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(71) Applicant: **Bridgestone Europe NV/SA**
1932 Zaventem (BE)

(72) Inventors:
- **Ciaravola, Vincenzo**
00128 Roma (IT)
- **Fortunato, Gaetano**
00128 Roma (IT)
- **Giustiniano, Mattia**
00128 Roma (IT)

(74) Representative: **Marchetti, Alessio**
Bridgestone Europe N.V./S.A. - Italian Branch
Technical Center
Via del Fosso del Salceto, 13/15
00128 Roma (IT)

(54) **VEHICLE NOISE CANCELLING**

(57) A computer-implemented method of cancelling vehicle noise is provided which obtains information on a range of frequencies over which a user finds noise most annoying or over which tyre noise is loudest. Noise is cancelled over a range of frequencies in which the difference between the highest and lowest frequencies is less than 230 Hz. Accordingly, the method focusses the noise cancelling on a narrower noise frequency range which improves the efficiency of the noise cancelling and cancels noise in the most problematic range frequencies.

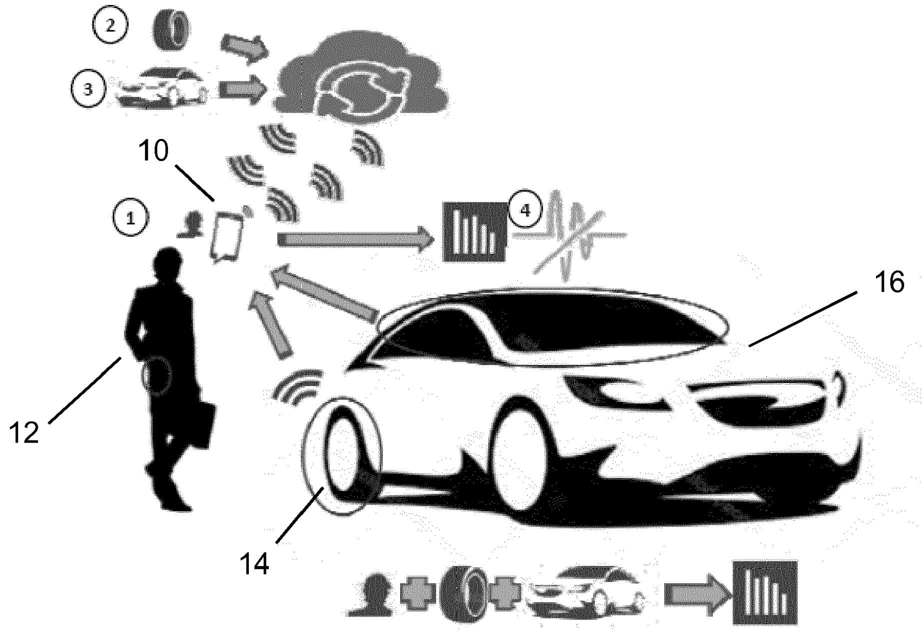

Fig. 1

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Description

[0001] The present invention relates to vehicle noise cancelling.

[0002] Vehicle noise is an annoying problem for the automotive industry, heavily impacting passenger comfort. A vehicle's tyre induces cabin noise by transmitting vibration to the cabin frame: The perceived cabin noise is a combination of tyre particular characteristics, cabin frame geometry and structure and subjective sensitivity to noise emission and frequencies.

[0003] The focus on this particular source of noise (namely, the tyre) is going to increase according to the following trends:

- Autonomous mobility is expected to create higher sensitivity of users to the cabin noise as they will not be focused on driving, but on cabin living.
- Shared mobility is expected to create higher sensitivity of users to the cabin noise as people will use different vehicles every time, zeroing the effect of "habituation" typical of a vehicle owner.
- The electrification of the vehicles is reducing the component coming from the engine, emphasizing tyre-borne noise.

[0004] So-called active noise cancelling involves producing a second sound from a first sound which is intended to cancel the first sound. A first signal is produced from the first sound, a second (noise cancelling) signal is produced from the first signal, and a second sound is produced from the second signal. Typically, the second signal is produced by inverting the first signal. The closer the second signal is to being a mirror image of the first, the better noise cancelling will be.

[0005] The present invention aims to provide improved vehicle noise cancelling.

[0006] The present inventors have realised that a) different people find different noise frequencies annoying; b) different tyres produce different noise frequency spectrums; and c) different vehicles transmit different some noise frequencies more than others.

[0007] The present inventors have also realised that a noise cancelling signal is less efficient if it is has to work on a wide noise frequency range.

[0008] Accordingly, the present inventors have found that vehicle noise cancelling can be improved by focussing the noise cancelling on a narrower noise frequency range in which a) a user desires to cancel noise or finds noise annoying, b) noise of a particular tyre is loudest, or c) tyre noise transmitted by a vehicle body is highest.

[0009] A first aspect of the present invention provides a computer-implemented method of adjusting vehicle noise cancelling, the method comprising:

i) obtaining information on:

a) a range of frequencies over which a vehicle user desires to cancel noise; or
b) a range of frequencies over which noise produced by a tyre is loudest; or
c) a range of frequencies over which tyre noise transmittance by a vehicle is highest; or
d) a range of frequencies over which noise produced by a tyre and vehicle combination is loudest; and

ii) setting a noise signal range of frequencies which includes a range of frequencies obtained in step i), the difference between the highest and lowest frequencies of the noise signal range being less than 230Hz , wherein the noise signal range is a range over which a noise signal is to be produced from a captured noise, the noise signal is a signal from which a noise cancelling signal is to be produced, and the noise cancelling signal is a signal from which a sound is to be produced to cancel the noise.

[0010] Noise cancelling tends to be more efficient over a narrower frequency range. This is because the noise cancelling signal can be made closer to being a mirror image of the noise signal when the noise signal has a smaller number of different frequencies. When the noise cancelling is then focused on a range of frequencies which is appropriate for the particular user/tyre/vehicle then more efficient noise cancelling is provided over the range of frequencies that matter or that is most problematic.

[0011] The first aspect of the invention may provide a method of cancelling vehicle noise, the method comprising steps i) and ii) and: iii) capturing a noise to produce a noise signal over the noise signal range set in step ii), and

iv) producing a noise cancelling signal from the noise signal captured in step iii), and producing sound from the noise cancelling signal to cancel the noise.

[0012] Accordingly, there is provided a computer-implemented method of cancelling vehicle noise, the method comprising:

i) obtaining information on:

a) a range of frequencies over which a vehicle user desires to cancel noise; or
b) a range of frequencies over which noise produced by a tyre is loudest; or
c) a range of frequencies over which tyre noise transmittance by a vehicle is highest; or
d) a range of frequencies over which noise produced by a tyre and vehicle combination is loudest;

ii) setting a noise signal range of frequencies which includes a range of frequencies obtained in step i), the difference between the highest and lowest frequencies of the noise signal range being less than 230Hz;

iii) capturing a noise to produce a noise signal over the noise signal range set in step ii), and

iv) producing a noise cancelling signal from the noise signal captured in step iii), and producing sound from the noise cancelling signal to cancel the noise.

