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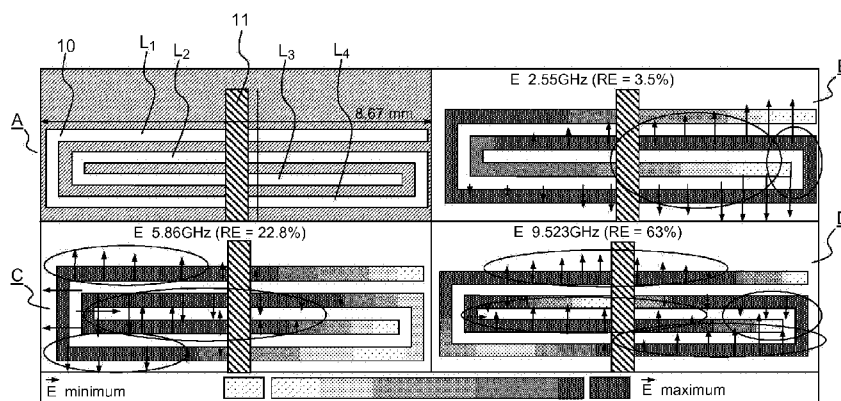
(54) **Title:** SLOT LINE RESONATOR FOR FILTERS

FIG.3

- (57) **Abstract:** The present invention relates to a slot line resonator for single or multiple passband filters comprising: a dielectric substrate with a first surface equipped with a conductive layer and a second parallel face, a slot line (10) etched in the conductive layer, an excitation line (11) implemented on the second face of the substrate and feeding the slot line by electromagnetic coupling. The slot line has an electrical length L less than or equal to $k\lambda/2$ where λ is the guided wavelength in the slot at the harmonic frequency of order $(k-1)$ and k is an integer greater than or equal to 1 (the fundamental mode being the zero harmonic); The slot line is folded in a spiral pattern, with a shape factor such that the slot line has parallel sections $L1, L2, L3, L4$, the electric field of two parallel sections being in phase opposition.

SLOT LINE RESONATOR FOR FILTERS

TECHNICAL FIELD OF THE INVENTION

5 The present invention relates to a slot line resonator for a filter. The invention further relates to a filter comprising a said slot line resonator and a method of manufacturing a slot line resonator..

TECHNOLOGICAL BACKGROUND

10 Increasingly, devices used for mobile communications or in home networks must be able to operate according to several different standards. In such cases, in order to maintain the integrity of the signal corresponding to the different standards, very narrow-band filters comprising high quality factor resonators are often used. In general, the implementation of such filters requires a compromise between the electrical performance of the filter and its cost and size. Thus, the performance of a
15 filter depends on the quality factor Q of the resonator used. The higher the quality factor, the better the performance. However, a high quality factor Q currently leads to the use of technologies whose cost is significant. These technologies also entail bulky filters, which is hardly compatible with the necessities of mobile devices.

20 Generally, for the manufacture of such filters, it is known to use resonators made using a microstrip line technology such as quarter wave resonators. Moreover, although the quality factor Q may depend on the shape of the resonator, it is mainly determined by the parameters of the substrate, in particular by the losses due to the conductive material and to the substrate. Furthermore, the resonant frequency of this type of resonator is also highly dependent on the parameters of the
25 substrate such as the relative permittivity and the thickness, as well as on manufacturing processes.

SUMMARY OF THE INVENTION

The present invention has been devised with the foregoing in mind.

30 A first aspect of the invention concerns a slot line resonator for a filter comprising: a dielectric substrate with a first surface equipped with a conductive layer and a second surface parallel to the first surface, a slot line provided in the

conductive layer, an excitation line provided on the second surface of the substrate and for feeding the slot line by electromagnetic coupling, wherein the slot line is folded in accordance with a shape factor based on an operating mode of resonance such that the slot line has parallel (or concentric sections, the electric field of two adjacent parallel or concentric sections being in phase opposition to one another, in particular at one or more adjacent respective positions of the parallel or concentric sections.

In an embodiment, the excitation line is positioned with respect to the slot line such that it crosses the parallel or concentric sections, for example at a position where the electric field of the two parallel or concentric sections are in phase opposition at the operating mode of resonance.

In an embodiment, at least one capacitor is positioned in the slot line.

In an embodiment, the at least one capacitor is positioned in the slot line according to the electric field profile corresponding to the operating mode of resonance.

In an embodiment, the or each capacitor in the slot line is positioned with respect to the position where the electric field is maximum to control the quality factor of the resonator. The use of this capacitor makes it possible to tune the resonant frequency and therefore improve the quality factor.

In an embodiment, the slot line is folded in a spiral pattern.

In an embodiment, the shape factor of the spiral pattern is rectangular with a length at least twice as great as the width. In an embodiment, the shape factor of the spiral pattern is square.

In an embodiment, the operating mode of resonance is the fundamental mode or the first harmonic mode.

In an embodiment, the excitation line is a microstrip line.

In an embodiment, the microstrip line has an end positioned $\lambda_m/8$ from the centre of the pattern where λ_m is the guided wavelength in the microstrip line at the fundamental frequency.

In an embodiment, the slot line has an electrical length L less than or equal to $k \lambda/2$ where λ is the guided wavelength in the slot at the harmonic frequency of order

(k-1) and k is an integer greater than or equal to 1 (the fundamental mode being the zero harmonic)

A further aspect of the invention comprises at least one slot line resonator comprising: a dielectric substrate with a first surface equipped with a conductive layer and a second surface parallel to the first surface, a slot line provided in the conductive layer, an excitation line provided on the second surface of the substrate and for feeding the slot line by electromagnetic coupling, wherein the slot line is folded in accordance with a shape factor based on an operating mode of resonance such that the slot line has parallel (or concentric sections, the electric field of two adjacent parallel or concentric sections being in phase opposition to one another at one or more adjacent positions.

In an embodiment, the filter is a lossy filter.

Another aspect of the invention provides an electronic wireless device comprising a filter provided with at least one slot line resonator comprising: a dielectric substrate with a first surface equipped with a conductive layer and a second surface parallel to the first surface, a slot line provided in the conductive layer, an excitation line provided on the second surface of the substrate and for feeding the slot line by electromagnetic coupling, wherein the slot line is folded in accordance with a shape factor based on an operating mode of resonance such that the slot line has parallel (or concentric sections, the electric field of two adjacent parallel or concentric sections being in phase opposition to one another at one or more adjacent positions.

