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(54) **A RADIO FREQUENCY FILTER, A METHOD OF RADIO FREQUENCY FILTERING, AND A METHOD OF CONSTRUCTING A FILTER**

(57) A radio frequency filter (10') is provided comprising at least one resonant chamber (14'), each chamber housing a respective resonator (16'), in which each

resonant chamber is at least substantially filled by the respective resonator (16') and a granular dielectric material (18').

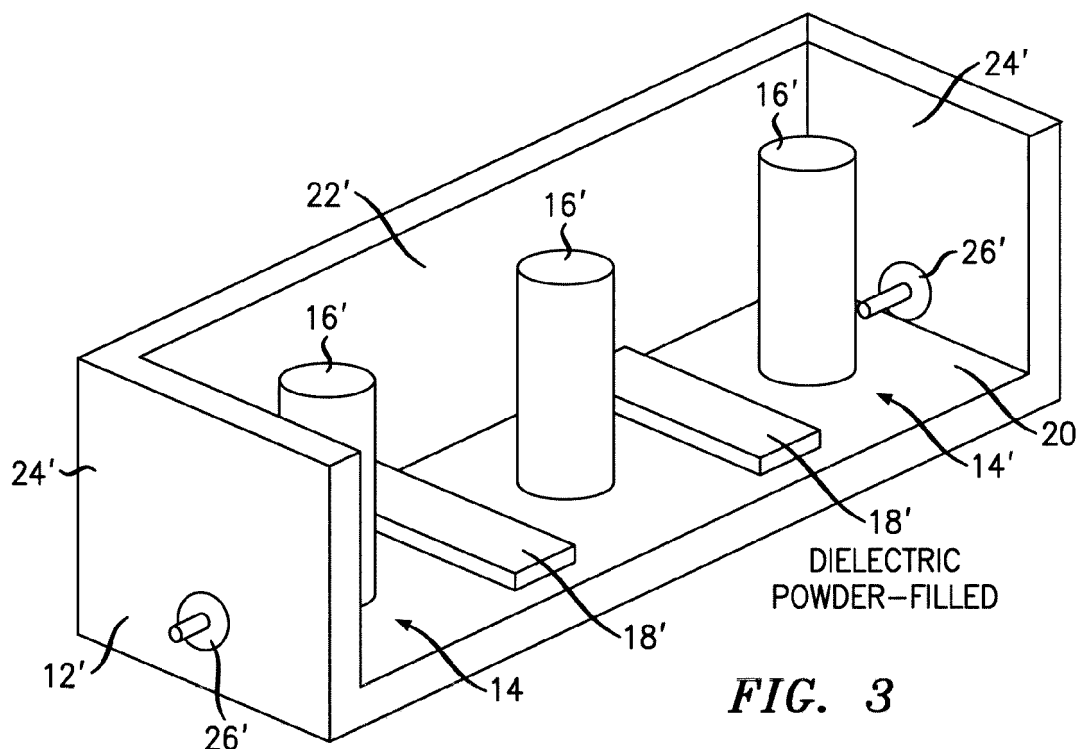


FIG. 3

Description

Field of the Invention

[0001] The present invention relates to filters for telecommunications, in particular to radio-frequency filters.

Description of the Related Art

[0002] Filters are widely used in telecommunications, in many applications, for example base stations, radar systems, amplifier linearization systems, point-to-point radio, and RF signal cancellation systems. Although a specific filter is chosen or designed dependent on the particular application, it is generally desirable for a filter to have low insertion loss in the pass-band and high attenuation in the stop-band. Furthermore, in some applications, the frequency separation (known as the guard-band) between stop-band and pass-band needs to be small, so a filter of a high order is required. Of course as the order of a filter is increased so does its complexity in terms of the number of components the filter requires and hence the filter's size. Furthermore, although increasing the order of a filter increases stop-band attenuation, insertion loss in the pass-band is also thereby increased.

Summary

[0003] The reader is referred to the appended independent claims. Some preferred features are laid out in the dependent claims.

[0004] An example of the present invention is a radio frequency filter comprising at least one resonant chamber, each chamber housing a respective resonator, in which each resonant chamber is at least substantially filled by the respective resonator and a granular dielectric material.

[0005] Preferably the dielectric material has a relative dielectric constant in the range 2 to 10, preferably in the range 3 to 5. Preferably the dielectric material has a loss tangent at least approximately in the range 4×10^{-4} to 6×10^{-5} . Preferably, the dielectric material is a manufactured dielectric powder or granular fused quartz.

