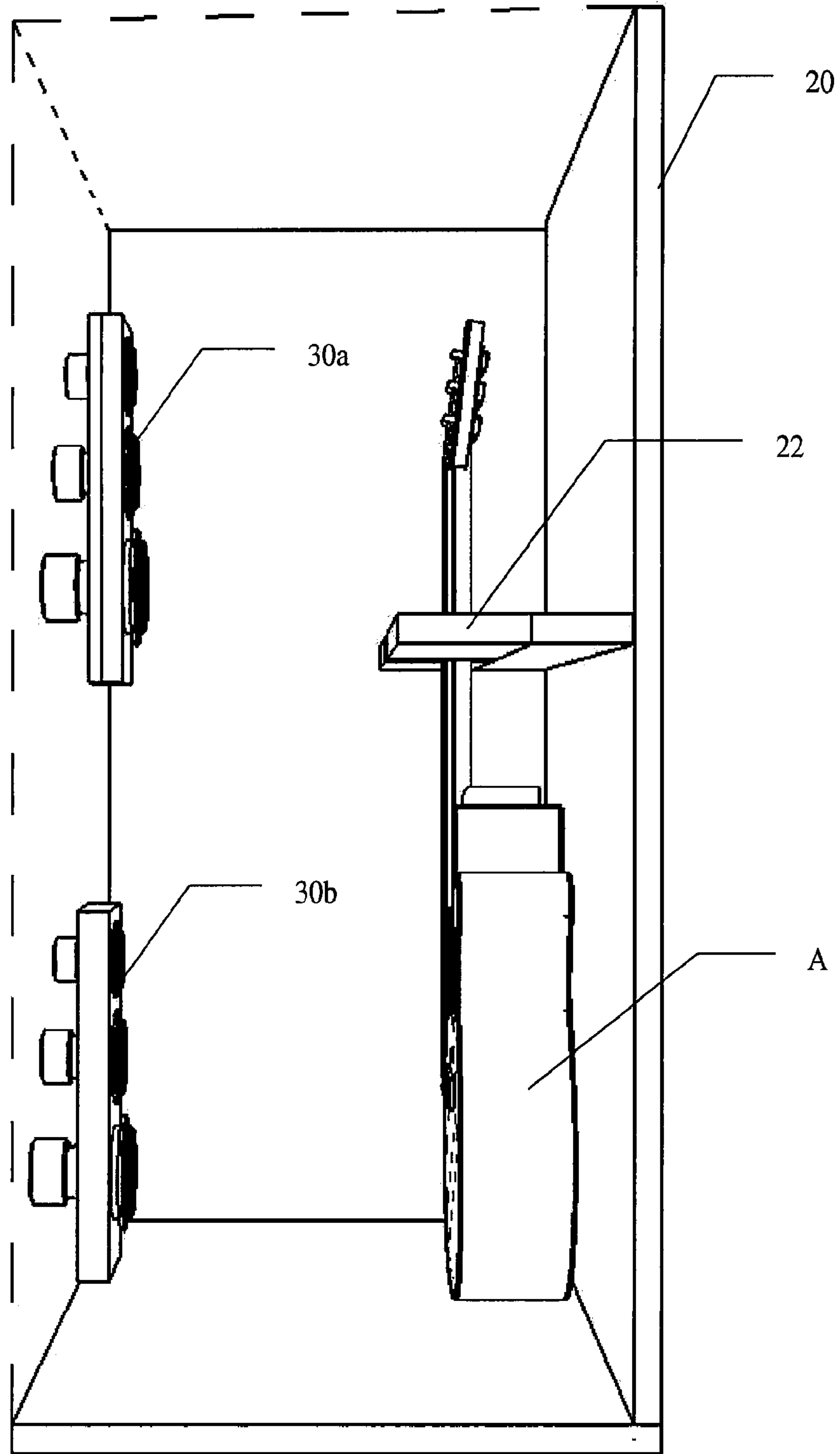
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**FIG. 1**



**FIG. 2**



**FIG. 3A**

$$P_{FF}(f) = \Sigma (F(f) F(f)^*) / n, P_{AA}(f) = \Sigma (A(f) A(f)^*) / n, P_{AF}(f) = \Sigma (F(f) A(f)^*) / n \quad (1)$$

where \* indicates complex conjugate.