In the first aspect of the present invention, the difference between the highest and lowest frequencies of the noise signal range being less than 230Hz. This provides more efficient noise cancelling than the prior art because, as referred to above, noise cancelling tends to be more efficient over a narrower frequency range. Hence the invention adjusts or tunes vehicle noise cancelling to be more efficient. In the prior art, noise cancelling is conducted over a broader frequency range. For example, in US patent application published as US 2015/124989 A1 relates to noise cancelling, and Fig. 4 illustrates a transfer function over a range of 20-260Hz (although this does not specifically disclose noise cancelling over this range).

[0013] In step i) the user may desire to cancel noise over a range of frequencies because the user finds noise most annoying over that range of frequencies.

[0014] In the first aspect of the invention, the range of frequencies of a), b), c) and d) is less than 230Hz.

[0015] In the first aspect of the present invention, a "range of frequencies" is defined between two numerical limits.

[0016] In the first aspect of the present invention, "loudest" is in comparison to another range of frequencies where noise is less loud.

[0017] The loudness broadly corresponds to the amplitude of the noise. However, a user may perceive sounds of the same amplitude but different frequencies as having different loudness. The method may take the user's perception into account when obtaining information on a range of frequencies over which noise produced is loudest.

[0018] In the first aspect of the present invention, frequencies may be only within human audible range i.e. 20Hz-20kHz.

[0019] In the first aspect of the invention, in step i), obtaining information on a) may comprise playing noises in a plurality of ranges of frequencies to a user, asking in which range the user desires to cancel noise or noise is most annoying, and choosing the range over which the user indicates desire to cancel noise or noise is most annoying. Thereby, the preferences or annoyance of different ranges of a user is tested. Alternatively, the method may comprise just obtaining the chosen range over which the user indicates desire to cancel noise or noise is most annoying. Thereby, just the results of the test would be obtained.

[0020] Preferably, in step i) the method comprises obtaining information on two or more of a), b), c) and d), and, in step ii), the method comprises setting a noise signal range of frequencies which includes the ranges of frequencies obtained in step i).

[0021] Preferably, information on b) a range of frequencies over which noise produced by a tyre is loudest is obtained by measuring force at the tyre spindle (wheel hub) during running.

[0022] In this case, loudness of noise may be taken to be proportional to the force measured. Alternatively, the measured force could be adjusted according to human ear's perception of relative loudness of sound of different frequencies to give the loudness.

[0023] Tyre forces may be measured at the tyre spindle along the three directions (Vertical, Lateral and Fore & Aft). Preferably, the force is measured as it varies with time to give a force signal, and the force signal is split into its component frequencies using a Fourier transform.

[0024] Preferably, information on b) a range of frequencies over which noise produced by a tyre is loudest is obtained by integrating the force over different ranges of frequencies, comparing the integrated forces, and selecting the range with the largest force. The selected range is judged to be the range over which noise produced by the tyre is loudest.

Preferably, information on c) a range of frequencies over which tyre noise transmittance by a vehicle is highest is obtained by measuring sound pressure inside the vehicle, more preferably inside the vehicle cabin. Preferably, the force at a tyre spindle is also measured, and the noise transmittance is calculated from the measured sound pressure and measured force.

[0025] The measuring may use a microphone. The noise transmittance by the vehicle may be calculated from the measured sound pressure and the force measured on the tyre. Noise transmittance can be calculated by vibrating a tyre over a range of frequencies and at a range of amplitudes, measuring the force at the tyre spindle in the three directions, measuring the sound pressure inside the vehicle, and calculating noise transmittance (transfer function) for each of the three directions from the sound pressure and the forces measured. The noise transmittance for each of the three directions may be integrated over different ranges of frequencies. A vehicle will typically transmit noise more at some frequencies than others. Thereby, the range of frequencies with the highest noise transmittance for the three directions can be identified. For example, the range of frequencies with the largest integrated noise transmittance in any of the three directions may be considered the range with the highest noise transmittance.

[0026] Preferably, information on d) a range of frequencies over which noise produced by a tyre and vehicle combination is loudest is obtained by measuring force at the tyre spindle during running and/or by measuring sound pressure inside the vehicle.

[0027] Preferably, in step ii), the difference between the highest and lowest frequencies of the noise signal range is less than or equal to 200Hz, more preferably less than or equal to 100Hz, more preferably less than or equal to 70Hz. For example, the difference between the highest and lowest frequencies of the noise signal range is from 30-70Hz. This provides the advantage that the range can be relatively narrow and focused.

[0028] Preferably, the lowest frequency of the noise signal range is 50Hz or more, for example 50Hz, 120Hz, 180Hz or 250Hz. Preferably, the highest frequency of the noise signal range is 320Hz or less, for example, 320Hz, 250Hz, 180Hz or 120Hz.

[0029] Preferably, in at least one of the ranges of frequencies in step i), the difference between the highest and lowest frequencies is less than or equal to 100Hz, more preferably less than or equal to 70Hz. Accordingly, any of the ranges in step i) can be relatively narrow and focused.

[0030] Preferably, in obtaining information on at least one a) to d) in step i), the range of frequencies is obtained by comparison to desire to cancel noise or annoyance, loudness or transmittance of noise in another range of frequencies, and preferably the difference between the highest and lowest frequencies in both ranges is the same. Preferably, the difference in both ranges is less than or equal to 70Hz.

[0031] Preferably, the comparison is to two, three or more than three other ranges of frequencies. Preferably, the difference in all the ranges is less than or equal to 70Hz. Preferably, the difference in all the ranges is the same.

[0032] Preferably, in step ii), the noise signal range of frequencies is set to be the same as the range of frequencies of a), b), c) or d).

[0033] The lower limit of the noise signal range may be the lower limit of one range of frequencies of a), b), c) or d), and the higher limit may be the higher limit of one range of frequencies of a), b), c) or d).

[0034] Preferably, when more than one of a), b), c) or d) is obtained in step i), if the ranges of frequencies are different, in step ii) the noise signal range of frequencies is set to include the different ranges.

[0035] Preferably, when more than one of a), b), c) or d) is obtained in step i), if the ranges of frequencies are the same, in step ii) the noise signal range of frequencies is set to be the same range.

[0036] A second aspect of the present invention provides a system for adjusting vehicle noise cancelling, the system being configured to:

i) obtain information on:

a) a range of frequencies over which a vehicle user desires to cancel noise; or
b) a range of frequencies over which noise produced by a tyre is loudest; or
c) a range of frequencies over which tyre noise transmittance by a vehicle is highest; or
d) a range of frequencies over which noise produced by a tyre and vehicle combination is loudest; and

ii) set a noise signal range of frequencies which includes a range of frequencies obtained in step i), the difference between the highest and lowest frequencies of the noise signal range being less than 230Hz, wherein the noise signal range is a range over which a noise signal is to be produced from a captured noise, the noise signal is a signal from which a noise cancelling signal is to be produced, and the noise cancelling signal is a signal from which a sound is to be produced to cancel the noise.

[0037] The second aspect of the invention may provide a system for cancelling vehicle noise, the system being configured according to i) and ii) and being configured to:

iii) capture a noise to produce a noise signal over the noise signal range set in step ii), and
iv) produce a noise cancelling signal from the noise signal captured in step iii), and produce sound from the noise cancelling signal to cancel the noise.