[0006] In preferred embodiments, the use a granular dielectric material give good design flexibility, and provide a cavity filter having good performance but small size.

[0007] Preferred embodiments advantageously have a granular dielectric material in the resonant cavities that provided a good compromise between high dielectric constant and low insertion loss. A relative dielectric constant in the range of about 1.5 to 10 is preferably provided.

[0008] Preferred filters are filled with granular dielectric material and retain the design flexibility traditionally attributed to air-filled filters. The granular dielectric material may be easily poured in without special consideration of the particular shape and size of resonators. This has an

advantage as compared to the known dielectric ring loaded filter that resonator posts need be no longer a particular shape, such as cylindrical, to accommodate solid dielectric rings of a given shape.

[0009] The present invention also relates to corresponding methods of radio frequency filtering comprising passing a signal for filtering through at least one resonant chamber, each chamber housing a respective resonator and being at least substantially filled by the respective resonator and a granular dielectric material.

[0010] The present invention also relates to a method of constructing a filter comprising: designing a substantially air-filled filter operating at a given operating frequency; selecting a granular dielectric material; from knowledge of the dielectric constant of the material, calculating the reduced size filter dimensions appropriate for a filter having substantially the same band pass properties but filled with the dielectric material in place of the air; constructing the filter with the reduced dimensions, and pouring the granular dielectric material into the filter. In a preferred embodiment, space in each resonant chamber of the filter is thereby filled with the granular dielectric material.

[0011] In another aspect the present invention provides a radio frequency filter comprising at least one resonant chamber, each chamber including a resonator, in which each resonant chamber is filled with a granular dielectric material. In another aspect the present invention also provides a method of radio frequency filtering comprising passing a signal for filtering through at least one resonant chamber, each chamber including a resonator, in which each resonant chamber is filled with a granular dielectric material.

Brief Description of the Drawings

[0012] An embodiment of the present invention will now be described by way of example and with reference to the drawings, in which:

Figure 1 is an oblique view illustrating a known third order air-filled combline filter (PRIOR ART)

Figure 2 is an oblique view illustrating a known third order combline filter with dielectric rings (PRIOR ART), and

Figure 3 is an oblique view illustrating a third order combline filter according to a first embodiment of the present invention,

Figure 4 is a graph of insertion loss vs. radio frequency for three filters: (a) an Eccosorb dielectric powder-filled filter as shown in Figure 3, (b) a fused quartz powder-filled filter according to a second embodiment of the present invention, and for comparison (c) a known filter as shown in Figure 1.

Figure 5 is a graph showing a portion of Figure 4 expanded, and

Figure 6 is a graph of return loss as a function of radio frequency for these three filters.

[0013] The drawings are not to scale but are schematic representations.

Detailed Description

[0014] Cavity-based filters are known for use in cellular wireless base stations. Known filters provide low insertion loss but are relatively large. An example of such a filter is shown in Figure 1.

[0015] Figure 1 shows a known third-order combline filter 10 having an aluminium housing 12, with copper and/or silver plating on the inside of the housing 12. The filter 10 includes three cavities (also known as resonant chambers) 14 each cavity including a cylindrical resonator 16. Inside the filter, the cavities are air-filled and separated by low walls 18. The housing 12 includes not only a bottom wall 20, a back wall 22 and end walls 24, but also a top wall (not shown) and a front wall (not shown) that completes the housing 12. The filter 10 includes input ports 26, one through each end wall 24.

[0016] In designing filters, it is known to seek to increase the dielectric constant of the cavity, and so reduce the size of the filter in consequence by loading filters with rings of ceramic material. An example of such a filter is shown in Figure 2.

[0017] Figure 2 shows a known filter of essentially the same configuration as the filter shown in Figure 1, save that the cylindrical resonators 16' are loaded with a respective cylindrical ceramic sleeve 28, each of which can also be considered as a ceramic "ring". Use of ceramic rings allows filters to be designed that are smaller but with similar performance to the known example shown in Figure 1. For example by using ceramic rings, the effective relative dielectric constant was increased to a value of 3.6, as compared to a value of 1 for the corresponding air-filled cavity case. As the possible reduction in size is known to be proportional to the value of the effective relative dielectric constant, the filter is smaller in consequence.

[0018] Another known approach in filter design is to have the resonant cavities basically filled with ceramic material. However ceramic is difficult to work being sintered into fixed shapes that are very difficult to drill. Drilling is an irreversible process, so tuning in just one direction is possible. Furthermore, even though a substantial size reduction is achieved as compared to an equivalent air-filled filter, for example more than 20 times, ceramic filters produced in this way have a high insertion loss, for example 2 to 3 dB which may be undesirable in many applications.