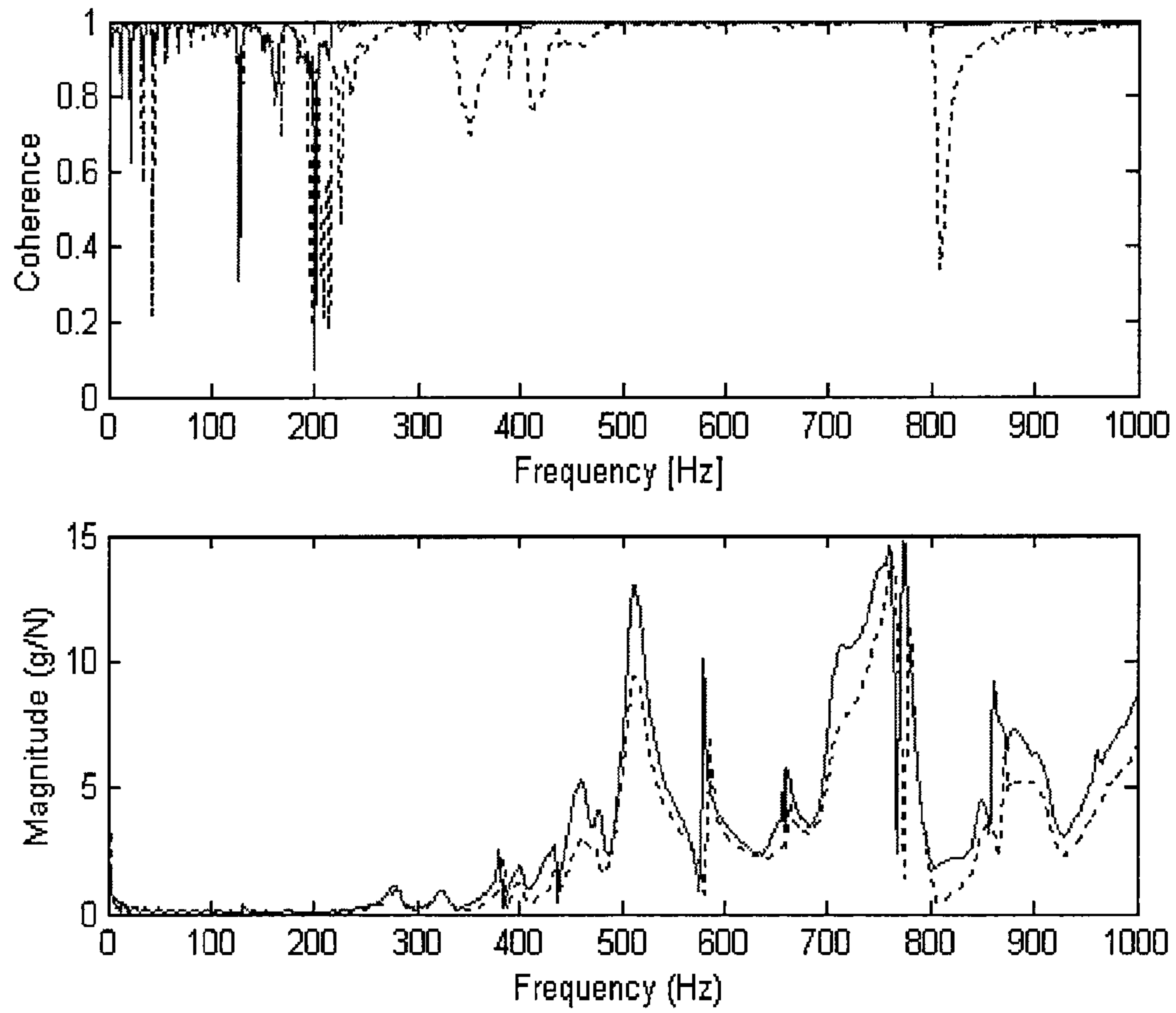
**FIG. 3B**

$$FR(f) = \frac{P_{AF}(f)}{P_{FF}(f)} \quad (2)$$

