April 26, 1949. W. P. MASON 2,468,454

ACOUSTIC WAVE FILTER WITH RESISTIVE TERMINATION, INCLUDING SIDE BRANCH CHAMBER

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FIG. 1

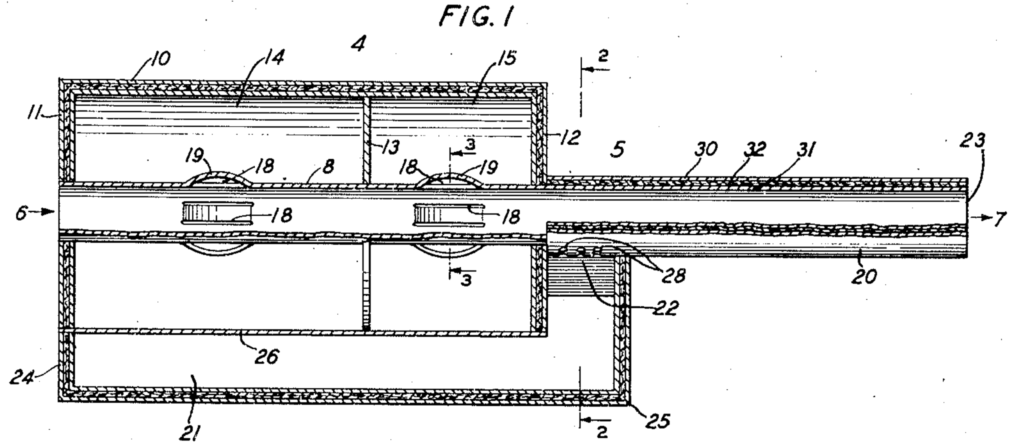


FIG. 2

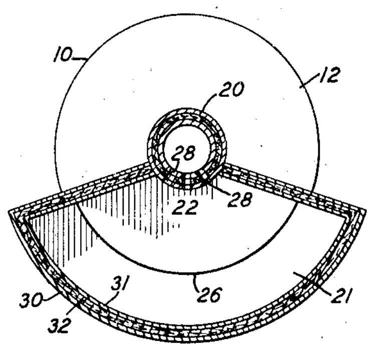
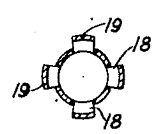


FIG. 3



INVENTOR
W. P. MASON
BY
Ralph T. Holcomb
ATTORNEY

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ACOUSTIC WAVE FILTER WITH RESISTIVE TERMINATION, INCLUDING SIDE BRANCH CHAMBER

Warren P. Mason, West Orange, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

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2 Claims. (Cl. 181—33)

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This invention relates to acoustic wave filters and more particularly to a special resistive termination for use with such a filter.

The principal object of the invention is to improve the performance of an acoustic wave filter which works into a load having a lower impedance than the image impedance of the filter. Another object is to provide for such a filter a termination which is mainly resistive and substantially equal to the image impedance of the filter over the major part of the transmission band. A further object is to provide an efficient narrow band low-pass acoustic filter which will freely transmit a steady flow of gas.

When a narrow band low-pass acoustic filter is to work into a low impedance load, such as the atmosphere, it is practically impossible to design a filter of reasonable size having an image impedance which is low enough to match the load. Such a filter may, for example, be used as a muffler to silence the exhaust of an internal combustion engine. The filter must freely transmit a steady flow of gas but must attenuate down to a very low frequency. Due to this lack of a proper resistive termination for the filter in its transmission band, at certain engine speeds the frequencies corresponding to the natural resonances of the filter may be accentuated and the noise actually increased. Furthermore, with ordinary acoustic filters it is very difficult to provide attenuation at the low frequencies.

In accordance with the invention these difficulties are overcome by providing for the filter a special resistive termination which substantially matches its image impedance over the portion of the transmission band where these resonance effects occur but does not interfere appreciably with the steady flow of gas through the filter. Furthermore, the termination adds considerable loss in the low frequency range.

In the preferred embodiment the termination comprises an outlet tube, a side branch and an acoustic resistance. The outlet tube communicates with the filter at one end, is open to the atmosphere at its other end, has a characteristic impedance approximately equal to the nominal image impedance R of the filter and is antiresonant at some frequency f within the transmission band. The side branch has a characteristic impedance preferably smaller than R, is resonant at approximately the frequency f and is connected to the inner end of the outlet tube through the acoustic resistance which has a value approximately equal to R. The frequency f is preferably in the neighborhood of three-quarters of the cut-

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off frequency of the filter. The exposed portions of the termination and the filter are preferably made of layers of sheet metal with an interposed layer of some sound absorbing material such as felt.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawings in which like reference characters refer to similar or corresponding parts and in which:

Fig. 1 is a longitudinal sectional view of an acoustic filter with a resistive termination in accordance with the invention;

Fig. 2 is a cross-sectional view taken along the line 2—2 of Fig. 1; and

Fig. 3 is a cross section of the central conduit of Fig. 1 taken at the line 3—3.

Taking up the figures in more detail, Figs. 1 and 2 show an acoustic wave filter 4 to which is attached a resistive termination 5 in accordance with the invention. It is assumed that the sound waves, for example, from the exhaust of an internal combustion engine, enter at the left, as indicated by the arrow 6 and, after passing through the filter 4 and the termination 5, are discharged into a low impedance load, such as the atmosphere, at the right, as indicated by the arrow 7.

