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- (72) Inventor; and
- (71) Applicant : RHODES, David [GB/GB]; Dabarda, West Winds, Moor Lane, Menston, Yorkshire LS29 6QD (GB).
- (74) Agent: HEPWORTH BROWNE; 7 Wragley House, Valley Road, Hebden Bridge, Yorkshire HX7 7BN (GB).
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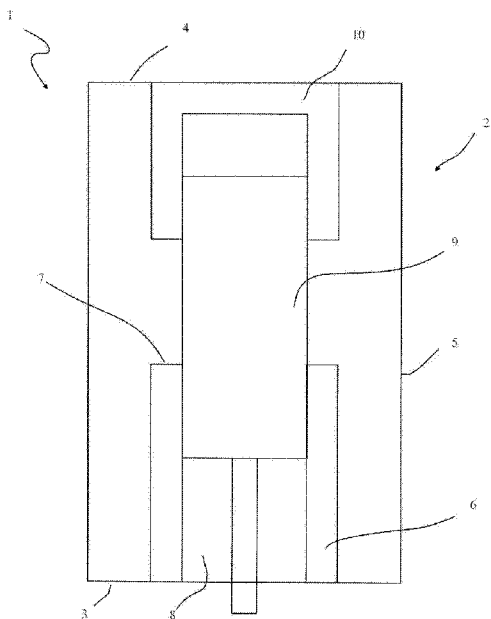


Figure 1

(57) Abstract: A tuneable microwave filter having a passband and a stop-band with a substantially constant passband bandwidth across a tuneable band, the filter comprising a plurality of resonators, each resonator having an equivalent electrical circuit comprising a short circuited stub in parallel with a capacitor; the resonators being electrically coupled together such that each resonator is electrically coupled to at least one other resonator by an electrical coupling equivalent to a short circuited stub; each short circuited stub being dimensioned such that its electrical length Θ varies between $2\pi/9$ and $13\pi/36$ or a portion of that range across the tuneable band.

A tuneable microwave filter and a tuneable microwave multiplexer

The present invention relates to a tuneable microwave filter. More particularly, but not exclusively, the present invention relates to a tuneable microwave filter comprising a plurality of coupled resonators, the short circuited stub of the equivalent circuit of each of the resonators being dimensioned such that its electrical length lies between $2\pi/9$ and $13\pi/36$ or a portion thereof across the tuneable band of the microwave filter. The present invention further relates to a tuneable microwave multiplexer comprising a plurality of tuneable microwave filters according to the invention, a resonator of each filter being connected to a matching circuit.

Tuneable microwave filters comprising a plurality of resonators are known. Such filters have a passband with a bandwidth. By varying a property of each resonator one can move the centre of the passband up and down within a tuneable band. A problem with such filters is that the bandwidth varies with frequency due to the variation in inter-resonator coupling with frequency. Because of this, whenever one adjusts the position of the center of the passband it is also necessary to manually alter the inter-resonator coupling to return the bandwidth to its original value. This can be a complex operation often requiring the adjustment of tuning screws to adjust the inter-resonator coupling. Because of this an operator must visit the filter in situ to make the necessary adjustments which can be expensive and time consuming.

The tuneable microwave filter according to the invention seeks to overcome the problems of the prior art.

Accordingly, in a first aspect, the present invention provides a tuneable microwave filter having a passband and a stopband with a substantially constant passband bandwidth across a tuneable band, the filter comprising

a plurality of resonators, each resonator having an equivalent electrical circuit comprising a short circuited stub in parallel with a capacitor;

the resonators being electrically coupled together such that each resonator is electrically coupled to at least one other resonator by an electrical coupling equivalent to a short circuited stub;

each short circuited stub being dimensioned such that its electrical length θ varies between $2\pi/9$ and $13\pi/36$ or a portion of that range across the tuneable band.