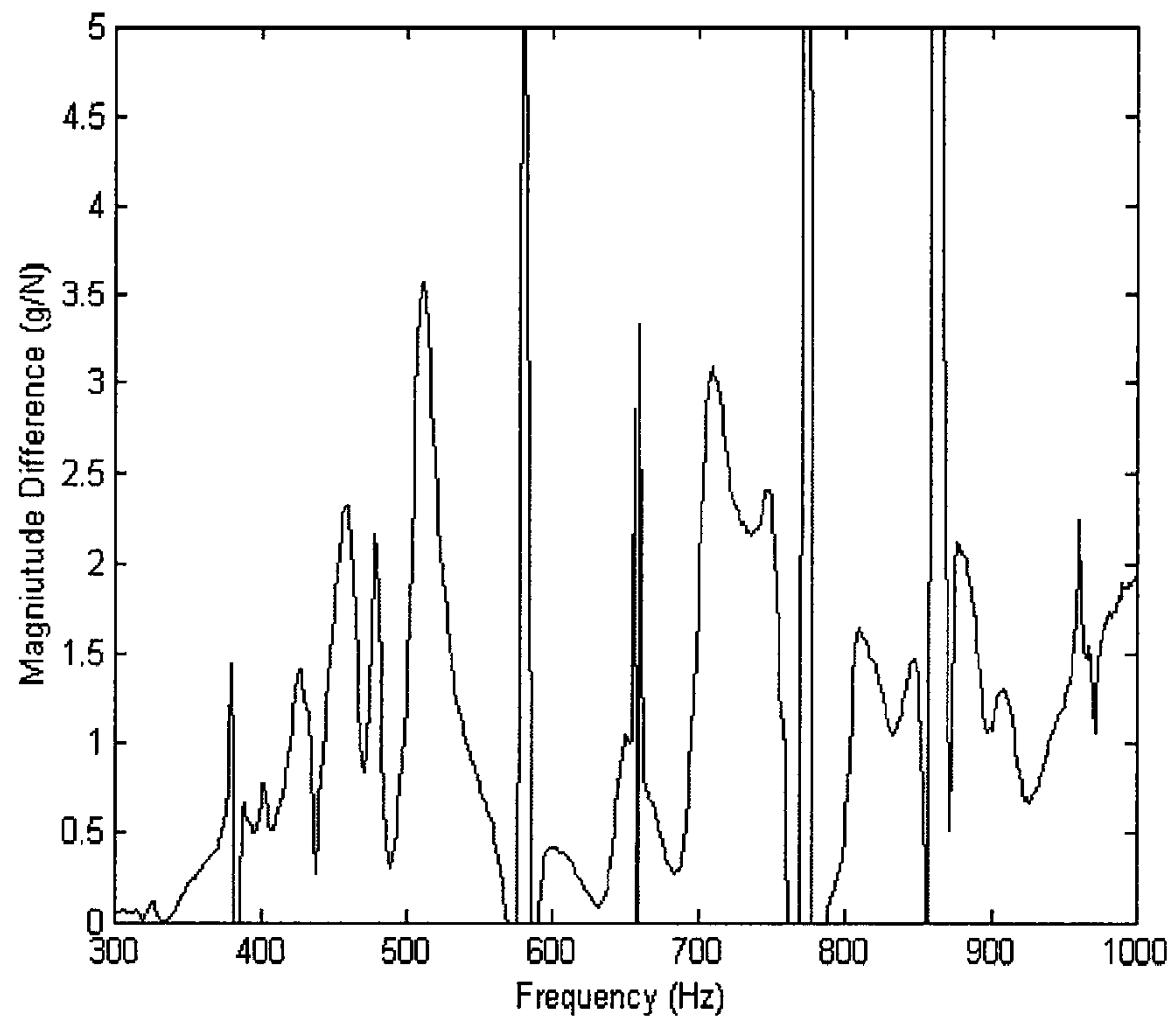
**FIG. 3C**

$$\gamma^2(f) = \frac{P_{AF}(f) P_{AF}(f)^*}{P_{FF}(f) P_{AA}(f)} \quad (3)$$

**FIG. 4A**

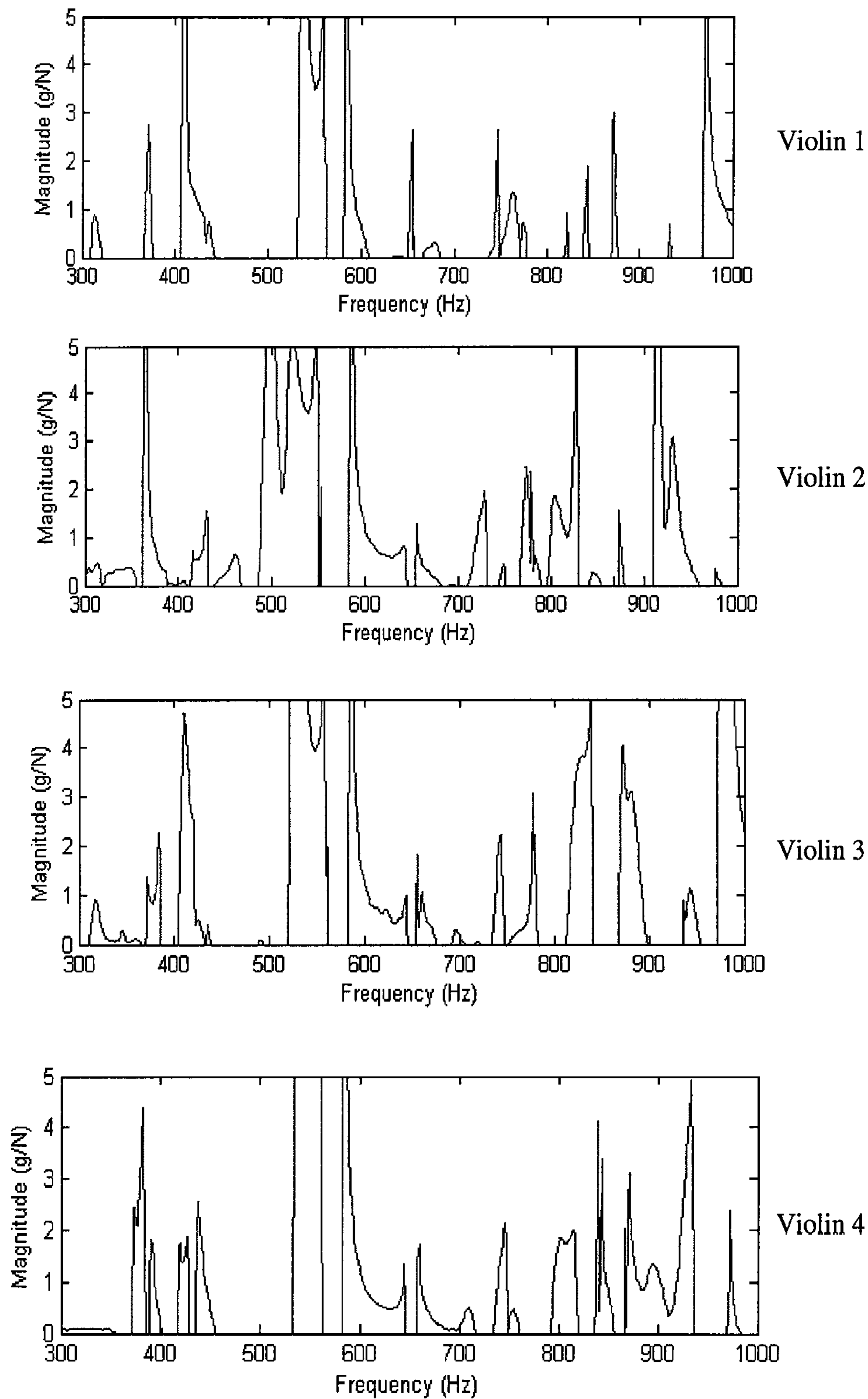


**FIG. 4B**