A further aspect of the invention provides a method of manufacturing a slot line resonator for a pass band filter comprising providing a slot line in a conductive layer of a first surface of a dielectric substrate, the slot line being folded with a shape factor based on the operating mode of resonance such that the slot line has parallel or concentric sections, the electric field of two adjacent parallel or concentric sections being in phase opposition at one or more adjacent positions; and providing an excitation line on a second face of the substrate, parallel to the first surface for feeding the slot line by electromagnetic coupling

Another aspect of the present invention relates to a slot line resonator for single or multiple passband filters comprising: a dielectric substrate with a first face equipped with a conductive layer and a second parallel face, a slot line etched in the

conductive layer, a feed line implemented on the second face of the substrate and feeding the slot by electromagnetic coupling, characterised in that the slot line has an electrical length L less than or equal to $k\lambda/2$ where λ is the guided wavelength in the slot at the harmonic frequency of order $(k-1)$ and k is an integer greater than or equal to 1 (the fundamental mode being the zero harmonic), the slot line being folded in a spiral pattern with a shape factor such that the slot line has parallel or concentric sections, the electric field of two parallel sections being in phase opposition.

In an embodiment, the shape factor of the spiral pattern is rectangular with a length at least twice as great as the width.

In an embodiment at least one capacitor is positioned in the slot line. The use of this capacitor makes it possible to tune the resonant frequency and therefore improve the quality factor.

In an embodiment a Knorr-type coupling is provided between the excitation line and the slot line.

Further aspects of the invention relate to a single or multiple passband filter comprising at least one slot line resonator as described above.

Embodiments of the invention propose a new type of printed resonator which is small and has a high quality factor Q and a reduced sensitivity to the parameters of the substrate. The present invention is based on the use of a slot line to make a resonator for filters.

BRIEF DESCRIPTION OF THE DRAWINGS

Other characteristics and advantages of the present invention will appear upon reading the description of different embodiments, made below with reference to the enclosed drawings, wherein:

- Figure 1 already described shows very diagrammatically a microstrip line/slot line coupling making it possible to explain the present invention.
- Figure 2 already described shows the intensity of the electric field as a function of the length of the slot line for different operating modes.
- Figure 3 shows a first embodiment of a slot line resonator and the electric field in this resonator for different operating modes.

- Figure 4 is a curve giving the resonance as a function of the frequency for the operating mode of figure 3.
- Figure 5 shows, in the left part, a second embodiment of a slot line resonator in accordance with the present invention and the distribution of the electric field inside the slot line for different frequencies corresponding to the different resonance modes, and, in the right part, the curve of resonance as a function of the frequency.
- Figure 6 is a diagrammatic perspective view of a resonator in accordance with the present invention.
- Figure 7 shows, in the right part, a variant embodiment of a slot line resonator in accordance with the present invention and in the left part, different resonance curves showing the advantages of the embodiment shown.
- Figure 8 shows, in the left part, a slot line resonator in accordance with the present invention and a resonator of the same type whose dimensions have been significantly reduced and, in the right part, the resonance curves of the two embodiments.
- Figure 9 diagrammatically shows a filter made with a resonator in accordance with the present invention.

DESCRIPTION OF DIFFERENT EMBODIMENTS

An example of a slot line used to make a radiating antenna is illustrated in Figure 1. In this case, the radiating antenna uses a microstrip line/slot line electromagnetic coupling. The resonant slot 1 has a length $\lambda_{\text{slot}}/2$ so as to operate at a frequency F with λ_{slot} slightly less than λ_0 ($\lambda_0 = c/F$), due to the permittivity of the substrate. In the example shown in figure 1, $\lambda_{\text{slot}}/2$ is equal to 25.2 mm. The electromagnetic coupling is achieved using a microstrip line 2 having a length $\lambda_0/2$ equal to 28.8 mm. This microstrip line has, like the slot line, a width of 0.8 mm. One of the ends of the microstrip line is connected at A to an excitation circuit not shown. To obtain a radiation of the antenna, the microstrip line 2 crosses the slot line 1 at one crossover point found a distance substantially equal to $\lambda_0/4$ from the open-circuited end of the microstrip line and $\lambda_{\text{slot}}/4$ from the short-circuited ends of the slot line. A so-called Knorr-type coupling is thus obtained. The behaviour of the slot line of Figure 1 is illustrated in figure 2 which shows the intensity of the electric field E as a function of the frequency. If the distribution of the electric field is examined for

different operating modes, namely the fundamental mode for which the total length of the slot L equals λ slot/2 and the first higher-order mode wherein the resonance is approximately twice the fundamental frequency (L approximately equal to $2 \times \lambda$ slot/2) and the second higher-order mode with a resonance approximately three times the fundamental frequency (L approximately equal to $3 \times \lambda$ slot/2), for the distribution of the field E , the following phenomena are observed:

- In the case of the fundamental mode operating at the fundamental frequency F , the field E is maximal at a distance equal to $L/2$ from the edge of the slot (i.e. in the middle of the slot)
- For the first higher-order mode, namely the first harmonic, the maximum of the field E is observed at the first quarter from each edge, namely at $L/4$ and $3L/4$
- And for the second higher-order mode, a maximal electric field is observed for $L/6$, $L/2$ and $5L/6$.

Embodiments of the present invention rely on this distribution of the electric field E to make a slot line resonator for filters which is compact and low-cost.

Embodiments of the invention involve folding a slot line having a length L determined by the desired resonant frequency so that the electric fields are in phase opposition in order to be able to cancel each other out. The folding is done in a spiral pattern so as to obtain a structure which is the most compact possible.

A description will first be given, with reference to figures 3 and 4, of a first embodiment of a non-radiating slot line resonator in accordance with the present invention. As shown in part A of figure 3, the resonator has been made by etching, in the ground plane of a substrate, a slot line 10 of approximate length 25.2 mm folded according to a rectangular shape factor with a length much greater than the width. In embodiment shown, the length is 8.67 mm. As a result, if in a first approximation the width is disregarded, the slot is folded in a rectangular spiral pattern having 4 parallel line sections L_1 , L_2 , L_3 and L_4 .

The slot line 10 is excited by electromagnetic coupling by a microstrip line 11 made in a known manner on the other face of the substrate. The microstrip line crosses the 4 line sections L_1 , L_2 , L_3 , L_4 in their middle. It will be appreciated by those in the skilled art that other positions for the microstrip line can be envisaged.