[0019] From considering these known approaches, the inventors realised that the effective dielectric constant in the resonant chambers plays a major role in filter size reduction. They realised that in the known filter shown in Figure 2, dielectric rings of a high dielectric constant, namely 37, are used to increase the effective dielectric constant of each resonant chamber, in that case to 3.6. The inventors realised that although a higher value of

effective dielectric constant could be achieved by using larger dielectric rings or using dielectric rings of a higher dielectric constant, insertion loss, in other words attenuation, would correspondingly increase, to likely unacceptable levels. This was seen in known commercially available filters that include ceramic rings. The inventors realised that the effective dielectric constant inside the resonant chamber should not be large, but values in a range of 3 to 10 allow significant size reduction whilst keeping attenuation, and hence the deterioration of the filter's response, to acceptably low levels.

Use of Granular Dielectric Materials

[0020] The inventors realised that one can load a resonant chamber with a granular dielectric material having an appropriately high dielectric constant but low loss. In consequence, as there are effectively no substantial air-to-powder boundaries in the resonant chamber, the dielectric constant of the powder or granular material is the same as the effective dielectric constant in the resonant chamber.

[0021] We first consider the general principles as to why dielectrics are beneficial then consider two examples filters, one filter involving Eccosorb dielectric powder, the other filter involving granular fused quartz (also known as sand).

Filter size reduction by using a granular dielectric material

[0022] The size of a radio frequency filter is directly proportional to its operational frequency and hence wave length. Basically speaking, the relationship between the length (L_a) of an air-filled filter and the length (L_d) of a dielectric-filled filter operating at the same frequency is:

$$L_d = \frac{L_a}{\sqrt{\epsilon_{\text{eff}}}} \quad (1)$$

where ϵ_{eff} is the effective (relative) dielectric constant. Therefore, the reduction of the length is equal to:

$$\frac{L_a}{L_d} = \sqrt{\epsilon_{\text{eff}}} \quad (2)$$

[0023] Since cavity based filters are three dimensional devices, the overall reduction of the volume by dielectric loading is equal to:

$$\frac{V_a}{V_d} = \sqrt{(\epsilon_{\text{eff}})^3} \quad (3)$$

where V_a is the volume of the air-filled filter and V_d is the volume of the dielectric-filled filter. From this equation (3) it is seen that, as compared to air, using a dielectric of even a modest value of the dielectric constant greatly reduce the overall volume.

Eccosorb Example

[0024] Low loss dielectric powders are available in a range of dielectric constant values, for example from <http://www.eccosorb.com> sold under the trademark Eccosorb.

[0025] These powders are in a range of available dielectric constants of 2.5 to 12 and a corresponding range of loss tangents of $\tan(\delta)=4 \times 10^{-4}$ to $\tan(\delta)=7 \times 10^{-4}$. A loss tangent is ϵ''/ϵ' where ϵ'' is the imaginary component of the electric permittivity and ϵ' is the real component.

[0026] A filter using this powder is shown in Figure 3.

[0027] As shown in Figure 3, a third-order combline filter 10' is provided having an aluminium housing 12', with copper and/or silver plating on the inside of the housing 12'. The filter 10' includes three cavities (also known as resonant chambers) 14' each cavity including a cylindrical resonator 16'. Inside the filter, the cavities are air-filled and separated by low walls 18'. The housing 12' includes not only a bottom wall 20', a back wall 22' and end walls 24', but also a top wall (not shown) and a front wall (not shown) that completes the housing 12'. The filter 10' includes input ports 26', one through each end wall 24'.

[0028] The filter in this example is filled with Eccosorb Eccostock HiK Powder (not shown) which is a dielectric powder of dielectric constant (also known as relative real permittivity) $\epsilon_r = 4$ and loss tangent $\tan(\delta) = 4 \times 10^{-4}$ (data taken from the website of <http://www.eccosorb.com>). The filter was simply filled by the dielectric powder having been poured in, for example until the resonant chambers are all full.

Sand Example (granular fused quartz)

[0029] The inventors realised that sand is suitable for dielectric loading of RF filters. The inventors realised that sand is a widely available ceramic material that displays dielectric properties and has a low loss tangent.

[0030] For example, sand in the form of fused quartz powder having a dielectric constant of about 4 and a loss tangent of $\tan(\delta) = 6 \times 10^{-5}$ is available from, for example, <http://www.goodfellow.com>. This loss tangent is about an order of magnitude lower than manufactured dielectric powders on the market such as the Eccosorb range.