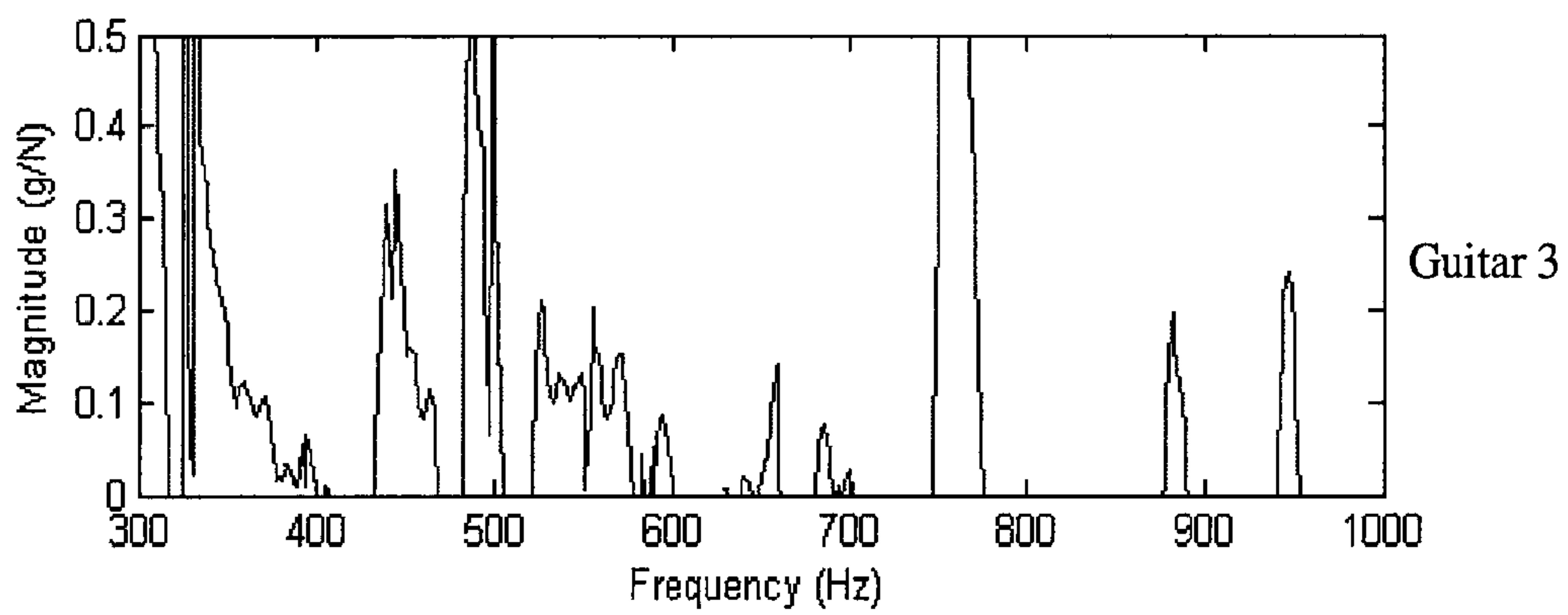
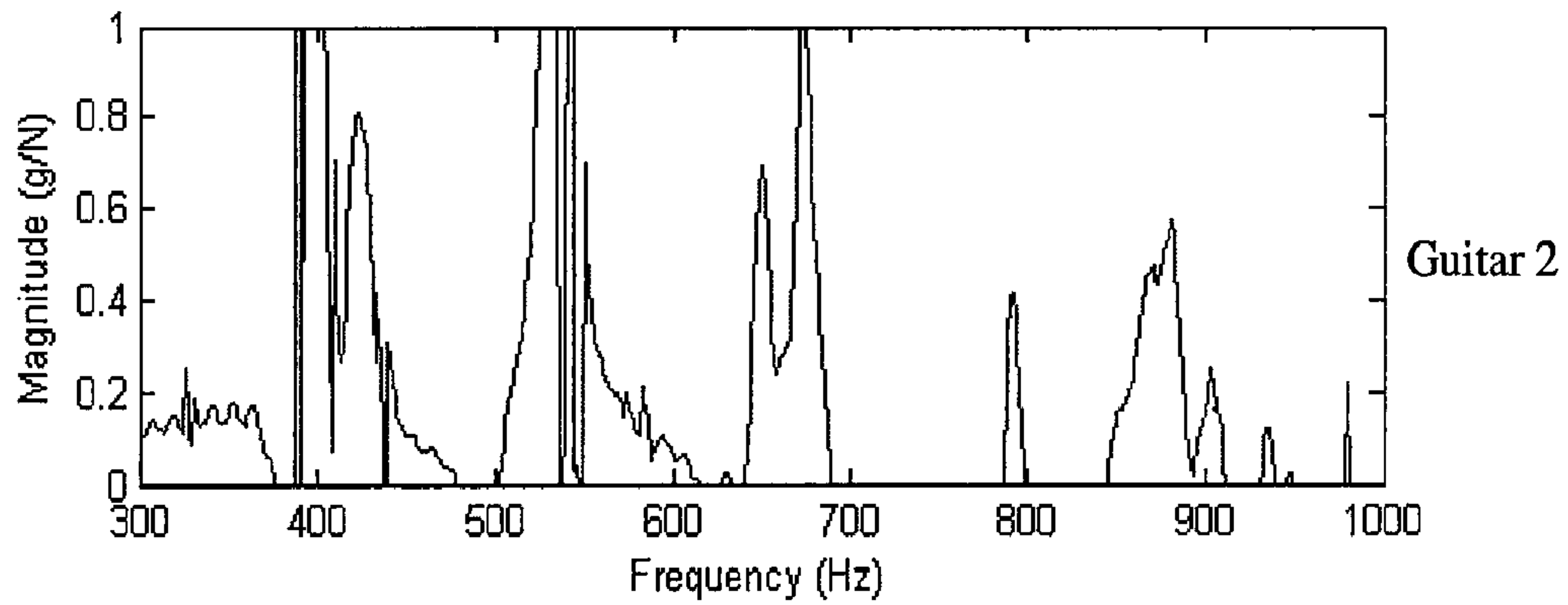
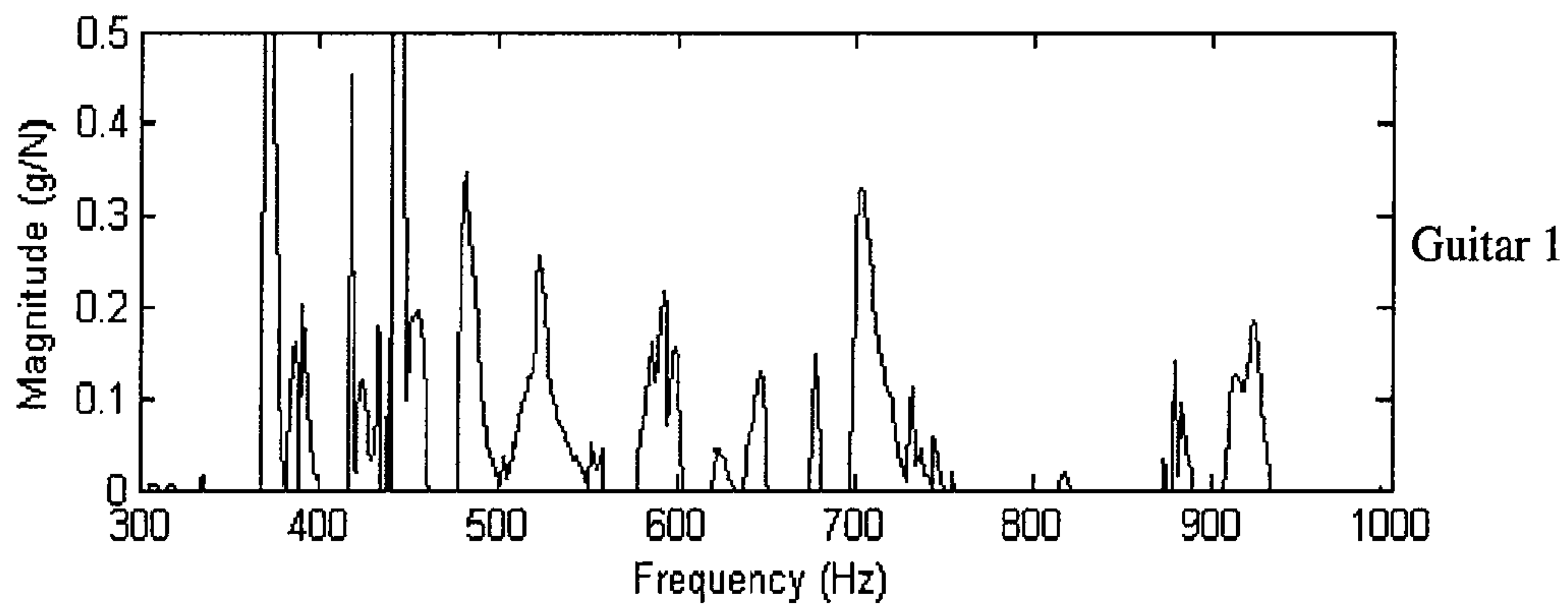