[0038] Accordingly, there is provided a system for cancelling vehicle noise, the system being configured to:

i) obtain information on:

a) a range of frequencies over which a vehicle user desires to cancel noise; or
b) a range of frequencies over which noise produced by a tyre is loudest; or
c) a range of frequencies over which tyre noise transmittance by a vehicle is highest; or
d) a range of frequencies over which noise produced by a tyre and vehicle combination is loudest;

ii) set a noise signal range of frequencies which includes a range of frequencies obtained in step i), the difference between the highest and lowest frequencies of the noise signal range being less than 230Hz;
iii) capture a noise to produce a noise signal over the noise signal range set in step ii), and
iv) produce a noise cancelling signal from the noise signal captured in step iii), and produce sound from the noise cancelling signal to cancel the noise.

[0039] Preferably, the system has a processor which executes step i) and/or ii).

[0040] In step i), the information may be obtained from a remote database.

[0041] The system may be configured to communicate with a tyre of the vehicle (for example, a tag in the tyre) to determine the model of tyre used. The system may be configured to obtain information on that model of tyre from a remote database.

[0042] The system may be configured to communicate with the vehicle (for example, a tag in the vehicle) to determine the model of vehicle used. The system may be configured to obtain information on that model of vehicle from a remote database.

[0043] Preferably, the system comprises a microphone to capture the noise signal in step iii) and/or a speaker to produce the noise cancelling signal in step iv).

[0044] The system (for example, the microphone and/or speaker) may be integrated in a vehicle and/or in a mobile phone. The system may therefore make use of existing components of the vehicle or mobile phone.

[0045] Preferably, the system is installed in a mobile phone, the mobile phone being configured to execute steps i) and ii).

[0046] Preferably, the system is installed in a mobile phone, the mobile phone being configured to execute steps i) to iv).

[0047] Preferably, the system is installed in a mobile phone, the mobile phone being configured to execute steps i) and ii), and the vehicle being configured to execute steps iii) and iv).

[0048] A third aspect of the invention provides computer program instructions which, when executed in a device comprising a processor, cause the processor to perform a method of the first aspect of the invention.

[0049] A fourth aspect of the invention provides a non-volatile memory comprising computer executable code which, when executed in a device comprising processor, causes the processor to perform a method of the first aspect of the invention.

[0050] A fifth aspect of the invention provides a device comprising a processor and a memory, the memory storing program instructions for execution by the processor, the program instructions, when executed by the processor, causing the processor to perform a method of the first aspect of the invention.

[0051] The device may perform at least one of the steps of the method of the first aspect, and another device may be provided of the same type which performs the other steps of the method of the first aspect.

[0052] In the fifth aspect, the device may be integrated in a vehicle or mobile phone. When there is another device, one device may be integrated in a vehicle, and the other device may be integrated in a mobile phone.

[0053] For example, the mobile phone may be configured to execute steps i) and ii), or steps i) to iv). The vehicle may be configured to execute steps iii) and iv).

[0054] Preferable features of the first aspect of the invention are equally applicable to the second or fourth aspects of the invention.

[0055] A preferred embodiment of the invention will now be described, purely as an example, with reference to the drawings in which:

Figure 1 is schematic view of a user and vehicle according to a preferred embodiment of the invention;

Figure 2 is a schematic perspective view of a test rig according to the preferred embodiment of the invention;

Figure 3 has graphs showing the vibration forces measured on the tyre of the test rig of Figure 2 plotted against frequency;

Figure 4 has graphs showing the total of the measured vibration forces separated into frequency ranges;

Figure 5 has graphs showing the force transmittance by different vehicle bodies from a tyre separated into frequency ranges; and

Figure 6 has a graph showing force transmittance by a vehicle body from a tyre against frequency, and a graph showing force transmittance by a vehicle body from a tyre separated into frequency ranges.

[0056] Referring to Fig. 1, a mobile phone 10, a user 12, a tyre 14 and a vehicle 16 are shown. Also shown are steps 1-4 which will be described in more detail below.

[0057] In the preferred embodiment of Fig. 1, a system for cancelling vehicle noise comprises the mobile phone 10, the tyre 14, the vehicle 16, and a remote database in the cloud.

[0058] As indicated at 1, the mobile phone 10 is configured to characterize the noise perception of the user 12 through a standard test aimed to verify the level of annoyance or disturbance that the user associates with specific frequencies/amplitudes. From the results of the test the mobile phone 10 creates a user profile.

[0059] In the preferred embodiment, the user profile is stored on a remote database in the cloud. Alternatively, it may be stored directly on the mobile phone 10.

[0060] Tyre characterization, as indicated at 2, has been executed by the tyre manufacturer or other specialized entities, and stored on a database accessible remotely by the mobile phone 10. The tyre characterization has to be executed once. The tyre characterization is a full characterization of the tyre in terms of vibration amplitude and frequency.

[0061] The tyre 14 is equipped with a device, specifically an RFID tag, able to communicate specific information, namely the model of the tyre, to the mobile phone 10.

[0062] Vehicle or cabin characterization, as indicated at 3, has been executed by the vehicle manufacturer or other specialized entities, and stored on a database accessible remotely by the mobile phone 10. The vehicle characterization has to be executed once.

[0063] The vehicle 16 is equipped with a device, specifically an internet link, able to communicate specific information, namely the model of the vehicle, to the mobile phone 10.

[0064] The mobile phone 10 has a microphone and a speaker and in the preferred embodiment noise is captured using the microphone and a sound is produced by the speaker which cancels the noise. However, the speaker and/or microphone could be integrated into the vehicle 16.

[0065] The system in use will now be described.

[0066] The user 12 approaches the vehicle 16. The mobile phone 10:

μ communicates with the tyre 14, acquiring information on it from the tyre RFID tag, and accesses the remote database to download the tyre characteristics;

• communicates with the vehicle, acquiring information on it from the vehicle internet connection, and accesses the remote database to download the vehicle (cabin) characteristics;

• retrieves the user acoustic profile from the remote database;

• combines the abovementioned data, and determines from the combination the most suited parameters to be used for noise cancelling (i.e. calibrates the noise cancelling system);

• adjusts or tunes, as indicated at 4, the noise cancelling system according to the obtained calibration to provide the most suited output to minimize the vehicle noise.

[0067] An example of how tyre characterization may be carried out will now be described with reference to Fig. 2.

[0068] Fig. 2 shows a schematic test rig with a tyre 20 and a drum 22. The drum 22 simulates a road surface and induces vibrations in the tyre 20.

[0069] Forces on the spindle of the tyre 20 are measured in three orthogonal directions, Fy being the force in the axial direction, Fx being the force in the forwards/backwards direction of the vehicle, and Fz being in the up/down direction of the vehicle.

[0070] Fig. 3 shows graphs of the forces Fx, Fy, Fz (in Newtons) plotted against frequency (Hz). In each graph, lines are plotted for three different tyres. Tyre 1 has a stiff structure, Tyre 2 has a soft structure, and Tyre 3 has a soft structure with sponge.