[0031] An example filter using sand is not shown, but

one example is of a similar structure and configuration as the commercial dielectric powder-filled filter shown in Figure 3. The sand was simply poured in to fill the filter, for example until the resonant chambers are all full.

Comparison of examples

[0032] We now compare both the Eccosorb dielectric-filled filter described above and shown in Figure 3 and the granular fused quartz -filled filter described above with the known air-filled filter described with reference to Figure 1. These three filters are third-order Chebyshev filters. The three filters have a pass-band ripple of 0.1dB, a central frequency of 1.88 GHz and a usable pass-band of 60MHz.

Dimensions

[0033] Using the equations (1) to (3) above the dimensions calculated for the filters were:

Eccosorb-filled filter: 55 mm x 15mm x 15mm = 12,375 mm³.

Fused quartz-filled filter: 55 mm x 15mm x 15mm = 12,375 mm³.

Air-filled filter for comparison: 100mm x 30mm x 30mm = 90,000mm³.

[0034] It will be seen that compared to the air-filled filter, the use of granular dielectric material means the volume is reduced more than seven-fold (namely by a factor of 7.27). There is a small difference from the expected theoretical volume reduction of 8 to be expected from equation 3, as the coupling walls 18' between the resonators 16' were not altered.

Performance

[0035] The performances of the three filters are shown graphically in Figures 4 to 6. Figure 4 is a graph of insertion loss vs. radio frequency for the three filters. Figure 5 is a graph which is an expanded portion of Figure 4, and Figure 6 is a graph of return loss vs radio frequency for those three filters. In each of those three Figures, the performance of Eccosorb dielectric powder-filled filter is indicated by squares, the performance of the fused quartz powder-filled filter is indicated by triangles, and for comparison the performance of the known air-filled filter is indicated by circles.

[0036] It will be seen that compared to the air-filled filter, the Eccosorb powder-filled filter provides an insertion loss increase of approximately 0.4dB which corresponds to approximately 0.13dB per resonator, and the fused quartz-filled filter provides an insertion loss increase of merely 0.2dB which corresponds to 0.066 dB per resonator.

[0037] It is believed that these small increases in insertion loss are usually acceptable particularly in view of

the relative size reduction compared to an air-filled filter.

[0038] Further dielectric powder-filled filters retain the design flexibility traditionally attributed to air-filled filters. The dielectric powder may be easily poured in without special consideration of the particular shape and size of resonators. This has an advantage as compared to the known dielectric ring loaded filter that by using powder resonator posts need be no longer a particular shape, such as cylindrical, to accommodate solid dielectric sleeves of a given shape. Another advantage as compared to the known dielectric ring loaded filter lies in the fact that dielectric rings are costly, while granular dielectric powder materials are much cheaper.

Some further embodiments

[0039] In some similar further embodiments, conventional tuning techniques using tuning screws are applied as the tip of the tuning screw may move through the powder.

[0040] In some similar further embodiments, for greater size reduction a dielectric powder with a higher dielectric constant is used. However, this has an increased insertion loss meaning that greater signal attenuation occurs.

General

[0041] The present invention may be embodied in other specific forms without departing from its essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes that come within the meaning and range of equivalency of the claims are to be embraced within their scope.

[0042] A person skilled in the art would readily recognize that steps of various above-described methods can be performed by programmed computers. Some embodiments relate to program storage devices, e.g., digital data storage media, which are machine or computer readable and encode machine-executable or computer-executable programs of instructions, wherein said instructions perform some or all of the steps of said above-described methods. The program storage devices may be, e.g., digital memories, magnetic storage media such as a magnetic disks and magnetic tapes, hard drives, or optically readable digital data storage media. Some embodiments involve computers programmed to perform said steps of the above-described methods.

Claims

1. A radio frequency filter comprising at least one resonant chamber, each chamber housing a respective resonator, in which each resonant chamber is at

least substantially filled by the respective resonator and a granular dielectric material.