The tuneable microwave filter according to the invention has a passband with a bandwidth which is substantially independent of frequency of the centre of the passband across the tuneable band. Accordingly, when changing the frequency of the centre of the passband there is no need to adjust the inter-resonator coupling. This makes adjustment of the filter much simpler and can now be achieved remotely.

Preferably each short circuited stub is dimensioned such that its electrical length θ is substantially $2\pi/9$ at one end of the tuneable band and substantially $13\pi/36$ at the other end of the tuneable band, more preferably $\pi/4$ at one end of the tuneable band and $\pi/3$ at the other end of the tuneable band.

Preferably each resonator is identical

Preferably each short circuited stub is identical

Preferably the tuneable band is in the range 1.7 to 2.7GHz or 700MHz to 1GHz

Preferably the bandwidth is less than 50% of width of the tuneable band, more preferably less than 20% of the width of the tuneable band, more preferably less than 10% of the width of the tuneable band.

Preferably each resonator comprises

a resonator cavity comprising first and second spaced apart electrically conducting end faces and an electrically conducting side wall extending therebetween;

an electrically conducting resonator body arranged within the resonator cavity extending from the first end face to a resonator body end face part way towards the second end face; and,

a dielectric body within the resonator cavity, at least a portion of the dielectric body being adapted to be displaced in the gap between the resonator body and second end face towards and away from the second end face to alter the resonant frequency of the resonator.

Preferably the resonator body has a conduit extending therethrough from the first end face to the resonator body end face, at least a portion of the dielectric body being arranged in the conduit.

In a further aspect of the invention there is provided a tuneable microwave filter having a passband and stopband with a substantially constant passband bandwidth across a tuneable band, the filter comprising

a plurality of resonators, each resonator being electrically coupled to at least one other resonator;

each resonator having an equivalent circuit comprising a short circuited stub in parallel with a capacitor

the plurality of resonators having an equivalent electrical circuit comprising the equivalent circuits for each resonator, the equivalent circuit for each resonator being connected in cascade by first and second signal lines to the equivalent circuit for at least one other resonator, the first signal line comprising a further short circuited stub;

each short circuited stub being dimensioned such that its electrical length θ varies between $2\pi/9$ and $13\pi/36$ or a portion of that range across the tuneable band.

Preferably the tuneable microwave filter further comprises at least one matching circuit, the matching circuit being connected to one of the resonators.

Preferably the tuneable microwave filter comprises an input matching circuit connected to one resonator and an output matching circuit connected to a different resonator.

Preferably the resistive part of the admittance of the matching circuit varies as $1/f(\theta)$ with $f(\theta)$ increasing with θ across the tuneable band.

Preferably the resistive part of the admittance of the matching circuit varies substantially as $1/\tan \theta$ across the tuneable band.

Preferably $f(\theta)$ is a polynomial in θ .

Preferably $f(\theta)$ is a polynomial in $\tan \theta$.

Preferably the matching circuit comprises an inductor connected to the resonant body of the resonator and extending out of the resonator cavity.

Preferably the inductance L of the inductor is calculated from

$$F(\theta_1) = F(\theta_2)$$

where

$$F(\theta) = \frac{\tan \theta}{1 + A^2 \theta^2}$$

and θ_1 and θ_2 are the values of the electrical length at spaced apart points of the tuneable band and with a unitary resistive load connected between the inductor and earth.; and,

$$A\theta = L\omega$$

where $\omega=2\pi f$, and f is the frequency of the signal.

Preferably the matching circuit comprises an electrically conducting impedance matching bar arranged within the resonator cavity of the resonator spaced apart from the resonator body and

extending from the first end face part way towards the second end face; and, a signal line extending from the impedance matching bar out of the resonator cavity.

Preferably the value of the characteristic impedance Z of the matching bar is calculated from

$$F(\theta_1) = F(\theta_2)$$

where

$$F(\theta) = \frac{\tan \theta}{1 + Z^2 \tan^2 \theta}$$

and θ_1 and θ_2 are the values of the electrical length at spaced apart points of the tuneable band with a unitary resistive load connected between the signal line and earth.