[0071] Fig. 4 has graphs showing the total of the measured vibration forces separated into frequency ranges. The total forces are obtained from the graphs shown in Fig. 3 by integrating between the limits of the four frequency ranges. The frequency ranges are:

- 50-120Hz ("Low Rumble (LR)")
- 120-180Hz ("High Rumble (HR)")
- 180-250Hz ("Cavity (Cav)")
- 250-320Hz ("High Frequency (HF)")

[0072] As can be seen, the difference between the highest and lowest frequencies in the frequency ranges is 70Hz or less in the preferred embodiment. The frequency ranges are chosen to have about the same "widths" (i.e. the difference between highest and lowest frequencies) so that a fair comparison between the total forces obtained by integration can be made.

[0073] From the graphs shown in Fig. 4 it can be determined in what frequency range the force is highest. For example, for Tyre 1, it can be seen that the highest force is in the High Frequency range where the force Fy is about 200 Newtons. For Tyre 2, it can be seen that the highest force is also in the High Frequency range where the force Fy is about 190 Newtons. For Tyre 3, it can be seen that the highest force is also in the High Frequency range where the force Fy is about 200 Newtons.

[0074] An example of how vehicle characterization may be carried out will now be described with reference to Fig. 5.

[0075] A microphone is placed in the vehicle (labelled "MIC FL" in Fig. 5). When the vehicle is running, each of the four tyres will contribute to noise inside the vehicle, but the following will just consider the vibrations from the front left tyre (not the front right, irrespective of what is shown in Fig. 5). The front left tyre is rolled against a rotating drum to produce vibrations over a range of frequencies and at a range of amplitudes. The range of amplitudes is achieved by running the tyre over a range of speeds in ramp up and coast down. The forces on the tyre are measured, using wheel force sensors. The microphone measures sound pressure in the vehicle cabin. The noise transmittance (transfer function) for each of the three directions is calculated from the measured sound pressure and the forces measured. The calculation is described in more detail below. The noise transmittance for each of the three directions is integrated over different ranges of frequencies. The ranges have about the same widths, i.e. the difference between highest and lowest frequencies. A vehicle will typically transmit noise more at some frequencies than others. Thereby, the range of frequencies with the highest noise transmittance for a particular direction can be identified. For example, the range of frequencies with the largest integrated noise transmittance in any of the three directions may be considered the range with the highest noise transmittance.

[0076] Neglecting airborne vibrations from the tyres, the noise in the cabin (as measured by the microphone) will be the sum of the vibrations from the four tyres transmitted through the vehicle body. Then, just considering the effects of one of the tyres, the sound pressure is the sum of each individual force component multiplied by a transfer function for that direction. Each transfer function will be valid at just one frequency.

[0077] By measuring the sound pressure and forces during ramp up and coast down, sufficient data can be obtained to calculate the transfer functions for each frequency in each of the three directions. These transfer functions correspond to the ability of the vehicle body to transfer vibrations at a particular frequency in a particular direction. Hence, for example, a relatively high transfer function in the y (lateral) direction at 50Hz means that vehicle is able to transfer vibrations at 50Hz in the y direction relatively well. In more detail, the forces on the tyre spindle are measured as they vary with time to give a force signal, and the force signal is split into its component frequencies using a Fourier transform. Similarly, the sound pressure is measured by the microphone as it varies with time to give a sound pressure signal, and the sound pressure signal is split into its component frequencies using a Fourier transform. As referred to above, the transfer functions relate the various forces at each frequency to the sound pressure at that frequency.

[0078] The transfer functions are then integrated over a particular range of frequencies to indicate the vehicle's ability to transfer vibrations over that frequency range.

[0079] In Fig. 5, the graphs show the transfer functions for directions x, y and z on the vertical axes plotted against the various frequency ranges:

- 50-120Hz ("Low Rumble (LR)")
- 120-180Hz ("High Rumble (HR)")
- 180-250Hz ("Cavity (Cav)")
- 250-320Hz ("High Frequency (HF)")

[0080] The transfer functions have been integrated over those frequency ranges. The transfer functions are labelled "y/Fx", "y/Fy" and "y/Fz". Here, "y" is the sound pressure at the front left microphone. "y/Fx", "y/Fy" and "y/Fz" are simplifications of the calculations described above to obtain the transfer functions from the measured sound pressure and tyre forces. The units of the transfer functions are kPa/N.

[0081] Referring to Fig. 5, it can be seen from the top left graph that in Vehicle A (a premium sedan front wheel traction), High Rumble is the most critical frequency range because it has the highest transmittance (in the y direction), namely about 4kPa/N.

[0082] From the top right graph it can be seen that in Vehicle B, (a compact sedan front wheel traction) Low Rumble is the most critical frequency range because it has the highest transmittance (in the y direction), namely about 2.5kPa/N.

[0083] From the bottom left graph it can be seen that in Vehicle C (a multipurpose front wheel traction), Low Rumble is the most critical frequency range because it has the highest transmittance (in the y direction), namely about 2kPa/N.

[0084] The following provides a further explanation of how vehicle characterization may be carried out (that is, how vehicle transfer functions may be calculated).

[0085] A general equation for relationship between the sound pressure and wheel forces may be expressed as:

$$y_k = \sum_{i=1}^{n} T_{ik} * F_i$$

where y is the sound pressure measured by the microphone, k is the k-th microphone, i is the i-th tyre, n is the number of tyres, T is a matrix of transfer functions, and F is a matrix of forces measured on the tyre spindles.

[0086] We will again neglect the airborne vibrations and only consider the vibrations from the first tyre. On that basis, for a particular frequency, the equation can be solved for the transfer functions using data measured for the sound pressure and forces, provided that sufficient different data points have been measured for the sound pressure and force.

[0087] Fig. 6 illustrates how the transfer functions T are calculated. The transfer functions represent the force transmittance by the vehicle (in this case Vehicle D). In the upper graph, sound pressure/total force is the solid upper line, and force transmittance (transfer functions) for the different directions are the lower lines. The sound pressure/total force in the upper solid line is calculated by summing the force transmittances of the lower lines y/Fx, y/Fy and y/Fz. The units of force transmittance are indicated on the left as Pa/N on a decibel scale. The values of the transfer functions are calculated from the measured forces and sound pressures using Multiple Input Multiple Output (MIMO) software.

[0088] The lower graph in Fig. 6 shows force transmittance (transfer functions) integrated over the different frequency ranges as was done for the graphs in Fig. 5. Here, it can be seen that the highest force transmittance is in the Low Rumble frequency range y direction, namely about 2.5kPa/N.

[0089] In putting noise cancelling into practice, according to the preferred embodiment, the mobile phone 10:

- Looks up the forces for each frequency range and force direction combination for a particular tyre (specifically, the forces shown in Fig. 4);
- Looks up the transmittance for each frequency range and force direction combination for a particular vehicle (specifically, the transmittances shown in Fig. 5);
- Calculates the transmitted force for each frequency range by combining the looked-up forces and transmittance;
- Determines which transmitted force is highest;
- Looks up the frequency range over which a user finds noise most annoying;
- Compares the frequency range where the transmitted force is highest and the frequency range selected as most annoying by the user;
    - ◦ If the ranges are the same, it sets the noise signal range to that frequency range, to focus noise cancelling on that frequency range;
    - ◦ If the ranges are different, it sets the noise signal to span both ranges, if the ranges are neighbouring;
    - ◦ Otherwise, if the ranges are not neighbouring, it sets the noise signal to the frequency range selected by the user.