With reference to parts B, C and D of Figure 6 the behavior of the resonator of part A is illustrated. Part B shows the electric field E when the resonator operates in its fundamental mode or zero harmonic namely at 2.55 GHz. In this case, the

significant electric fields are on sections L2 and L4 with almost identical amplitudes and in phase opposition. The radiation efficiency RE obtained is very low, namely 3.5%. A non-radiating resonance is therefore observed for the fundamental mode. Part C relates to operation at 5.86 GHz, namely at the first harmonic. In this case,

5 the significant electric fields are, for the first half-wave as shown in figure 2, in the second half of L1 and the first half of L4; the fields E have an equivalent amplitude in phase opposition and therefore cancel each other out. Likewise for the second half-wave, the significant electric fields E are on the second half of L2 and the first half of L3 with an equivalent amplitude in phase opposition. They therefore cancel each

10 other out. A second resonance equally weakly radiating and with a radiation efficiency RE equal to 22.8% is therefore observed. In the case of part D, operation is in the third mode as shown in figure 2 and it can be seen that the radiation efficiency is much higher since RE equals 63% and the electric fields tend to add together. Thus, to obtain a slot line resonator for filters having the required

15 efficiency, operation will be achieved either in the fundamental mode or in the first mode namely at the first harmonic. Figure 4 is a curve giving the reflection coefficient at the input of the microstrip line providing the excitation as a function of the frequency and clearly shows the 3 resonances obtained at the 3 frequencies indicated by the markers m1, m2 and m3.

20 A description will now be given, with reference to figure 5, of another embodiment of a slot line resonator in accordance with the present invention. In this case, the slot line of figure 1 has been etched in a spiral pattern having a substantially square shape factor, namely where the length is substantially equal to the width. With a slot line 20 of total length 25.2 mm for an operation at 2.26 GHz, a length and a width

25 substantially equal to 4.28 mm are therefore obtained. In this case, the slot line comprises 15 line portions starting from outer portions L1, L2, L3, L4 and going up to the innermost portion L15. The slot line 20 is excited by electromagnetic coupling using a microstrip line 21 implemented on the opposite face of the substrate. When this resonator operates in the fundamental mode, namely at 2.26 GHz, as shown in

30 part B the significant electric fields are on lengths L3, L4, L5, L6 with amplitudes which are quite close together and in phase opposition for L3 and L5 on one hand and L4 and L6 on the other hand. A non-radiating resonance is therefore observed for the fundamental mode or zero harmonic with a radiation efficiency RE of 3.2%, that is to say quite low. In the case of an operation at the first harmonic namely 5.71

35 GHz and as shown in part C of figure 5, the significant electric fields are on lengths

L2, L3, and L4 for the first half-wave and on lengths L7, L8, L9 and L10 for the second half-wave. Given the directions of the electric fields E, the horizontal components of L2 and L8 are in phase opposition with L4 and L10 and likewise the vertical components of L3 and L5 are in phase opposition with L7. In this case the radiation efficiency of the resonator for the first harmonic is equal to 13.8%. It therefore remains low. In the case of an operation at 8.86 GHz, the significant electric fields E are on lengths L6, L9, L10. However, in this case the horizontal or vertical electric fields add together and the radiation efficiency RE of the resonator is equal to 55.7%. This efficiency is therefore high. The right part of figure 5 is a curve giving the reflection coefficient at the input of the microstrip line providing the excitation as a function of the frequency and clearly shows the 3 resonances obtained at the 3 frequencies indicated by the markers m1, m2 and m3.

A description will now be given, with reference to figure 6, of a particular embodiment of a slot line resonator in accordance with the present invention, implementing the principles described above. In this case, on a substrate 30 having a ground plane 31, a slot line 32 which has been folded in a spiral pattern with a square shape factor has been etched into the ground plane 31. On the face of the substrate opposite the face comprising the ground plane, an excitation line 33 made using microstrip technology has been etched. This microstrip line 33 crosses a set of parallel sections of the slot line, passing over the central section 34. The excitation achieved in this case is an excitation of Knorr type and the centre 34 of the resonator pattern is approximately $\lambda_m/4$ from the edge of the microstrip line 33 where λ_m is the guided wavelength in the microstrip line at the first harmonic that is to say at approximately $\lambda_m/8$ of the fundamental.

A description will now be given, with reference to figure 7, of a refinement in accordance with an embodiment of the invention making it possible to tune the quality factor and the frequency of a slot line resonator. As shown in the right part of figure 7, the slot line resonator 40 has a square shape factor like the resonator shown in figure 5. It is excited by a microstrip line 41. In accordance with this refinement, at least one capacitor 42A, 42B, 42C has been mounted in the slot line 40 in different sections of the spiral pattern. Measurements of the resonance as a function of the frequency have been made by placing a 0.3pF capacitor on the different sections of the spiral pattern. It is therefore observed that, according to the position of the capacitor, the resonance frequency of the resonator can be modified. If the capacitor is placed as near as possible to the strongest zone of electric field E,

a very significant influence on the behaviour of the resonator is observed. Moreover, the quality factor Q decreases when we move away from the zone of maximum electric field. Thus, the insertion of a capacitor in the slot of a slot line resonator in a specific zone makes it possible to tune the quality factor Q and the frequency. The left part of figure 7 is a curve giving the reflection coefficient at the input of the microstrip providing the excitation as a function of the frequency showing the resonance frequencies (respectively markers m9, m10, m11) and indicating the quality coefficients corresponding to these resonances (respectively $Q_u=53$, 50, and 39), for the 3 positions of the capacitor indicated in the figure on the right (respectively 42A, 42B and 42C) and the resonance obtained in the absence of a capacitor (marker m12) and the corresponding quality factor ($Q_u=156$). This result clearly shows the possibility of controlling the quality factor and the resonance frequency of the compact resonator which is the object of the invention using the insertion of the capacitor at a judiciously chosen point in the slot. The nearer the location of the capacitor to the strongest zone of electric field E , the greater its influence on the reduction of the resonant frequency (which is equivalent, at fixed resonant frequency, to reducing the size of the resonator further) and on the reduction of the quality factor of the resonator.