Preferably the tuneable microwave filter comprises a plurality of groups of resonators, the resonators within each group being electrically coupled together;

an input matching circuit connected to a resonator of each group; and,

an output matching circuit connected to a different resonator of each group.

In a further aspect of the invention there is provided a tuneable microwave multiplexer comprising

a plurality of tuneable microwave filters as claimed in any one of claims 1 to 9; and,

a matching circuit connected to a resonator of each filter.

Preferably the resistive part of the admittance of the matching circuit varies as $1/f(\theta)$ with $f(\theta)$ increasing with θ across the tuneable band.

Preferably the resistive part of the admittance of the matching circuit varies substantially as $1/\tan \theta$ across the tuneable band.

Preferably $f(\theta)$ is a polynomial in θ .

Preferably $f(\theta)$ is a polynomial in $\tan \theta$.

Preferably the matching circuit comprises a plurality of inductors, the inductors being arranged such that each filter has one inductor connected to the resonator body of one of its resonators, the inductors being connected together at a common node

Preferably the multiplexer is a diplexer and wherein the inductance L of each inductor is calculated from

$$F(\theta_1) = F(\theta_2)$$

where

$$F(\theta) = \frac{\tan \theta}{4 + A^2 \theta^2}$$

and θ_1 and θ_2 are the values of the electrical length at spaced apart points of the tuneable band with a unitary resistive load connected between the common node and earth; and,

$$A\theta = L\omega$$

where $\omega=2\pi f$, and f is the frequency of the signal.

Preferably each of the resonators to which the matching circuit is connected share a common resonator cavity, the matching circuit comprising an electrically conducting matching bar arranged in the resonator cavity and spaced apart from the resonator bodies and extending from the first end face part way to the second end face; and, a signal line extending from the matching bar out of the resonator cavity.

Preferably the multiplexer is a diplexer and the value of the characteristic impedance Z of the matching is calculated from

$$F(\theta_1) = F(\theta_2)$$

where

$$F(\theta) = \frac{\tan \theta}{4 + Z^2 \tan^2 \theta}$$

and θ_1 and θ_2 are the values of the electrical length at spaced apart points of the tuneable band and where a unitary resistive load is connected between the signal line and earth.

Preferably the microwave multiplexer further comprises a plurality of output matching circuits, the number of output matching circuits being equal to the number of filters, a resonator of each filter having an output matching circuit connected thereto.

The present invention will now be described by way of example only and not in any limitative sense with reference to the accompanying drawings in which

Figure 1 shows a resonator of a microwave filter according to the invention in cross section;

Figures 2(a) and 2(b) show embodiments of tuneable microwave filters according to the invention.

Figure 3 shows the equivalent circuit of the filter according to the invention;

Figures 4(a) and 4(b) show an output matching circuit and its equivalent circuit of a filter according to the invention;

Figures 5(a) and 5(b) show a further embodiment of an output matching circuit and its equivalent circuit of a filter according to the invention;

Figures 6(a) and 6(b) show an embodiment of an input matching circuit and its equivalent circuit of a multiplexer according to the invention;

Figures 7(a) and 7(b) show a further embodiment of an input matching circuit and its equivalent circuit of a multiplexer according to the invention;

Figure 8 shows the first resonators and input matching circuit of a four filter multiplexer according to the invention;

Figure 9 shows a triplexer according to the invention having input and output matching circuits; and,

Figure 10 shows a bandpass filter with three channels according to the invention.

Shown in figure 1 is a resonator 1 of a tuneable microwave filter according to the invention. The resonator 1 comprises an electrically conducting resonator cavity 2. The resonator cavity 2 comprises first and second spaced apart end faces 3,4 and a side wall 5 extending therebetween.