[0090] The difference between the highest and lowest frequencies in the frequency ranges is 70Hz or 60Hz in the preferred embodiment, but alternatively could be 50, 40 or 30Hz.

[0091] In the preferred embodiment, four frequency ranges are used for tyre and vehicle characterization. The ranges are 50-120Hz ("Low Rumble (LR)"), 120-180Hz ("High Rumble (HR)"), 180-250Hz ("Cavity (Cav)"), 250-320Hz. However, the ranges may include a range of 20-50Hz ("Booming") in addition to, or instead of, one of these ranges.

[0092] In the preferred embodiment, difference between the highest and lowest frequencies in each frequency range is <230Hz. Accordingly, the range selected can be easily set as the noise signal range over which noise is captured by the microphone.

[0093] In the preferred embodiment, the noise cancelling signal is produced from the noise signal by inverting the noise signal, as is known in the art, but it could be done by delaying the signal by 180 degrees, or using another method known in the art.

Claims

1. A computer-implemented method of adjusting vehicle noise cancelling, the method comprising:

    i) obtaining information on:

        a) a range of frequencies over which a vehicle user desires to cancel noise; or
        b) a range of frequencies over which noise produced by a tyre is loudest; or
        c) a range of frequencies over which tyre noise transmittance by a vehicle is highest; or
        d) a range of frequencies over which noise produced by a tyre and vehicle combination is loudest; and

    ii) setting a noise signal range of frequencies which includes a range of frequencies obtained in step i), the difference between the highest and lowest frequencies of the noise signal range being less than 230Hz, wherein the noise signal range is a range over which a noise signal is to be produced from a captured noise, the noise signal is a signal from which a noise cancelling signal is to be produced, and the noise cancelling signal is a signal from which a sound is to be produced to cancel the noise.

2. A method of cancelling vehicle noise, the method comprising steps i) and ii) of claim 1 and:

    iii) capturing a noise to produce a noise signal over the noise signal range set in step ii), and
    iv) producing a noise cancelling signal from the noise signal captured in step iii), and producing sound from the noise cancelling signal to cancel the noise.

3. A method according to claim 1 or 2, wherein, in step i) the method comprises obtaining information on two or more of a), b), c) and d), and, in step ii), the method comprises setting a noise signal range of frequencies which includes the ranges of frequencies obtained in step i).

4. A method according to claim 1, 2 or 3, wherein information on b) a range of frequencies over which noise produced by a tyre is loudest is obtained by measuring force at the tyre spindle during running.

5. A method according to any one of claims 1 to 4, wherein information on c) a range of frequencies over which tyre noise transmittance by a vehicle is highest is obtained by measuring sound pressure inside the vehicle.

6. A method according to any preceding claim, wherein information on d) a range of frequencies over which noise produced by a tyre and vehicle combination is loudest is obtained by measuring force at the tyre spindle during running and/or by measuring sound pressure inside the vehicle.

7. A method according to any preceding claim, wherein, in step ii), the difference between the highest and lowest frequencies of the noise signal range is less than or equal to 100Hz.

8. A method according to any preceding claim, wherein, in step ii), the difference between the highest and lowest frequencies of the noise signal range is less than or equal to 70Hz.

9. A method according to any preceding claim, wherein, in step ii), the difference between the highest and lowest frequencies of the noise signal range is from 30-70Hz.

10. A method according to any preceding claim, wherein, in at least one of the ranges of frequencies in step i), the difference between the highest and lowest frequencies is less than or equal to 70Hz.

11. A method according to any preceding claim, wherein, in at least one of the ranges of frequencies in step i), the range of frequencies is obtained by comparison to desire to cancel noise or annoyance, loudness or transmittance of noise in another range of frequencies, and the difference between the highest and lowest frequencies in both ranges is the same.

12. A method according to any preceding claim, wherein, in step ii), the noise signal range of frequencies is set to be the same as the range of frequencies of a), b), c) or d).

13. A method according to any preceding claim, wherein obtaining information on a) a range of frequencies over which a vehicle user desires to cancel noise or finds noise most annoying comprises playing noises in a plurality of ranges of frequencies to a user, asking in which range the user desires to cancel noise or noise is most annoying, and choosing the range over which the user indicates desire to cancel noise or noise is most annoying.

14. A method according to any preceding claim, wherein, when more than one of a), b), c) or d) is obtained in step i), if the ranges of frequencies are different, in step ii) the noise signal range of frequencies is set to include the different ranges.

15. A method according to any preceding claim, wherein, when more than one of a), b), c) or d) is obtained in step i), if the ranges of frequencies are the same, in step ii) the noise signal range of frequencies is set to be the same range.

16. A system for adjusting vehicle noise cancelling, the system being configured to:

i) obtain information on:

a) a range of frequencies over which a vehicle user desires to cancel noise; or
b) a range of frequencies over which noise produced by a tyre is loudest; or
c) a range of frequencies over which tyre noise transmittance by a vehicle is highest; or
d) a range of frequencies over which noise produced by a tyre and vehicle combination is loudest; and

ii) set a noise signal range of frequencies which includes a range of frequencies obtained in step i), the difference between the highest and lowest frequencies of the noise signal range being less than 230Hz, wherein the noise signal range is a range over which a noise signal is to be produced from a captured noise, the noise signal is a signal from which a noise cancelling signal is to be produced, and the noise cancelling signal is a signal from which a sound is to be produced to cancel the noise.

17. A system for cancelling vehicle noise, the system being configured according to i) and ii) of claim 16, and being configured to:

iii) capture a noise to produce a noise signal over the noise signal range set in step ii), and
iv) produce a noise cancelling signal from the noise signal captured in step iii), and produce sound from the noise cancelling signal to cancel the noise.

18. A system according to claim 16 or 17, integrated in a vehicle and/or mobile phone.

19. A system according to claim 16 or 17, integrated in a mobile phone, the mobile phone being configured to execute steps i) and ii).

20. A system according to claim 17, integrated in a mobile phone, the mobile phone being configured to execute steps i) to iv).

21. A system according to claim 17, integrated in a vehicle and mobile phone, the mobile phone being configured to execute steps i) and ii), and the vehicle being configured to execute steps iii) and iv).

22. Computer program instructions which, when executed in a device comprising a processor, cause the processor to perform a method of any of claims 1 to 15.

23. A non-volatile memory comprising computer executable code which, when executed in a device comprising processor, causes the processor to perform a method of any of claims 1 to 15.

24. A device comprising a processor and a memory, the memory storing program instructions for execution by the processor, the program instructions, when executed by the processor, causing the processor to perform a method of any of claims 1 to 15.