The filter 4, which is of the low-pass type, comprises a central conduit 8 surrounded by a cylinder 10 having annular end plates 11 and 12 and an annular transverse partition 13 which form two chambers 14 and 15. The chambers 14 and 15 are preferably of different volume so that they will be resonant at different frequencies and thereby provide separate peaks of attenuation. Each of the chambers 14 and 15 is connected to the conduit 8 through a number of narrow apertures 18 formed by cutting longitudinal circumferentially spaced slits in the conduit 8 and pressing out each alternate portion 19, as shown in Fig. 1 and in the cross section of Fig. 3. Forming the apertures 18 in the manner shown helps to prevent a whistling effect which might otherwise develop, especially if the filter is required to handle a large flow of gas.

The filter is designed to have a nominal image impedance R and a cut-off at some desired frequency f_c. In a low-pass filter the nominal image impedance is the image impedance at zero frequency. A discussion of the principles, and the formulas, applicable to the design of the filter may be found, for example, in United States Patents 1,692,317 issued November 20, 1928 and 1,874,326 issued August 30, 1932.

The resistive termination **5** comprises an outlet tube **20**, a side branch **21** and an acoustic resistance **22**. The left end of the outlet tube **20** is connected to the central conduit **8** and its other end **23** is open to the atmosphere. The tube **20** and the conduit **8** are preferably of substantially the same diameter and in axial alignment. The tube **20** is antiresonant at some frequency *f* within the transmission band of the filter **4** and has a characteristic impedance approximately equal to the image impedance of the filter at that frequency. The frequency *f* is preferably chosen as approximately three-fourths of the cut-off frequency. In order to make the outlet tube **20** antiresonant at the frequency *f*, its length, measured from the line **3—3** to the discharge end **23**, is made equal to a quarter wavelength at that frequency. The length of the tube **20** may be shortened somewhat, but at a sacrifice in the efficiency of the filter, by making it antiresonant at a higher frequency, with the cut-off frequency as the upper limit.

The side branch **21** is connected at its upper end to the outlet tube **20** near the input end of the tube **20** and at its other end is closed by the plate **24**. In order to make the structure more compact the branch **21** has a 90-degree bend at the point **25** and folds against the lower side of the filter **4**. The lower portion **26** of the cylinder **10** forms the upper wall of the branch **21**. The branch **21** is resonant at approximately the frequency *f* and therefore has a length equal to a quarter wavelength at that frequency. In order to increase the attenuation of the filter in the low frequency range the characteristic impedance of the branch **21** should be low compared to R. Therefore, the cross-sectional area of the branch **21** is made as large as is convenient. The side branch **21** is coupled to the outlet tube **20** through the acoustic resistance **22** which comprises the apertures **28**, the number and cross-sectional area of which are so chosen that it will have a value approximately equal to the image impedance of the filter **4** at the frequency *f*.

In order to prevent the radiation of acoustic energy due to the shock excitation of the structure by the exhaust from the engine, all of the exposed portions of the filter **4** and the termination **5** are preferably made of a highly damped material. As shown, these parts may be made of two thin layers **30** and **31** of metal, such as sheet iron or steel, and an interposed layer **32** of sound absorbing material, such as felt.

When the termination **5** is designed in the manner set forth herein, it will present to the filter **4** substantially a zero impedance at zero frequency and therefore will not impede a steady flow of gas through the system. However, as the frequency increases the impedance of the termination **5** develops a gradually increasing resistive component and at the frequency *f* this impedance is non-reactive and equal to the image impedance of the filter, thus providing a perfect impedance match. Furthermore, over the major

part of the transmission band the impedance of the termination **5** will be mainly resistive and sufficiently nearly equal to the image impedance of the filter to prevent appreciable reflection effects at the junction or the establishment of standing waves within the filter. Therefore, the accentuation of the natural resonant frequencies of the filter will be prevented.

Another advantage of the resistive termination **5** is that it adds loss at low frequencies where it is difficult to provide loss by other means. The impedance of the branch **21** is infinite at zero frequency and gradually falls to zero at the resonant frequency *f*. On the other hand, the impedance of the outlet tube **20** is zero at zero frequency and increases to an infinite value at the frequency *f*. Therefore, as the frequency increases from zero to *f* more and more energy is shunted through the branch **21**. Since the acoustic resistance **22** is effectively in series with the branch **21** more and more of this energy is dissipated in the resistance and prevented from reaching the atmosphere. At the frequency *f* this increase in loss may reach twenty decibels or more.

What is claimed is:

1. In combination, a low-pass acoustic wave filter, an outlet tube connecting said filter with the atmosphere, an acoustic resistance, and a closed side branch connected to said outlet tube near the input end thereof through said resistance, said outlet tube and said side branch each having a length equal to a quarter wavelength at approximately three-quarters of the cut-off frequency of said filter, said outlet tube having a characteristic impedance approximately equal to the image impedance of said filter at said frequency, said side branch having a characteristic impedance which is low compared to the nominal image impedance of said filter, and said resistance having a value approximately equal to the image impedance of said filter at said frequency, whereby said filter is provided with a terminating impedance which substantially matches its image impedance over the major part of the transmission band.

2. The combination in accordance with claim 1 in which the exposed portions of said filter, said outlet tube and said side branch comprise two layers of metal and an interposed layer of sound absorbing material.

WARREN P. MASON.

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