Arranged within the resonator cavity 2 is an electrically conducting resonator body 6. The resonator body 6 extends from the first end face 3 to a resonator body end face 7 part way towards the second end face 4. A conduit 8 extends through the resonator body 6 from the first end face 3 to the resonator body end face 7.

Arranged partially within the conduit 8 as shown is a dielectric body 9. The dielectric body 9 extends into the gap between the resonator body 6 and second end face 4. The dielectric body 9 is adapted to be displaced towards and away from the second end face 4 to alter the resonant frequency of the resonator 1. A portion of the second end face 4 is shaped as a cup 10 to receive the dielectric body 9 as the dielectric body 9 approaches the second end face 4.

Shown in figure 2(a) is an embodiment of a tuneable microwave filter 11 according to the invention in plan view. The tuneable microwave filter 11 comprises a plurality of resonators 1 electrically coupled together. Each resonator 1 is coupled to at least one other resonator 1. Resonators share side walls 12. Coupling is achieved by means of apertures 13 extending through the side walls 12 through which the microwaves can pass. This coupling is electrically equivalent to a short circuited electrical stub as described below. At least one of the resonators, preferably all of the resonators are tuneable.

Input and output signal lines 14 are provided to provide the microwave signal to the filter 11 and to extract the microwave signal from the filter 11. The input signal line 14 extends through the cavity wall 5 of a first resonator 1 of the filter 11 to the resonator body 6 of that resonator. The output signal line 14 extends through the cavity wall 5 of a last resonator 1 of the filter 11 to the resonator body 6 of that resonator 1.

Shown in figure 2(b) is a further embodiment of a tuneable microwave filter 11 according to the invention in plan view. In this embodiment the resonators 1 are arranged in a chain with each resonator 1 connected to the next.

In this embodiment the tuneable filter 11 has a tuneable band in the range 1.7 to 2.7GHz or 700MHz to 1GHz. The bandwidth of the passband or stopband of the filter 11 is typically less than 50% of the width of the tuneable band, more preferably less than 20% of the width of the tuneable band, more preferably less than 10% of the tuneable band. By tuning the resonators (ie varying their resonant frequencies) one can vary the passband of the filter over the tuneable band.

Shown in figure 3 is the equivalent circuit for the tuneable microwave filter 11 of figure 2(b). Each resonator 1 has an equivalent circuit comprising a capacitor 15 in parallel with a short circuited stub 16. Each equivalent circuit for a resonator 1 is connected in cascade by first and second signal lines 17,18 to an equivalent circuit for another resonator 1. The first signal line 17 comprises a further

short circuited stub 19 representing the coupling between the resonators. Preferably all of the resonators 1 are identical and all of the stubs 16,19 are identical.

The admittance of a resonator 1 of the equivalent circuit is

$$Y = j(D\theta - B\cot\theta)$$

where θ is the electrical length of the of the short circuited stub 16 and is proportional to frequency. D is proportional to the value of the lumped capacitor 15 and B is the characteristic admittance of the shunt short circuited stub 19.

At resonance

$$D\theta_0 - B\cot\theta_0 = 0$$

To scale out the frequency dependence of the series short circuited stub 19 which provides the coupling between resonators 1, each admittance has to be multiplied by $\tan\theta$ to give an effective admittance of

$$Y_E = j(D\theta\tan\theta - B)$$

The bandwidth of the resonator is inversely proportional to the differential of Y_E with respect to θ evaluated at $\theta = \theta_0$. Hence,

$$\frac{1}{\text{Bandwidth}} \propto D(\tan\theta_0 + \theta_0(1 + \tan^2\theta_0))$$

$$\frac{1}{\text{Bandwidth}} \propto B \left[\frac{1}{\theta_0} + \frac{2}{\sin 2\theta_0} \right]$$

Thus, to obtain an approximation to constant bandwidth, then the function

$$F(\theta) = \frac{1}{\theta} + \frac{2}{\sin 2\theta}$$

must approximate to a constant over the tuneable band.