25. A device according to claim 24, integrated in a vehicle or mobile phone.

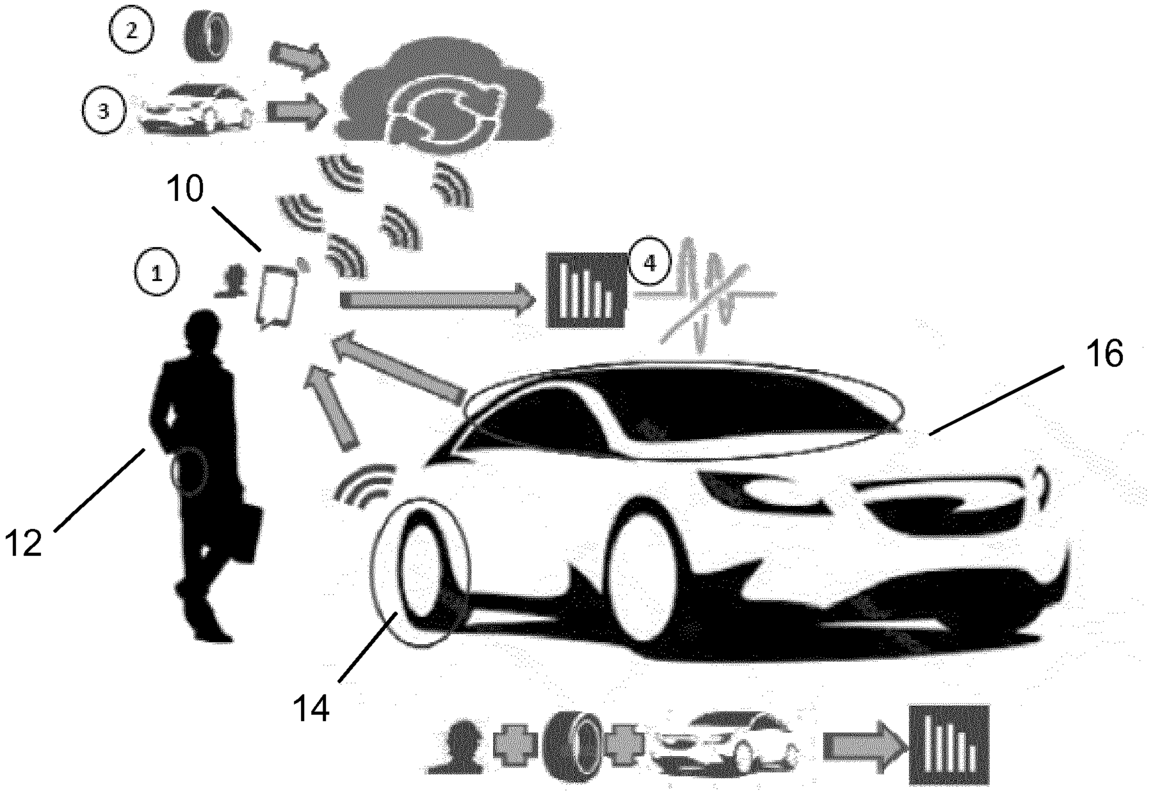


Fig. 1

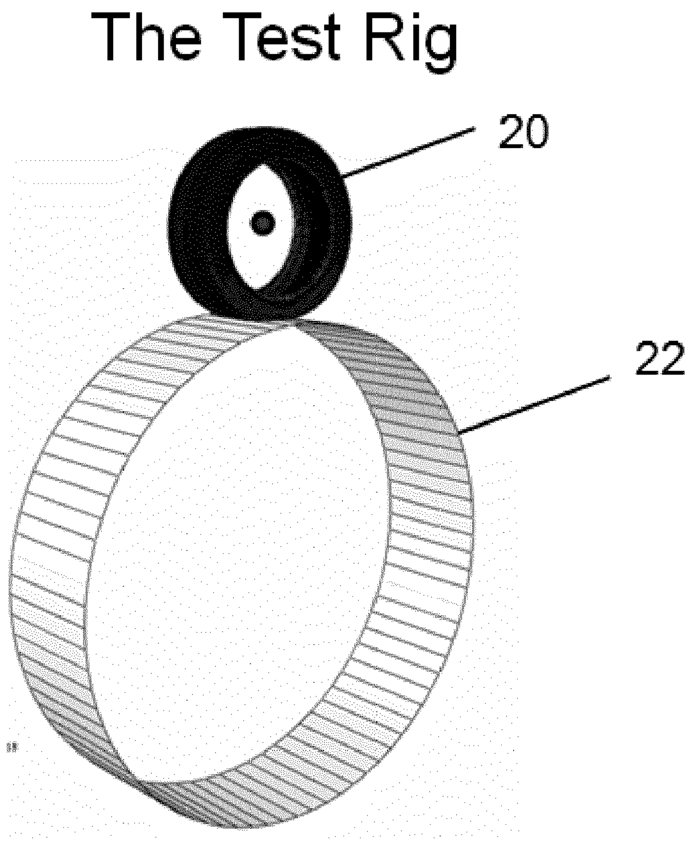


Fig. 2

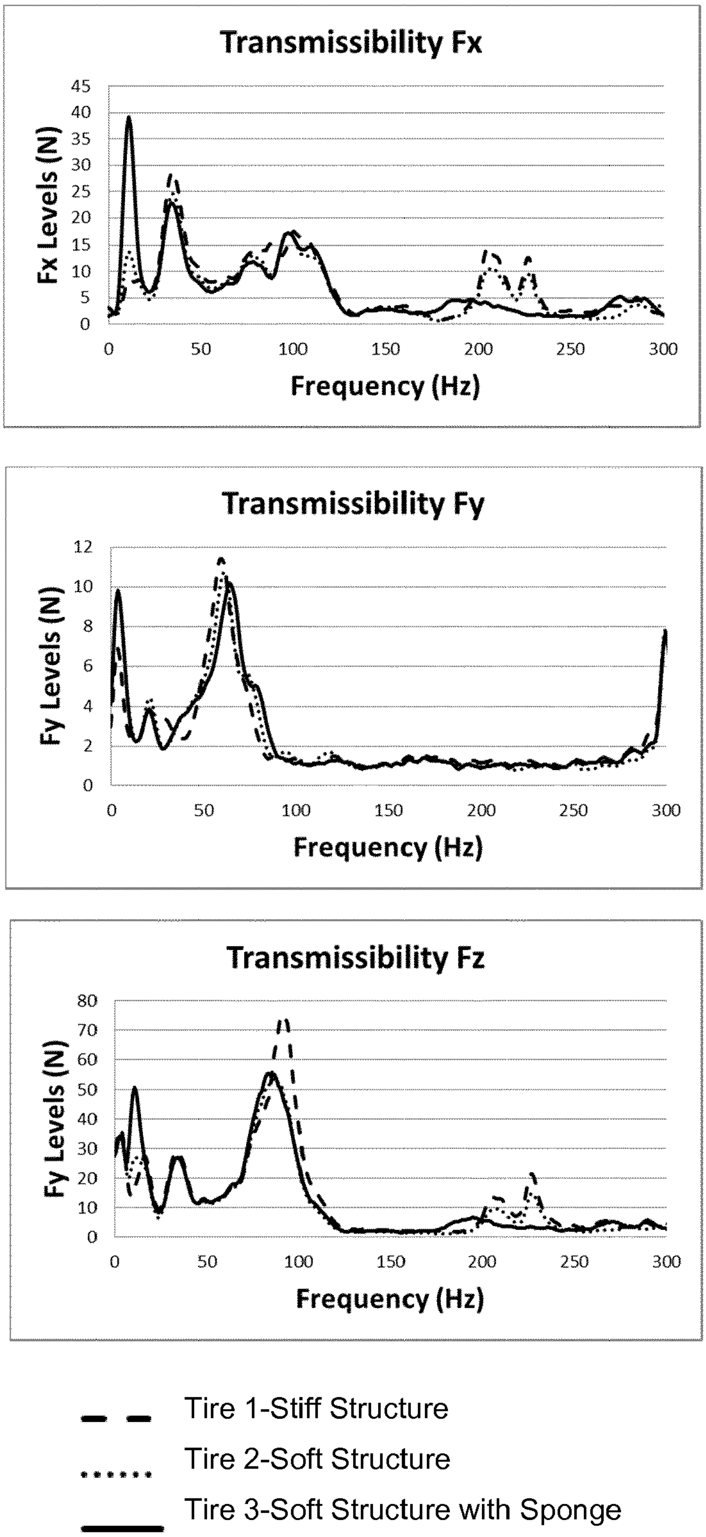

Transmissibility Fx
Fx Levels (N)
45
40
35
30
25
20
15
10
5
0
0
50
100
150
200
250
300
Frequency (Hz)
Transmissibility Fy
Fy Levels (N)
12
10
8
6
4
2
0
0
50
100
150
200
250
300