2. A radio frequency filter according to claim 1, in which the dielectric material has a relative dielectric constant in the range 2 to 10.
3. A radio frequency filter according to claim 2, in which the dielectric material has a relative dielectric constant in the range 3 to 5.
4. A radio frequency filter according to any preceding claim, in which the dielectric material has a loss tangent at least approximately in the range 4×10^{-4} to 6×10^{-5} .
5. A radio frequency filter according to any preceding claim, in which the dielectric material is a manufactured dielectric powder.
6. A radio frequency filter according to any preceding claim, in which the dielectric material is granular fused quartz.
7. A method of radio frequency filtering comprising passing a signal for filtering through at least one resonant chamber, each chamber housing a respective resonator and being at least substantially filled by the respective resonator and a granular dielectric material.
8. A method of radio frequency filtering according to claim 7, in which the dielectric material has a relative dielectric constant in the range 2 to 10.
9. A method of radio frequency filtering according to claim 8, in which the dielectric material has a relative dielectric constant in the range 3 to 5.
10. A method of radio frequency filtering according to any of claims 7 to 9, in which the dielectric material has a loss tangent at least approximately in the range 4×10^{-4} to 6×10^{-5} .
11. A method of radio frequency filtering according to any of claims 7 to 10, in which the dielectric material is a manufactured dielectric powder.
12. A method of radio frequency filtering according to any of claims 7 to 11, in which the dielectric material is granular fused quartz.
13. A method of constructing a filter comprising:
 - designing a substantially air-filled filter operating at a given operating frequency;
 - selecting a granular dielectric material;
 - from knowledge of the dielectric constant of the

material, calculating the reduced size filter dimensions appropriate for a filter having substantially the same band pass properties but filled with the dielectric material in place of the air; constructing the filter with the reduced dimensions; and pouring the granular dielectric material into the filter.

Amended claims in accordance with Rule 137(2) EPC.

1. A radio frequency filter (10') comprising at least one resonant chamber (14'), each chamber housing a respective resonator (16'), in which each resonant chamber is at least substantially filled by the respective resonator and a granular dielectric material.
2. A radio frequency filter according to claim 1, in which the dielectric material has a relative dielectric constant in the range 2 to 10.
3. A radio frequency filter according to claim 2, in which the dielectric material has a relative dielectric constant in the range 3 to 5.
4. A radio frequency filter according to any preceding claim, in which the dielectric material has a loss tangent at least approximately in the range 4×10^{-4} to 6×10^{-5} .
5. A radio frequency filter according to any preceding claim, in which the dielectric material is a manufactured dielectric powder.
6. A radio frequency filter according to any preceding claim, in which the dielectric material is granular fused quartz.
7. A radio frequency filter according to any of claims 1 to 6, constructed by:
 - designing a substantially air-filled filter operating at a given operating frequency;
 - selecting a granular dielectric material;
 - from knowledge of the dielectric constant of the material, calculating the reduced size filter dimensions appropriate for a filter (10') having substantially the same band pass properties but filled with the dielectric material in place of the air;
 - constructing the filter (10') with the reduced dimensions; and
 - pouring the granular dielectric material into the filter.

8. A method of radio frequency filtering (10') com-

prising passing a signal for filtering through at least one resonant chamber (14'), each chamber housing a respective resonator (16') and being at least substantially filled by the respective resonator and a granular dielectric material.