The turning point occurs substantially between $\theta=2\pi/9$ and $13\pi/36$ at approximately the arithmetic mean of $\theta=7\pi/24$. At these points $F(2\pi/9) = 3.46$ and $F(13\pi/36) = 3.49$, which is a difference of around 10% from the value of F at the mean value of $7\pi/24$. Accordingly, provided the short circuited stubs are dimensioned such that their effective length varies between $2\pi/9$ and $13\pi/36$ or a portion of that range over the tuneable band then the bandwidth of the passband (or stopband) of the filter 11 will vary by only around 10% as the centre frequency of the passband is varied over the tuneable band of the filter 11. If the electrical length varies over a smaller range of for example $\pi/4$ to $\pi/3$ then the bandwidth will only vary by about 3% over the tuneable range.

In use signals are passed to the microwave filter 11 from a device. Similarly, signals from the filter 11 are output to a further device. In order to do this input and output matching circuits are required. The input matching circuit is connected to the first resonator 1 of the filter 11. The output matching circuit is connected to the last resonator 1 of the filter 11. Embodiments of output matching circuits are described below. Such matching circuits can also be employed as input matching circuits.

To maintain a match to the admittance of the last resonator 1 of the filter 11 the resistive part of the admittance of the matching circuit seen at the output resonator should vary as

$$Y \approx \frac{K}{\tan\theta}$$

where K is a constant. In principle any imaginary component which is required can be obtained by retuning the resonant frequency of the first and last resonators of the filter. Some deviation from this relation will still produce an acceptable performance. More generally Y can be of the form $1/f(\theta)$ with $f(\theta)$ increasing with θ across the tuneable band. $f(\theta)$ can be a polynomial in θ or in $\tan\theta$.

Shown in figure 4(a) is an embodiment of a matching circuit 20. The matching circuit 20 comprises an inductor 21 of value L which extends through the cavity wall 5 of the last resonator 1 and is connected to the resonator body 6. The impedance of the further device to which the filter is

connected is modelled as an impedance of 1 Ohm for convenience although of course will vary depending on the further device.

The equivalent circuit of the matching circuit 20 of figure 4(a) is shown in figure 4(b). The equivalent circuit includes a transformer 22 of turns ratio 1:n. The input admittance of the matching circuit 20 (ie the admittance as seen by the last resonator of the filter) is

$$Y = \frac{n^2}{1 + jA\theta}$$

where n is the turns ratio of the transformer 22 and A is related to the value of the inductance L by $A\theta = L\omega$, where $\omega = 2\pi f$ with f being the frequency of the signal provided to the filter 11.

This has a real part

$$Y(\text{real}) = \frac{n^2}{1 + A^2\theta^2}$$

Thus, we require

$$F(\theta) = \frac{\tan \theta}{1 + A^2\theta^2}$$

to approximate to a constant as θ varies across the tuneable band. Hence, the value of A can be determined by

$$F(\theta_1) = F(\theta_2)$$

where

$$F(\theta) = \frac{\tan \theta}{1 + A^2\theta^2}$$

and θ_1 and θ_2 are the values of the electrical length at spaced apart points of the tuneable band. Preferably the spaced apart points are spaced apart by at least 50% of the width of the tuneable band, more preferably 70% of the width of the tuneable band, more preferably 90% of the width of the tuneable band, more preferably 100% of the width of the tuneable band. θ_1 and θ_2 lie within the range $2\pi/9$ to $13\pi/36$, more preferably $\pi/4$ to $\pi/3$.

The reactive component of the load requires that the first and last resonators 1 of the filter 11 to be tuned to a lower frequency than internal resonators. Also, the transformer effect which is significant will ultimately limit the tuneable band of the filter 11.

The tap point of the inductor 21 at the resonator body 6 determines the turns ratio of the transformer 22 which in turn determines the bandwidth of the matching circuit 20. This should be matched to the bandwidth of the filter 11 which is in turn determined by the inter-resonator coupling.