Frequency (Hz)
Transmissibility Fz
Fy Levels (N)
80
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
Frequency (Hz)
Tire 1-Stiff Structure
Tire 2-Soft Structure
Tire 3-Soft Structure with Sponge

Fig. 3

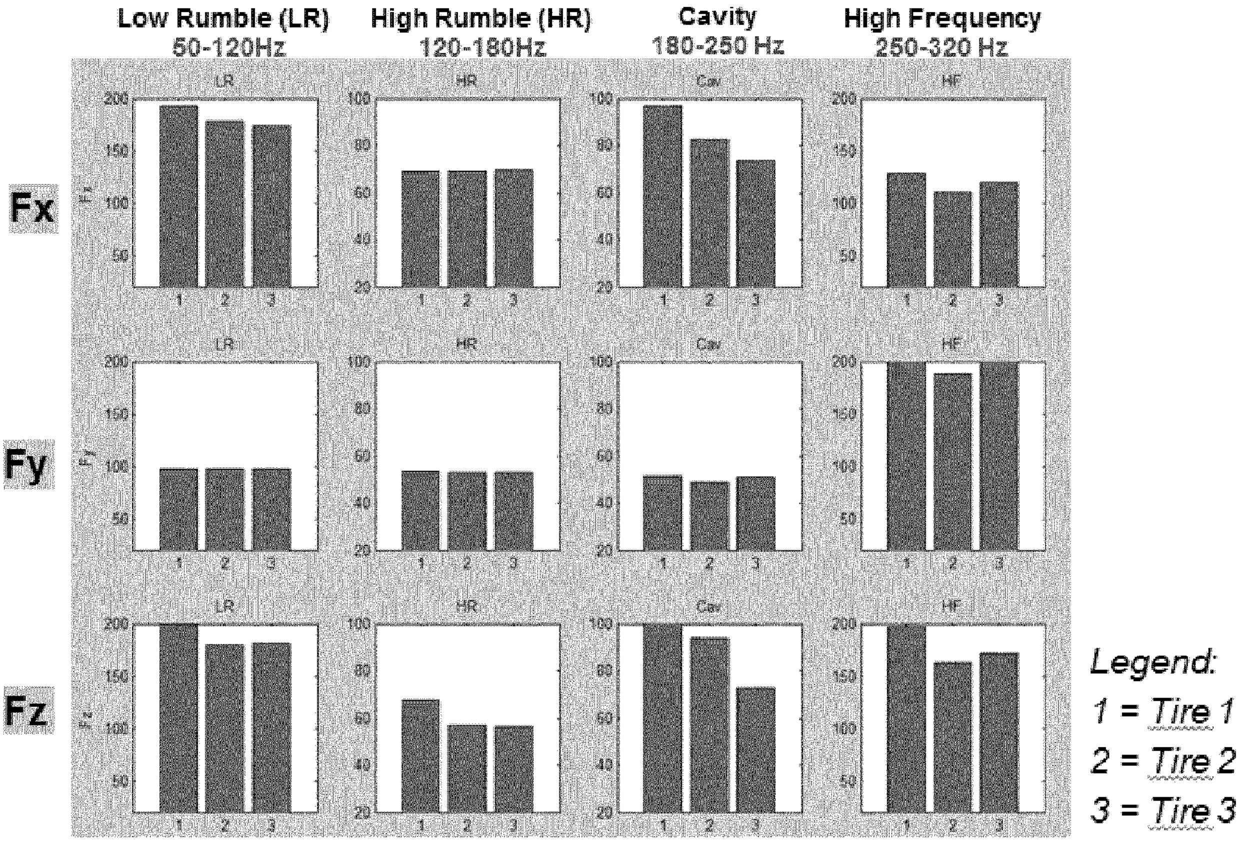

Low Rumble (LR)
50-120Hz
High Rumble (HR)
120-180Hz
Cavity
180-250 Hz
High Frequency
250-320 Hz
Fx
Fy
Fz
LR
HR
Cav
HF
Legend:
1 = Tire 1
2 = Tire 2
3 = Tire 3