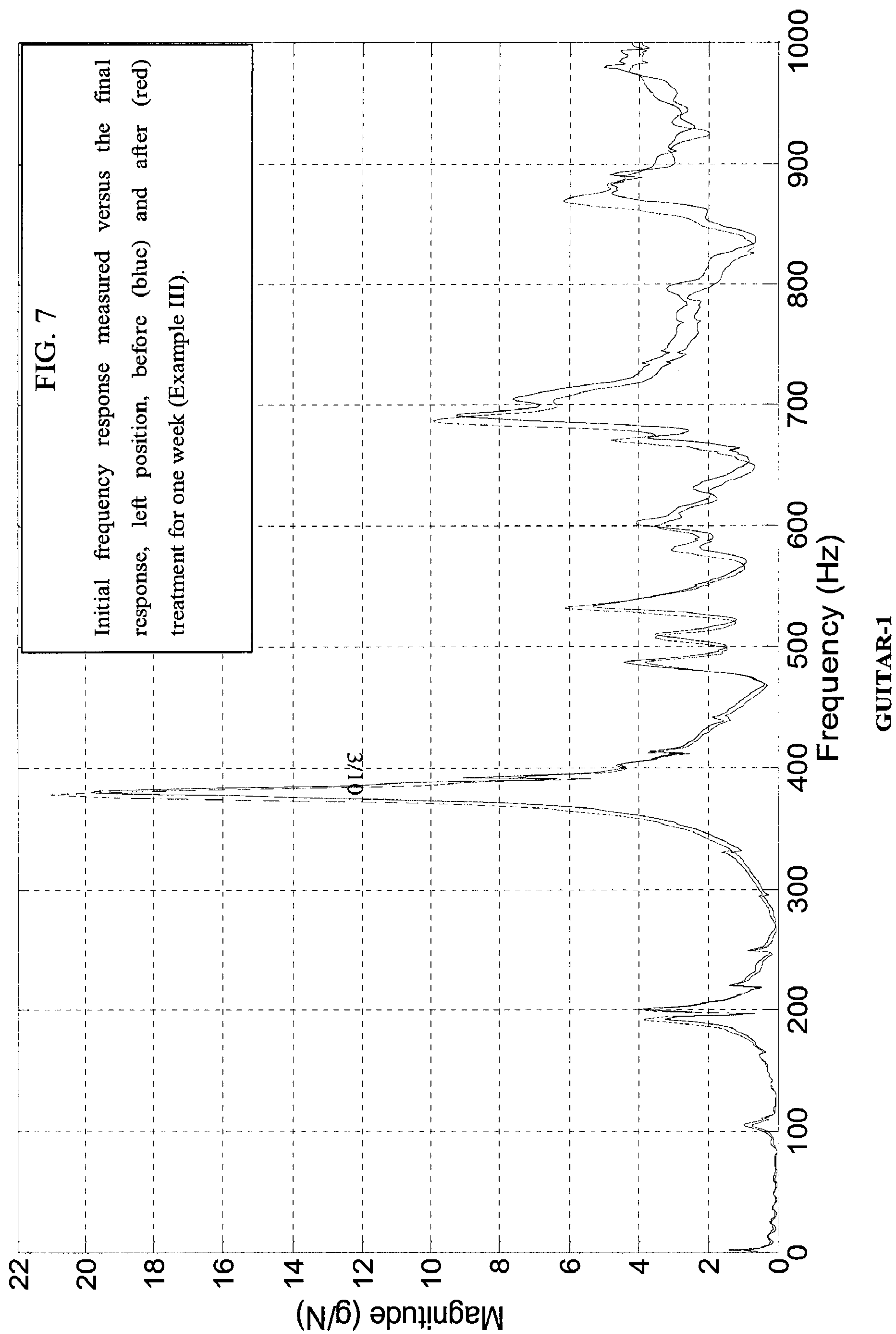


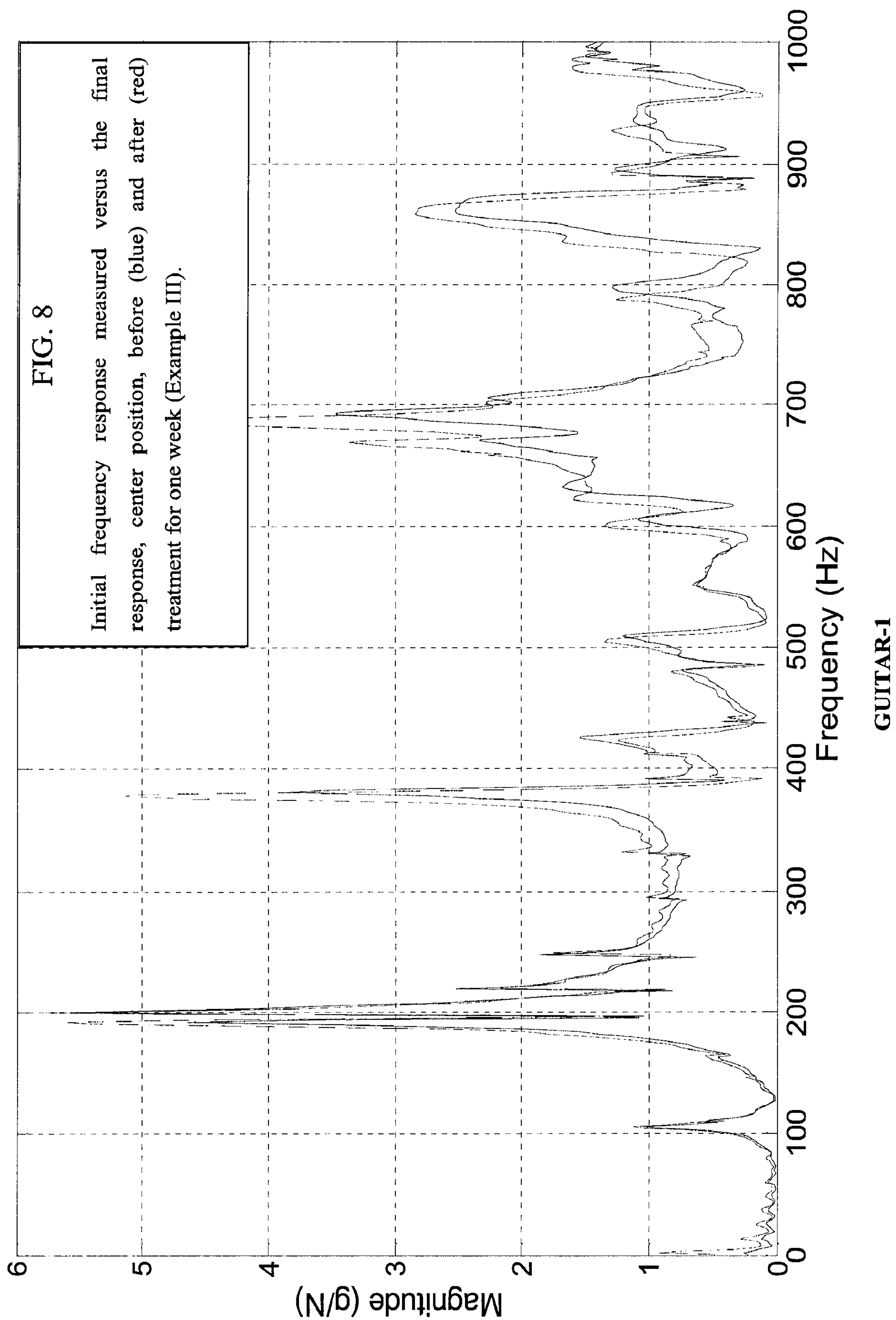