A description will now be given, with reference to figure 8, of an embodiment making it possible to obtain, using the slot line resonator shown in figure 3, a very compact slot line resonator. The slot line resonator of figures 3 and 4 has a rectangular shape factor with a length of 8.67 mm, the slot line 10 being folded so as to have 4 sections with long lengths while the widths are very small. This spiral structure is excited by an excitation line 11 made using microstrip technology on the opposite face of the substrate. The curve in the right part of figure 8 is a curve giving the reflection coefficient at the input of the microstrip line providing the excitation as a function of the frequency showing the resonant frequencies (respectively m1, m2, m3). According to the embodiment of figure 8, by reducing by 2 the shape factor of the resonator of figure 3, a slot line 50 folded in a spiral having a length of 4.3 mm and excited by a microstrip excitation line 51 is therefore obtained and the fundamental mode changes to approximately double (that is 5.09 GHz) the initial fundamental frequency (equal to 2.55 GHz); the resonances of modes 2 and 3 have also been eliminated.

Thus by folding in a spiral pattern a slot line whose length corresponds substantially to the operating frequency in the fundamental mode, the folding being done so that

the electric fields cancel each other out and are in phase opposition, it is possible to obtain a resonator for single or multiple passband filters which is very compact and low-cost. This resonator has a relatively high quality factor. Moreover, it is not very sensitive to the parameters of the substrate and to the production tolerances. It is also possible to control the quality factor Q by incorporating capacitors at chosen points of the slot line structure of the resonator.

This resonator can be used advantageously to make miniature filters tunable in the WiFi band as shown diagrammatically in figure 9. The filter shown in figure 9 comprises 4 resonators 60A, 60B, 60C, 60D, with outer resonators 60A and 60D and two resonators 60B and 60C parallel to each other. The two outer resonators are each excited by a microstrip line 61A and 61B according to a principle of Knorr type. An embodiment of an extremely compact fourth-order coupled resonator filter using the slot resonators which are the object of the present invention is thus obtained.

Embodiments of the invention provide a compact and inexpensive slot line resonator making it possible to make low-cost, highly selective filters.

Embodiments of the present invention make it possible to produce a very compact, low-cost resonator having a high, controllable quality factor Q and which is not very sensitive to the parameters of the substrate and to the production tolerances.

CLAIMS

1. A slot line resonator for a filter comprising:
 - 5 a dielectric substrate with a first surface equipped with a conductive layer and a second surface parallel to the first surface
 - a slot line (10, 20, 32, 40) provided in the conductive layer,
 - an excitation line (11, 21, 34, 41) provided on the second surface of the substrate and for feeding the slot line by electromagnetic coupling,
 - 10 wherein the slot line is folded in accordance with a shape factor based on an operating mode of resonance such that the slot line has parallel (L1, L2, L3, L4: L1 to L15) or concentric sections, the electric field of two adjacent parallel or concentric sections being in phase opposition to one another at one or more adjacent respective positions.
 - 15
2. A slot line resonator according to claim 1, wherein the excitation line is positioned with respect to the slot line such that it crosses the parallel or concentric sections at a position where the electric field of the two parallel or concentric sections are in phase opposition at the operating mode of resonance.
 - 20
3. A slot line resonator according to claim 1 or 2, further comprising at least one capacitor positioned in the slot line.
4. A slot line resonator according to claim 3, wherein the at least one capacitor
 - 25 is positioned in the slot line according to the electric field profile corresponding to the operating mode of resonance.
5. A slot line resonator according to claim 3 or 4, wherein the or each capacitor in the slot line is positioned with respect to the position where the electric field is maximum to control the quality factor of the resonator.
 - 30
6. A slot line resonator according to any preceding claim wherein the slot line is folded in a spiral pattern

7. A slot line resonator according to claim 6, wherein the shape factor of the spiral pattern is rectangular with a length at least twice as great as the width.
8. A slot line resonator according to claim 6, wherein the shape factor of the spiral pattern is square.
9. A slot line resonator according to any one of the preceding claims, wherein the operating mode of resonance is the fundamental mode or the first harmonic mode.
10. A slot line resonator according to any one of the preceding claims, wherein the excitation line is a microstrip line.
11. A slot line resonator according to any one of the preceding claims, wherein the microstrip line has an end positioned $\lambda_m/8$ from the centre of the pattern where λ_m is the guided wavelength in the microstrip line at the fundamental frequency.
12. A slot line resonator according to any one of the preceding claims wherein the slot line has an electrical length L less than or equal to $k \lambda/2$ where λ is the guided wavelength in the slot at the harmonic frequency of order $(k-1)$ and k is an integer greater than or equal to 1 (the fundamental mode being the zero harmonic)
13. Filter comprising at least one slot line resonator (60A, 60B, 60C, 60D) according to any one of the preceding claims.
14. Filter according to claim 13 wherein the filter is a lossy filter.
15. An electronic wireless device comprising a filter according to claim 13 or 14.
16. A method of manufacturing a slot line resonator for a pass band filter comprising
- providing a slot line (10,20, 32, 40) in a conductive layer of a first surface of a dielectric substrate, the slot line being folded with a shape factor based on the operating mode of resonance such that the slot line has parallel ($L_1, L_2, L_3, L_4: L_1$ to L_{15}) or concentric sections, the electric field of two adjacent parallel or

concentric sections being in phase opposition at one or more adjacent positions;
and

providing an excitation line on a second face of the substrate, parallel to the
first surface for feeding the slot line by electromagnetic coupling