Shown in figure 5(a) is a further embodiment of a matching circuit 20 according to the invention. In this embodiment the matching circuit 20 comprises an electrically conducting matching bar 23 of characteristic impedance Z arranged within the resonator cavity. The matching bar 23 is spaced apart from the resonator body 6 and extends from the first end face 3 part way to the second end face 4. The matching circuit 20 further comprises a signal line 24 extending from the matching bar 23 through the cavity wall 5 of the resonator 1. Again, the impedance of the additional device is modelled as 1 Ohm for convenience.

The equivalent circuit for figure 5(a) is shown in figure 5(b). The real part of the admittance of the matching circuit 20 is given by

$$\text{Re } Y = \frac{1}{1 + Z^2 \tan^2 \theta}$$

Therefore in this case one requires the function

$$F(\theta) = \frac{\tan \theta}{1 + Z^2 \tan^2 \theta}$$

to remain substantially constant across the tuneable band of the filter 11. Hence, one can determine the value of Z from

$$F(\theta_1) = F(\theta_2)$$

where

$$F(\theta) = \frac{\tan \theta}{1 + Z^2 \tan^2 \theta}$$

and θ_1 and θ_2 are the values of the electrical length at spaced apart points of the tuneable band. Preferably the spaced apart points are spaced apart by at least 50% of the width of the tuneable band, more preferably 70% of the width of the tuneable band, more preferably 90% of the width of the tuneable band, more preferably 100% of the width of the tuneable band. θ_1 and θ_2 lie within the range $2\pi/9$ to $13\pi/36$, more preferably $\pi/4$ to $\pi/3$.

In a further aspect the present invention provides a tuneable microwave multiplexer. The simplest embodiment of a multiplexer is a diplexer comprising first and second filters and which is described below. The filters have been described in detail with reference to figures 1 to 3 and so will not be described again. The last resonator of the first filter is connected to a first output matching circuit. The last resonator of the second filter is connected to a second output matching circuit. The output matching circuits have been described above.

The diplexer further comprises a common input matching circuit 25 which will now be described.

Figure 6(a) shows the input matching circuit 25 of the diplexer connected to the first resonator 1 of each of the two filters 11. The matching circuit 25 comprises an inductor 26 connected between a common node 27 and the resonant body 6 of the first resonator 1 of the first filter 11. It further comprises a second inductor 26 (which in this embodiment is identical to the first) connected between the common node 27 and the resonator body 6 of the first resonator 1 of the second filter 11. For convenience the input impedance of the device connected to the input of the diplexer is shown as 1 Ohm.

The equivalent circuit for figure 6(a) is shown in figure 6(b). For two bandpass filter channels having sufficient frequency separation the out of band channel essentially places a shunt inductor 27 across the input of the inband channel. For this matching circuit the real part of the input admittance for the matching circuit 25 is

$$\operatorname{Re} Y = \frac{n^2}{4 + A^2 \theta^2}$$

Resulting in the value of A being increased by a factor of 2 compared to the value of A of the matching circuit connected to only one filter 11.

Shown in figure 7(a) is a further example of an input matching circuit 25 of a tuneable microwave diplexer according to the invention. In this embodiment the first resonators 1 of each of the two filters 11 share a resonant cavity. Arranged within the resonant cavity is an electrically conducting impedance matching bar 28 of characteristic impedance Z. The impedance matching bar 28 is spaced apart from the resonator bodies 6 of the two resonators 1 and extends part way from the first end face 3 to the second end face 4. Extending from the impedance matching bar 28 is a signal line 29. Again, the impedance of the further device is shown as 1 Ohm.