**FIG. 5**

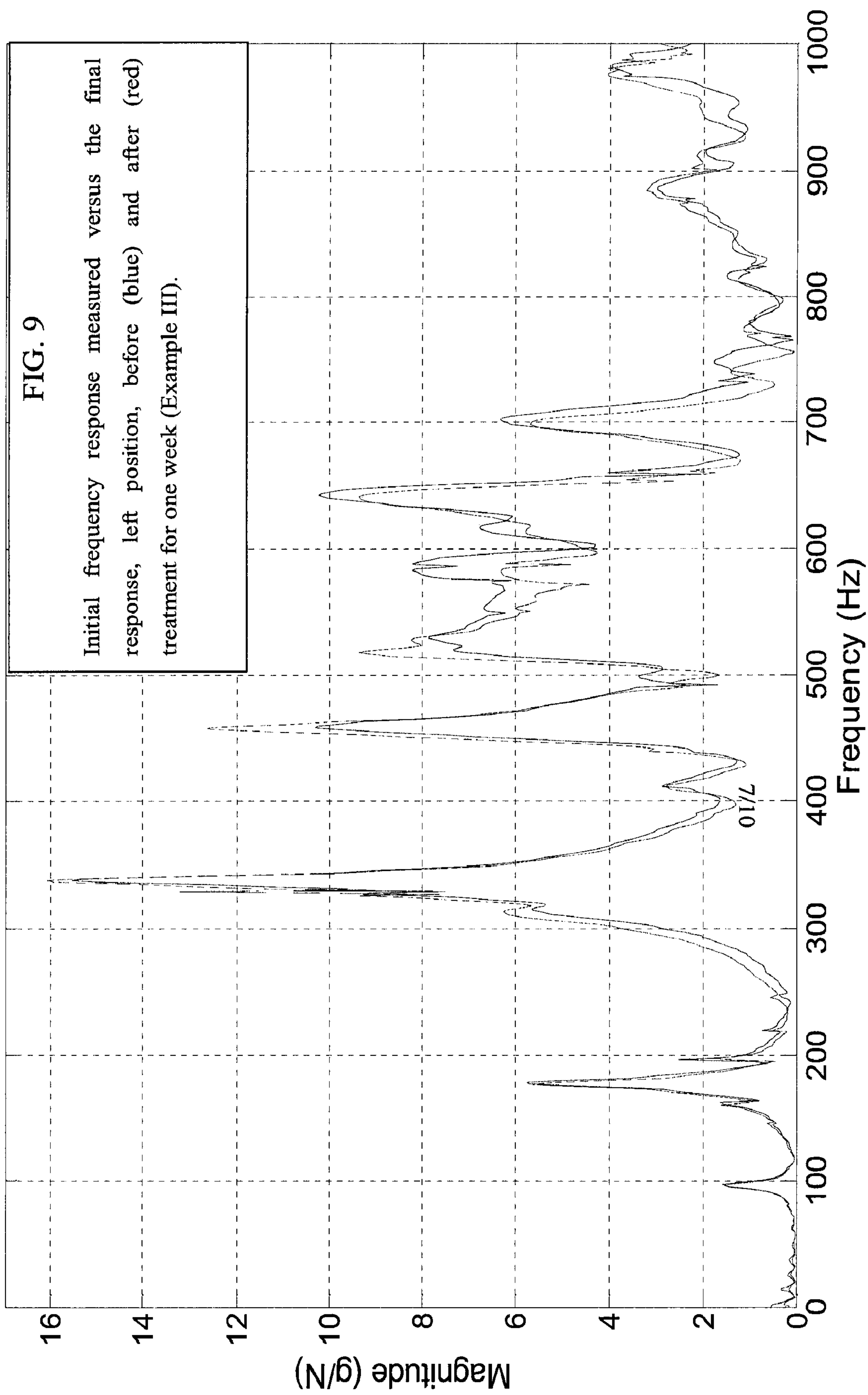