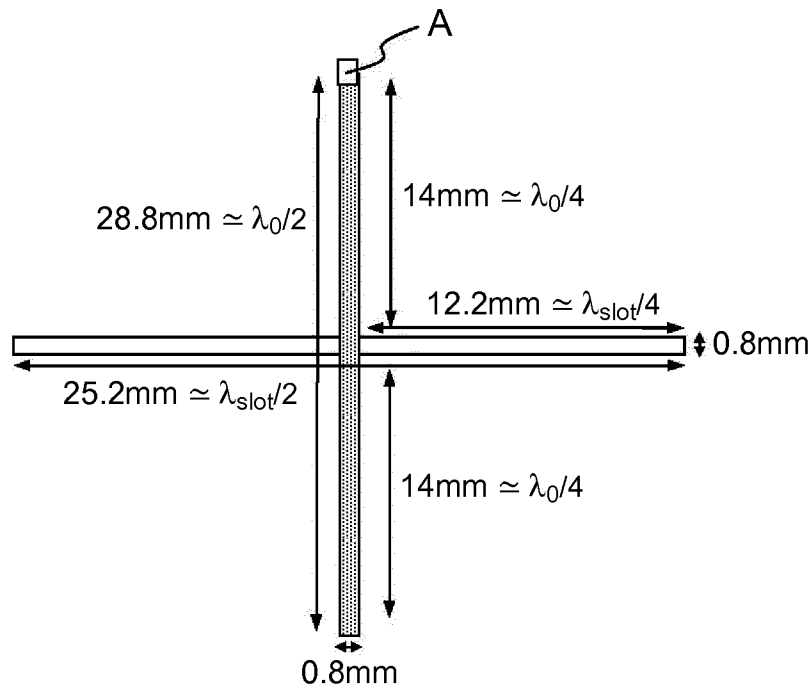


FIG.1

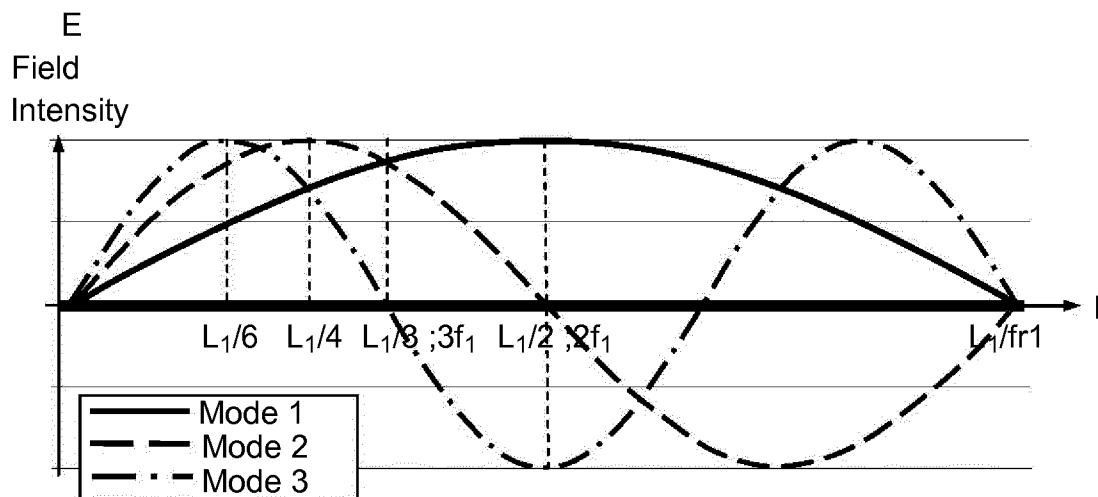


FIG.2

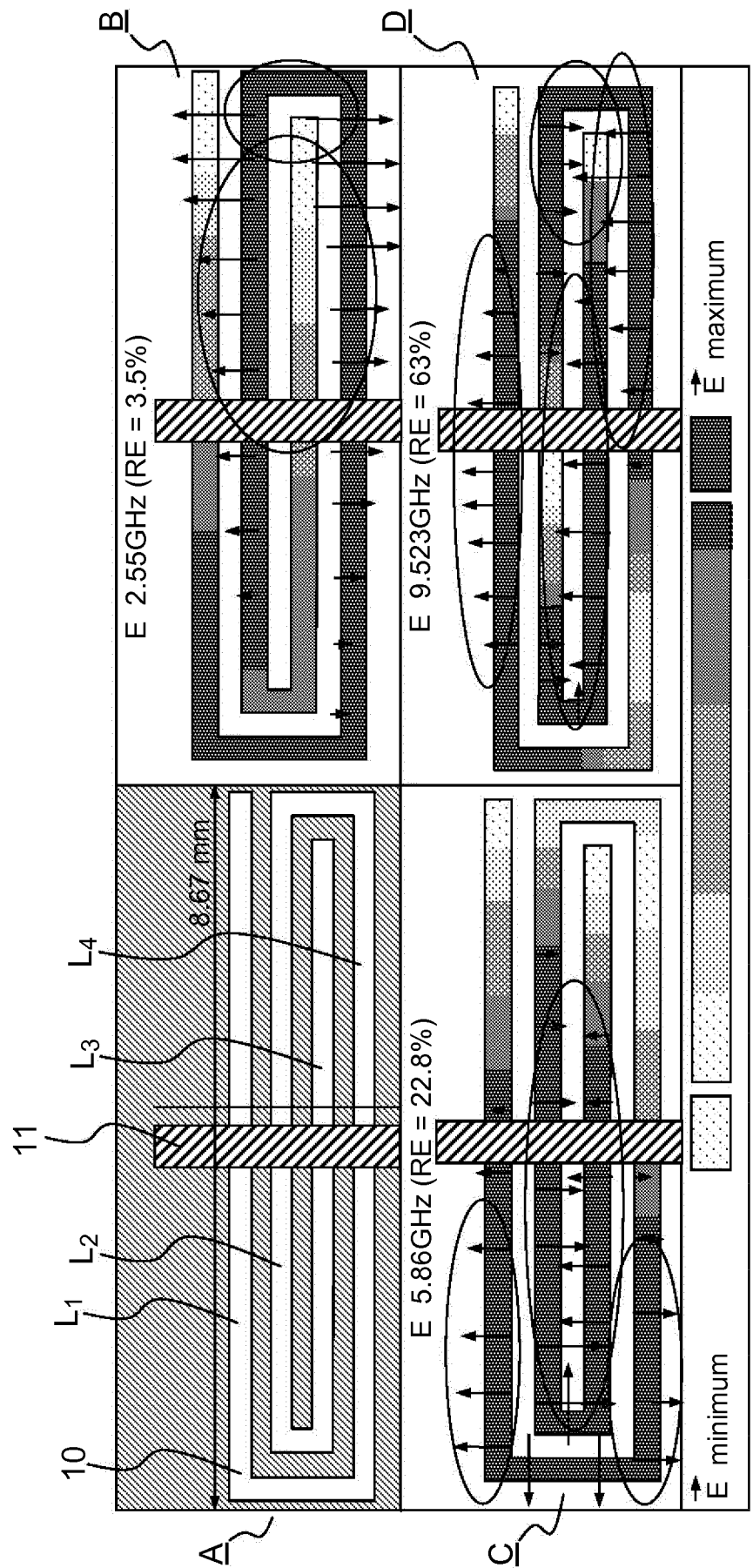