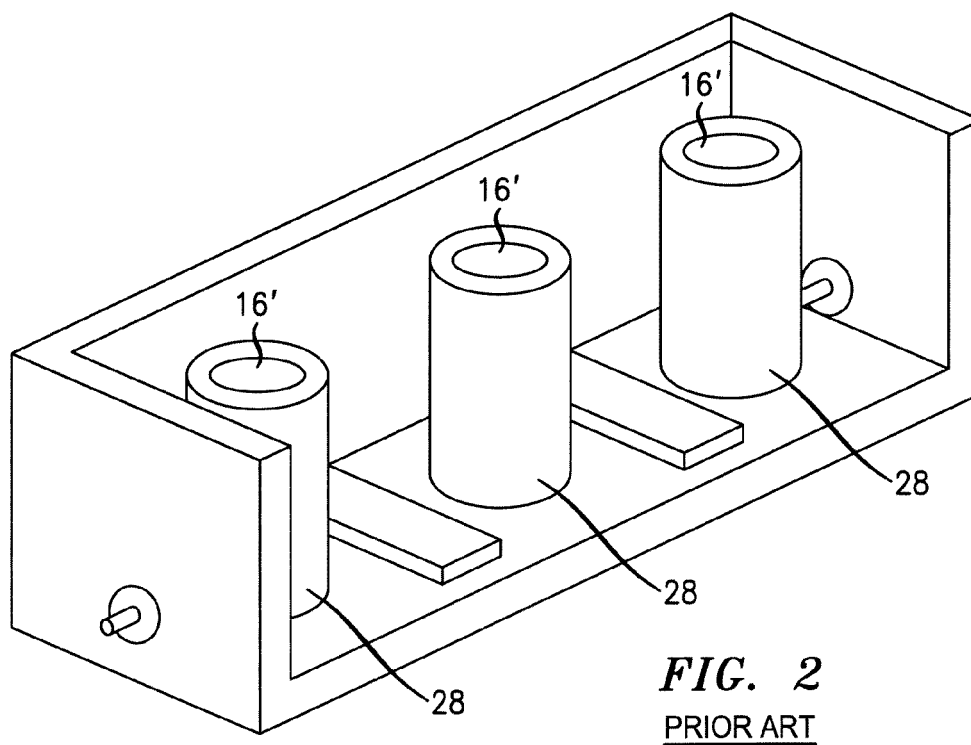
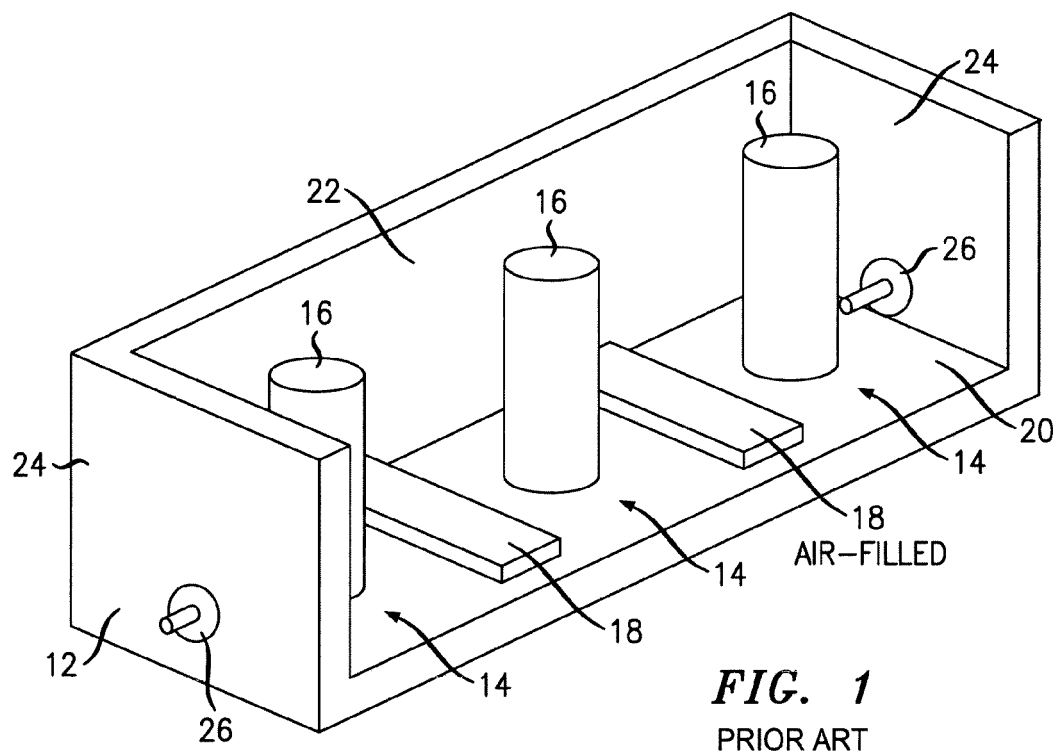
9. A method of radio frequency filtering according to claim 8, in which the dielectric material has a relative dielectric constant in the range 2 to 10.

10. A method of radio frequency filtering according to claim 9, in which the dielectric material has a relative dielectric constant in the range 3 to 5.

11. A method of radio frequency filtering according to any of claims 8 to 10, in which the dielectric material has a loss tangent at least approximately in the range 4×10^{-4} to 6×10^{-5} .

12. A method of radio frequency filtering according to any of claims 8 to 11, in which the dielectric material is a manufactured dielectric powder.

13. A method of radio frequency filtering according to any of claims 8 to 12, in which the dielectric material is granular fused quartz.