**FIG. 6**









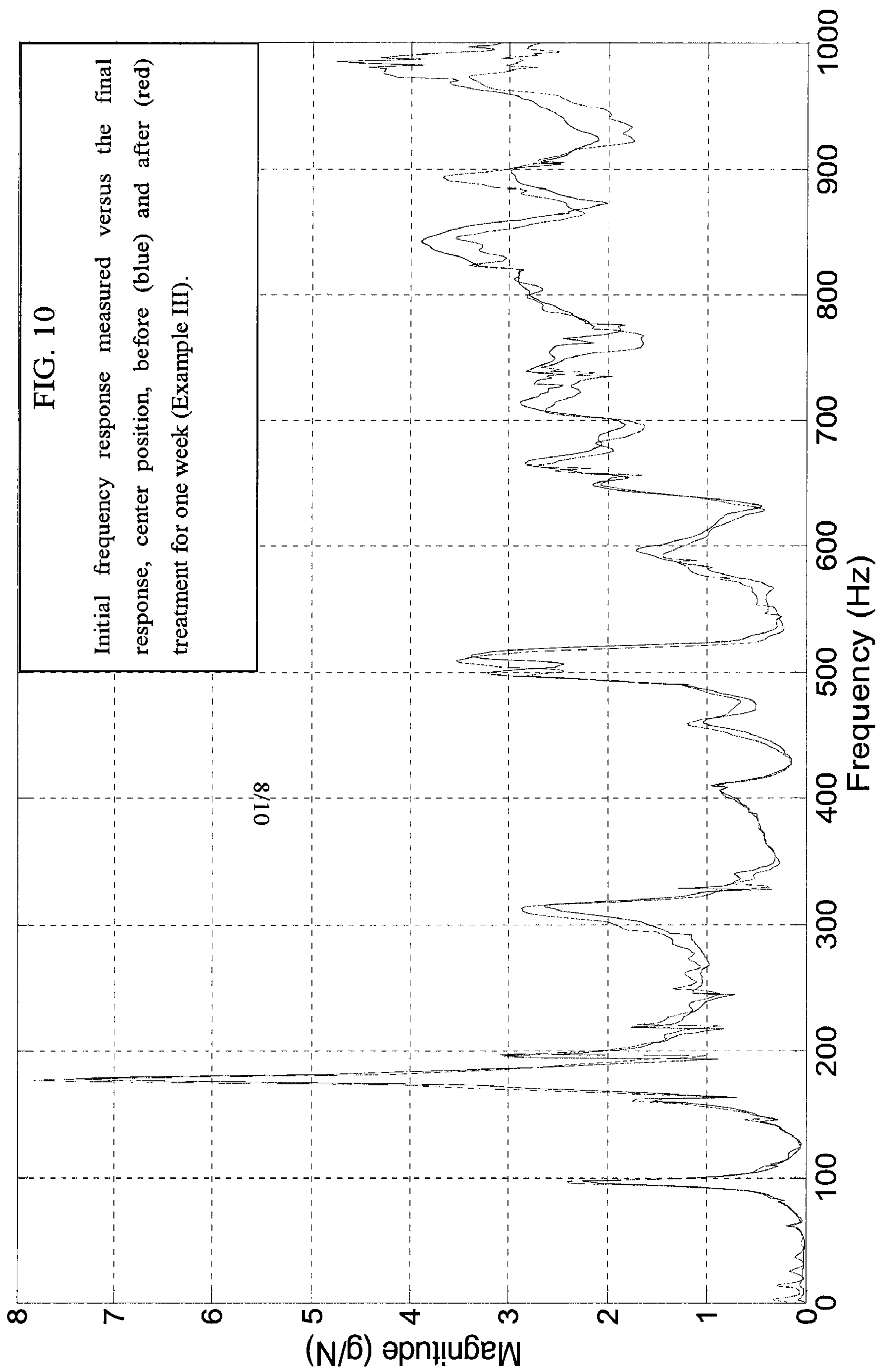


FIG. 1