FIG.3

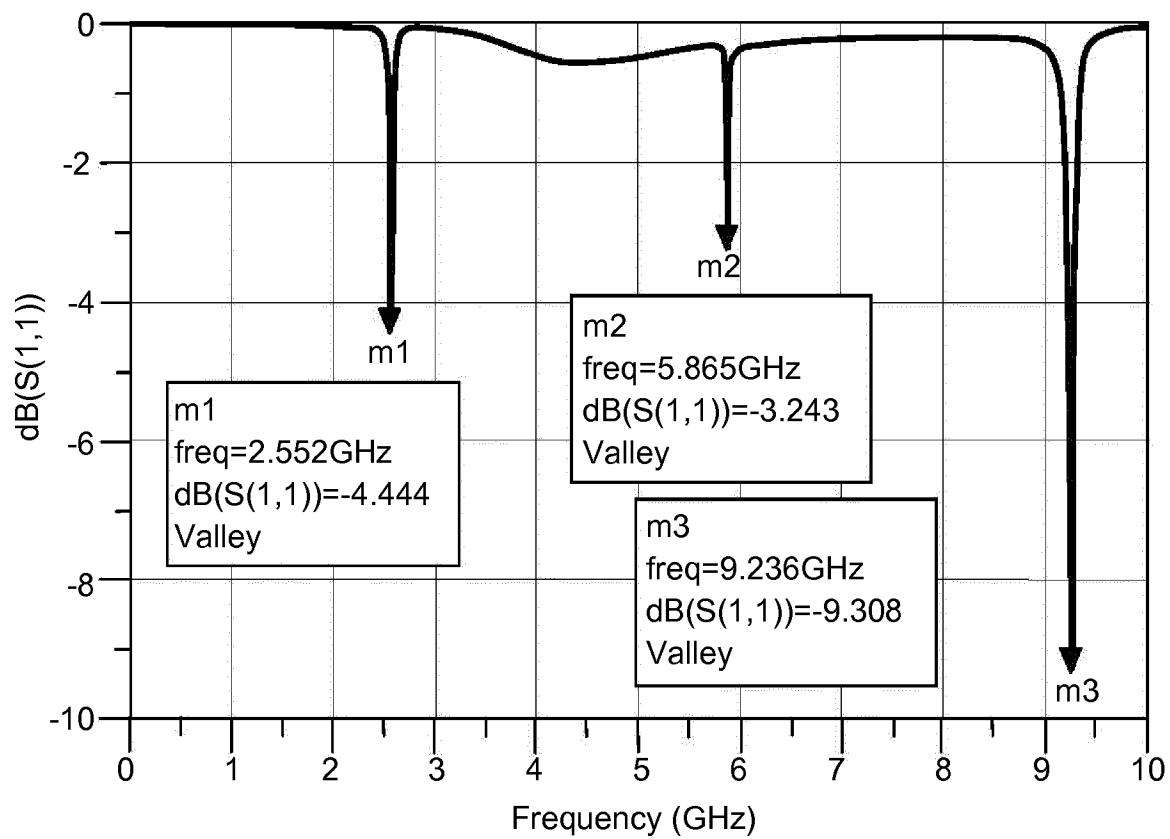


FIG.4

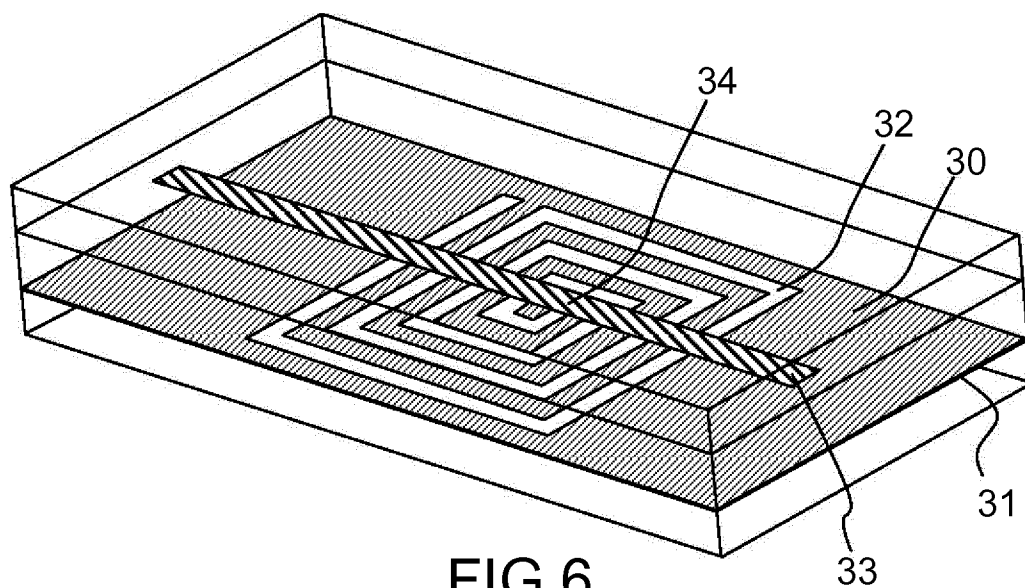
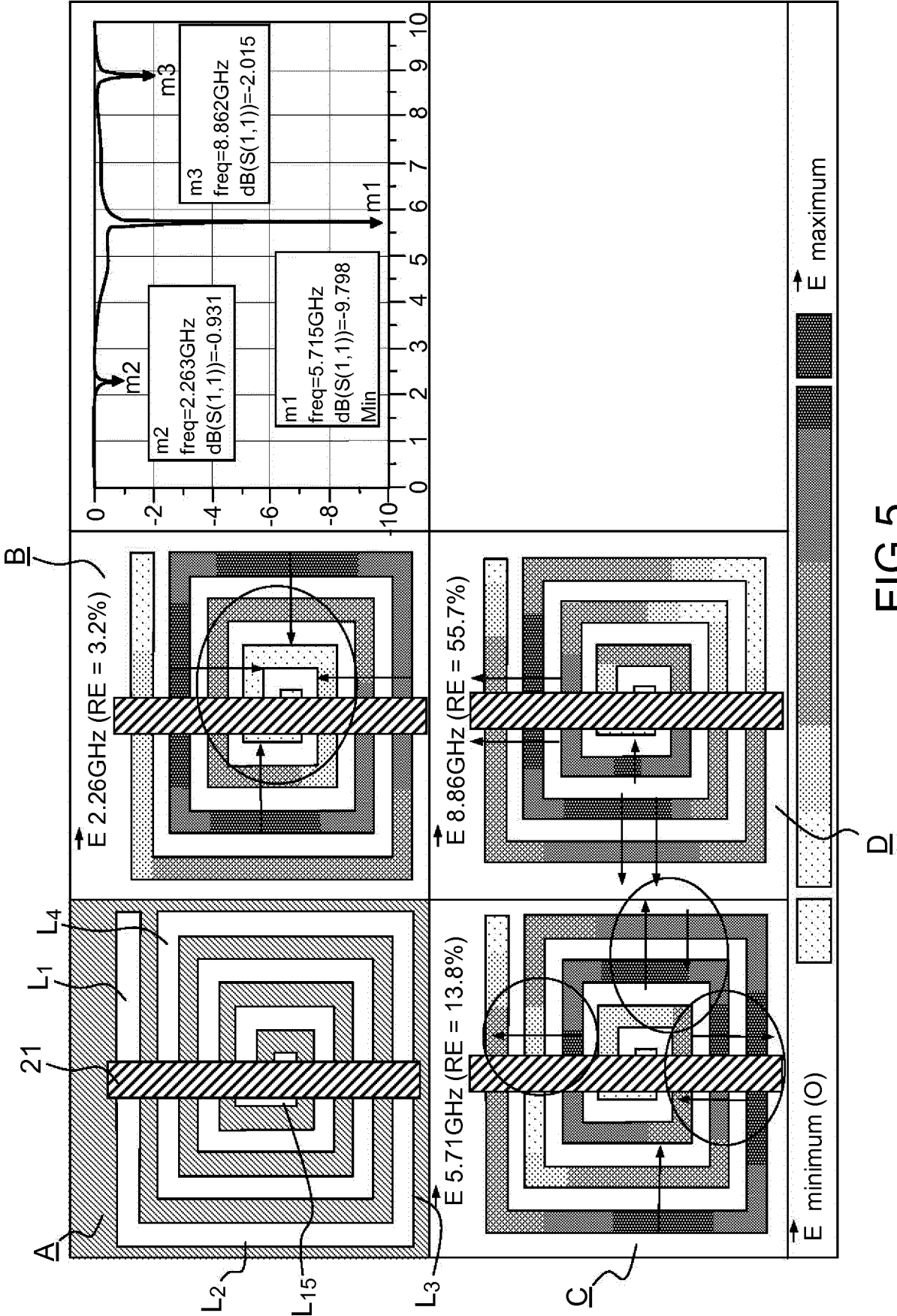