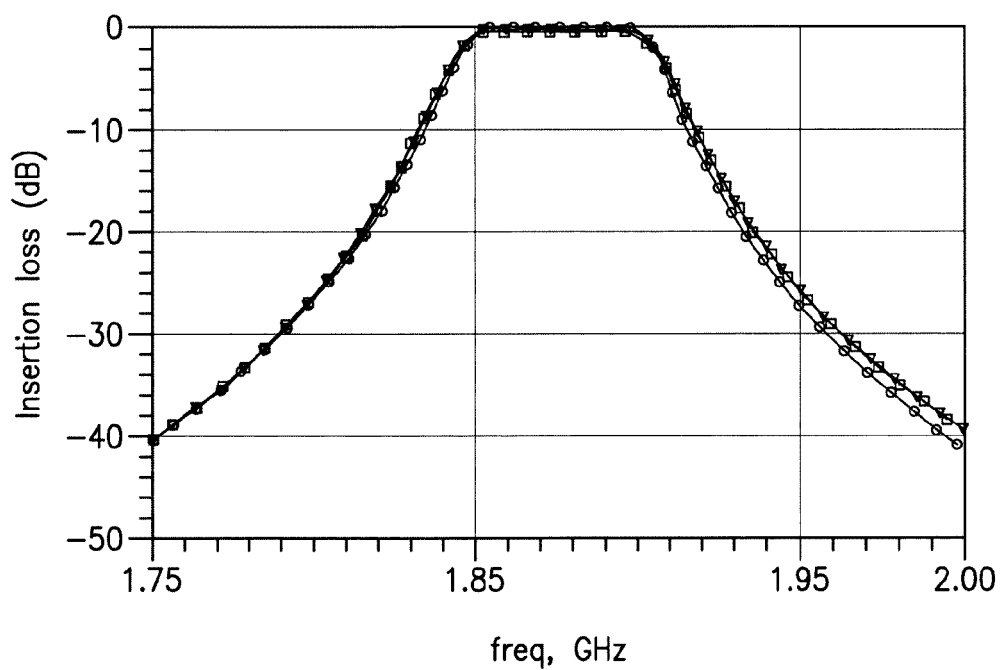
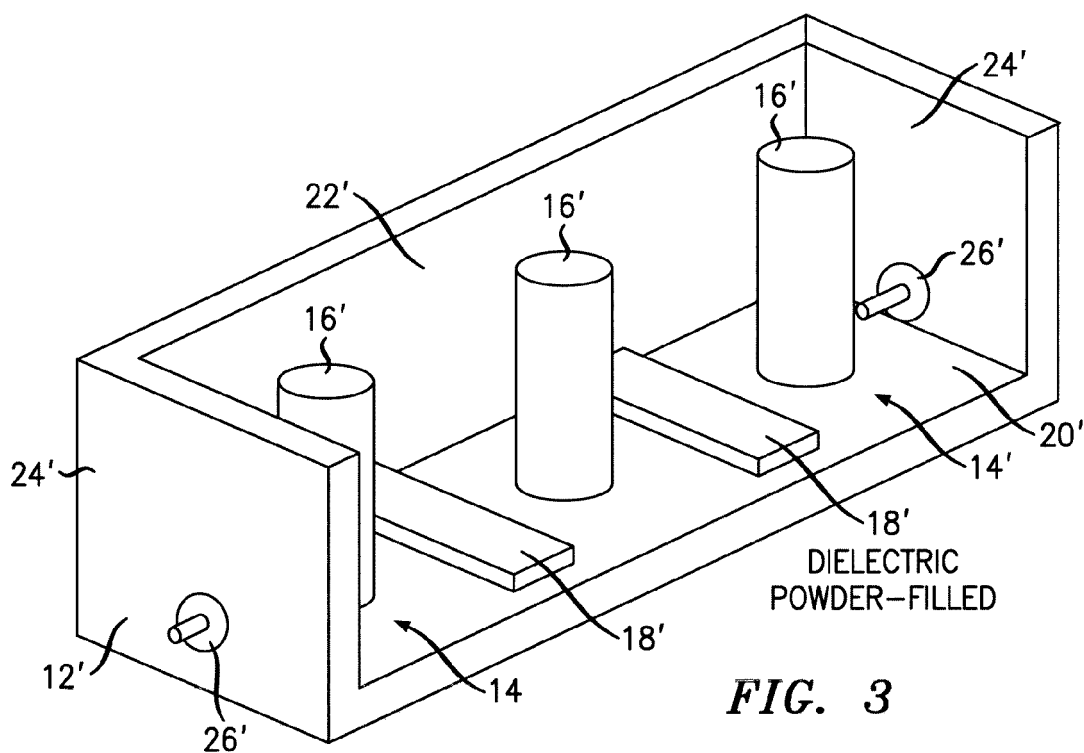