Fig. 4

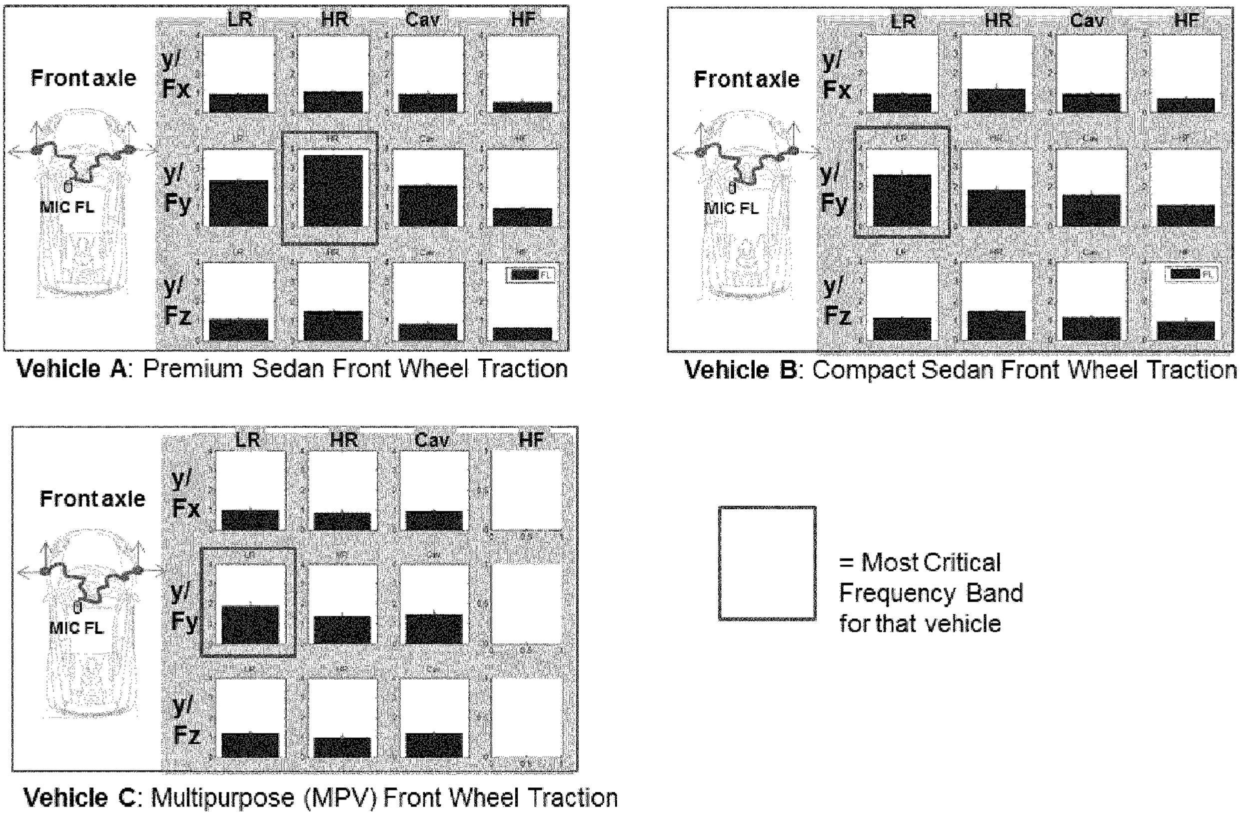
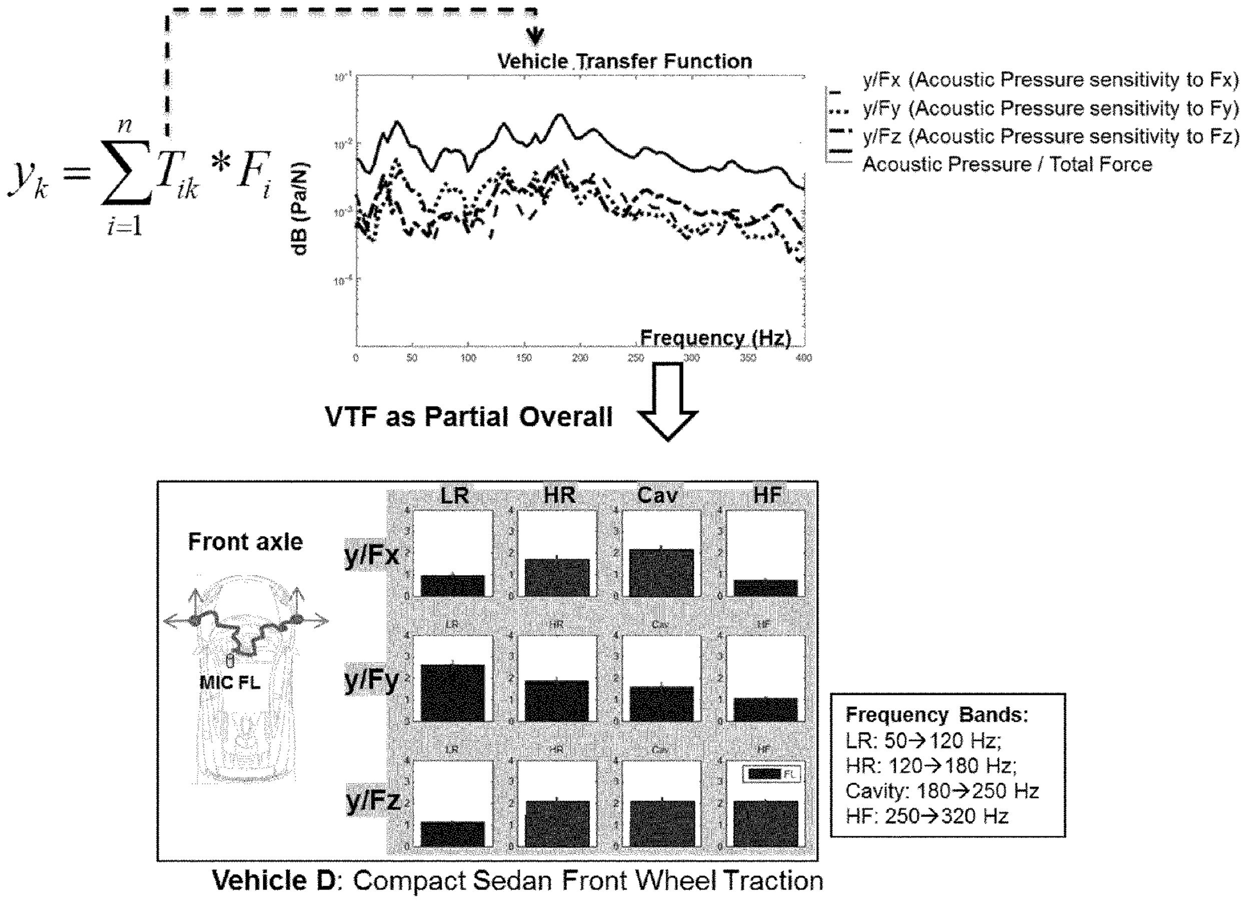

Front axle
MIC FL
y/ Fx
y/ Fy
y/ Fz
LR
HR
Cav
HF
Vehicle A: Premium Sedan Front Wheel Traction
Vehicle B: Compact Sedan Front Wheel Traction
Vehicle C: Multipurpose (MPV) Front Wheel Traction
= Most Critical Frequency Band for that vehicle

Fig. 5



$$y_k = \sum_{i=1}^{n} T_{ik} * F_i$$
Vehicle Transfer Function
dB (Pa/N)
Frequency (Hz)
y/Fx (Acoustic Pressure sensitivity to Fx)
y/Fy (Acoustic Pressure sensitivity to Fy)
y/Fz (Acoustic Pressure sensitivity to Fz)
Acoustic Pressure / Total Force
VTF as Partial Overall
Front axle
MIC FL
y/Fx
y/Fy
y/Fz
LR
HR
Cav
HF
Frequency Bands:
LR: 50→120 Hz;
HR: 120→180 Hz;
Cavity: 180→250 Hz
HF: 250→320 Hz
Vehicle D: Compact Sedan Front Wheel Traction

Fig. 6

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EUROPEAN SEARCH REPORT

Application Number
EP 18 21 0449

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2017/372690 A1 (VALERI FRANK C [US] ET AL) 28 December 2017 (2017-12-28)	1-3,5-7, 11,12, 16,17	INV. G10K11/178
Y	* paragraph [0036] - paragraph [0058]; figures 1-5 *	4,8-10, 13-15, 18-25	
Y	US 10 065 561 B1 (BASTYR KEVIN J [US] ET AL) 4 September 2018 (2018-09-04)	4,8-10, 13-15, 18-25	
A	* column 17, line 5 - column 21, line 10; figure 10 *	1-3,5-7, 11,12, 16,17	
A,D	US 2015/124989 A1 (PARK DONG CHUL [KR] ET AL) 7 May 2015 (2015-05-07) * paragraph [0035] - paragraph [0046]; figures 1-8 *	1-25	
A	DE 10 2016 005904 A1 (AUDI AG [DE]) 16 November 2017 (2017-11-16) * paragraph [0015] - paragraph [0221]; figure 1 *	1-25	TECHNICAL FIELDS SEARCHED (IPC)
			G10K
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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	13 May 2019	Raposo, Jorge

CATEGORY OF CITED DOCUMENTS

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13-05-2019

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