FIG.6



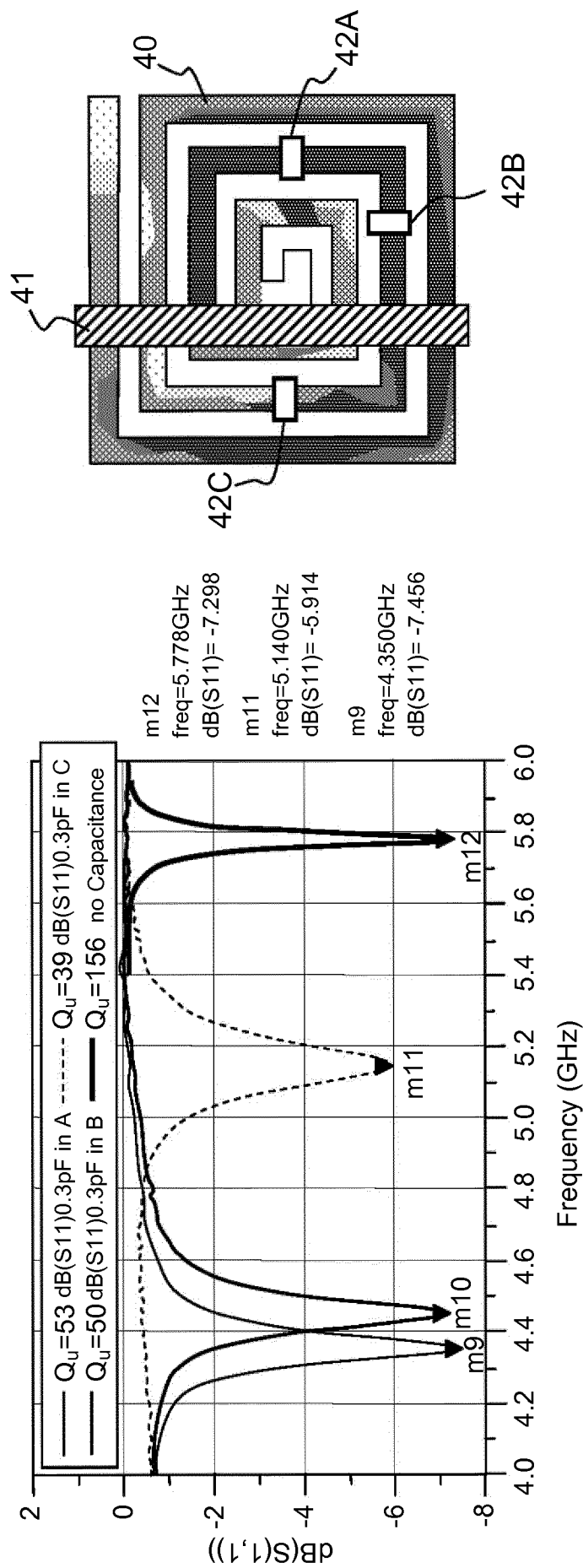


FIG.7

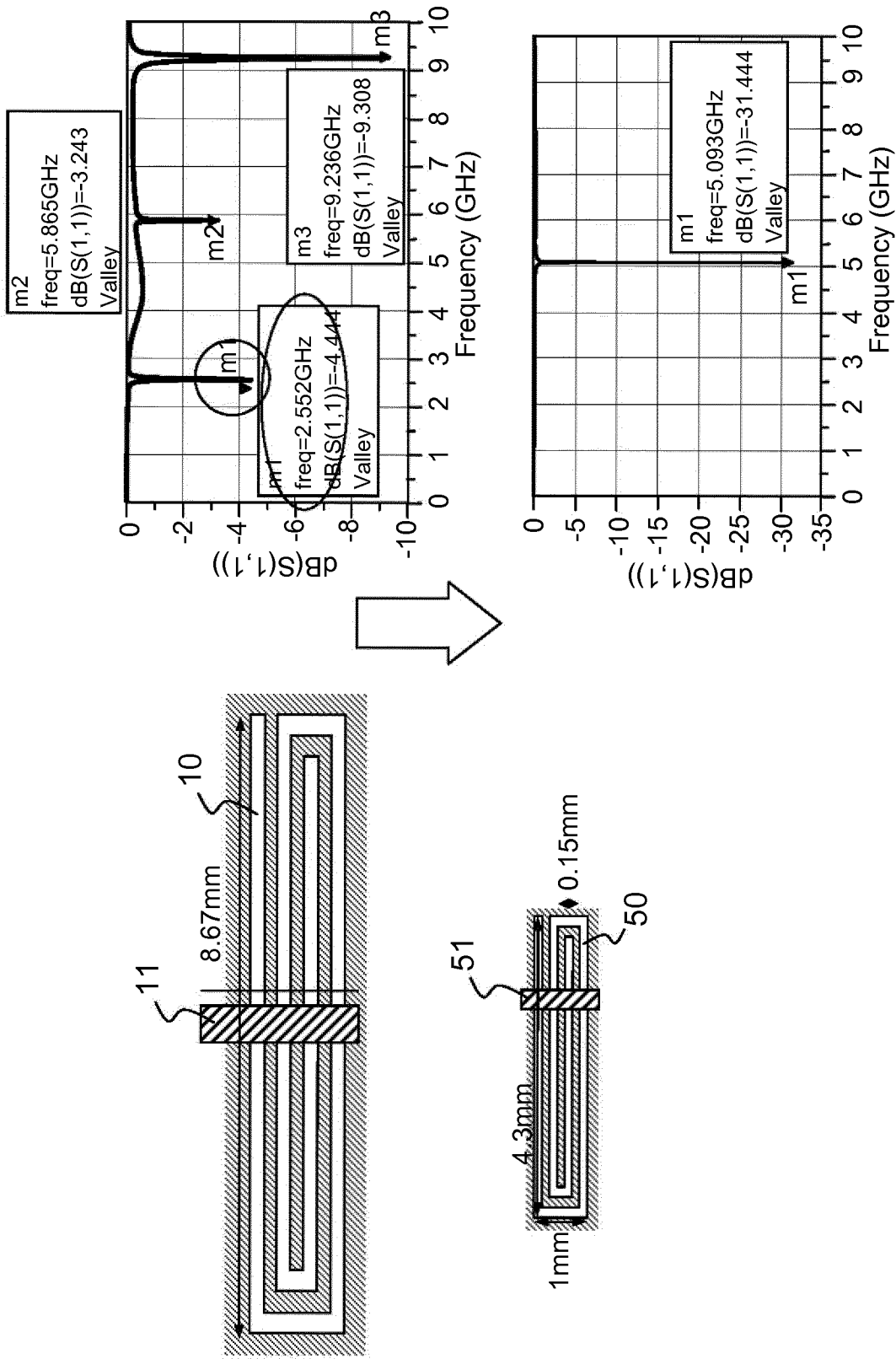


FIG. 8

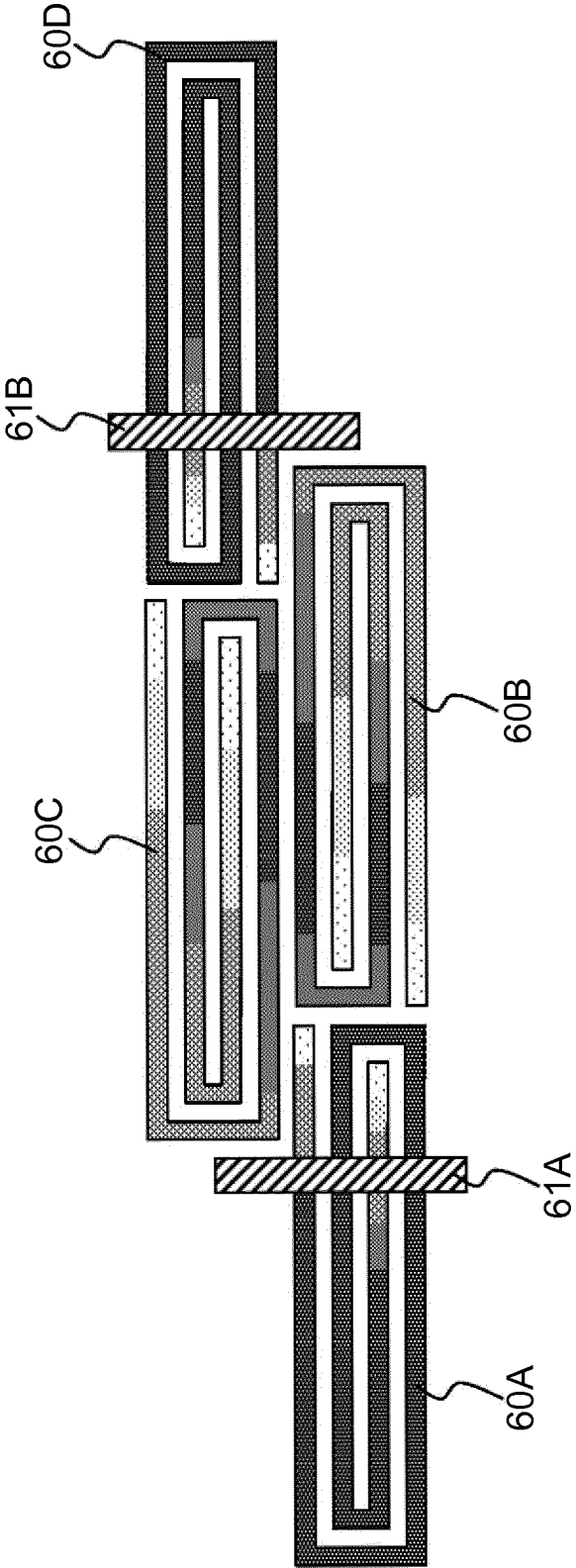


FIG.9

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2015/050394

A. CLASSIFICATION OF SUBJECT MATTER

INV. H01P7/00 H01P1/201
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H01P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2006/017527 A1 (KANNO HIROSHI [JP] ET AL) 26 January 2006 (2006-01-26)	1,2,6, 8-10, 12-16
Y	paragraph [0105]	7
A	paragraph [0109]	3-5,11
	paragraph [0150]	
	paragraph [0218] - paragraph [0221]	
	paragraph [0233]	
	figures 11A, 11B, 11C	
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Further documents are listed in the continuation of Box C.



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INTERNATIONAL SEARCH REPORT

International application No
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