FIG. 4

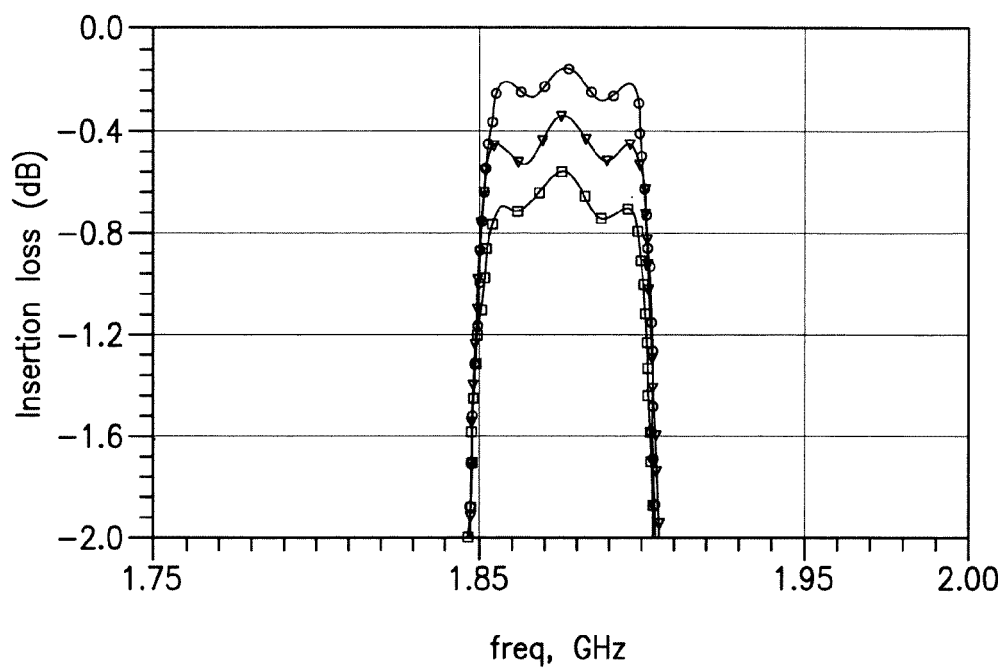


FIG. 5

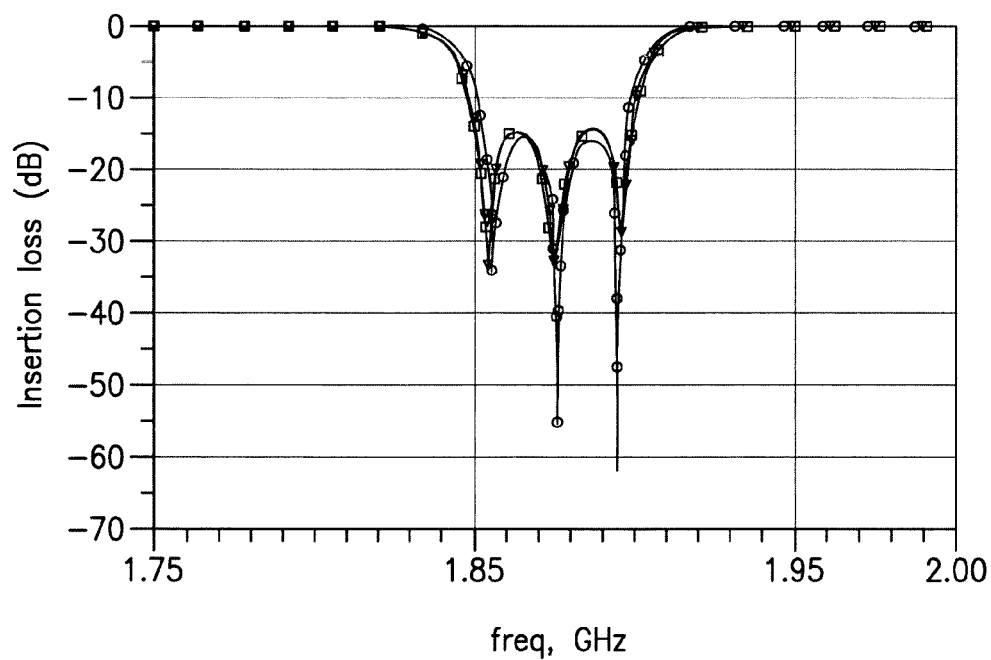


FIG. 6



EUROPEAN SEARCH REPORT

Application Number
EP 13 29 0105

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DOCUMENTS CONSIDERED TO BE RELEVANT			
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			TECHNICAL FIELDS SEARCHED (IPC)
			H01P
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 16 September 2013	Examiner van Norel, Jan
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