The equivalent circuit for figure 7(a) is shown in figure 7(b). The real part of the admittance for this matching circuit 25 is given by

$$\operatorname{Re} Y = \frac{1}{4 + Z^2 \tan^2 \theta}$$

Accordingly, the value of the characteristic impedance Z can be calculated from

$$F(\theta_1) = F(\theta_2)$$

where

$$F(\theta) = \frac{\tan \theta}{4 + Z^2 \tan^2 \theta}$$

and θ_1 and θ_2 are the values of the electrical length at spaced apart points of the tuneable band. Preferably the spaced apart points are spaced apart by at least 50% of the width of the tuneable band, more preferably 70% of the width of the tuneable band, more preferably 90% of the width of the tuneable band, more preferably 100% of the width of the tuneable band. θ_1 and θ_2 lie within the range $2\pi/9$ to $13\pi/36$, more preferably $\pi/4$ to $\pi/3$

As mentioned above, higher order multiplexers than diplexers are possible. Shown in figure 8 are the first resonators 1 of the four filters of a four filter multiplexer. The input matching circuit 30 is shown connected to these resonators. Again, one inductor 31 is connected to the resonator body 6 of each of the first resonators 1.

Shown in figure 9 is a triplexer 32 according to the invention. The triplexer comprises three filters 11 as previously described. Connected to the first resonators 1 of each of the three filters 11 is an input matching circuit 33. The last resonator 1 of each of the filters 11 is connected to a separate output matching circuit 34.

Shown in figure 10 is a bandpass filter 11 with three channels according to the invention. The resonators 1 are arranged in groups with the resonators 1 within each group being electrically coupled together. The last resonator 1 of each of the groups is connected to a common output matching circuit 35 as shown.

Electrical lengths are measured in radians.

CLAIMS

1. A tuneable microwave filter having a passband and a stopband with a substantially constant passband bandwidth across a tuneable band, the filter comprising

a plurality of resonators, each resonator having an equivalent electrical circuit comprising a short circuited stub in parallel with a capacitor;

the resonators being electrically coupled together such that each resonator is electrically coupled to at least one other resonator by an electrical coupling equivalent to a short circuited stub;

each short circuited stub being dimensioned such that its electrical length θ varies between $2\pi/9$ and $13\pi/36$ or a portion of that range across the tuneable band.
2. A tuneable microwave filter as claimed in claim 1 wherein each short circuited stub is dimensioned such that its electrical length θ is substantially $2\pi/9$ at one end of the tuneable band and substantially $13\pi/36$ at the other end of the tuneable band, more preferably $\pi/4$ at one end of the tuneable band and $\pi/3$ at the other end of the tuneable band.
3. A tuneable microwave filter as claimed in either of claims 1 or 2, wherein each resonator is identical
4. A tuneable microwave filter as claimed in any one of claims 1 to 3, wherein each short circuited stub is identical
5. A tuneable microwave filter as claimed in any one of claims 1 to 4, wherein the tuneable band is in the range 1.7 to 2.7GHz or 700MHz to 1GHz

6. A tuneable microwave filter as claimed in any one of claims 1 to 5, wherein the bandwidth is less than 50% of width of the tuneable band, more preferably less than 20% of the width of the tuneable band, more preferably less than 10% of the width of the tuneable band.

7. A tuneable microwave filter as claimed in any one of claims 1 to 6, wherein each resonator comprises

a resonator cavity comprising first and second spaced apart electrically conducting end faces and an electrically conducting side wall extending therebetween;

an electrically conducting resonator body arranged within the resonator cavity extending from the first end face to a resonator body end face part way towards the second end face;
and,

a dielectric body within the resonator cavity, at least a portion of the dielectric body being adapted to be displaced in the gap between the resonator body and second end face towards and away from the second end face to alter the resonant frequency of the resonator.

8. A tuneable microwave filter as claimed in claim 7, wherein the resonator body has a conduit extending therethrough from the first end face to the resonator body end face, at least a portion of the dielectric body being arranged in the conduit.

9. A tuneable microwave filter having a passband and stopband with a substantially constant passband bandwidth across a tuneable band, the filter comprising

a plurality of resonators, each resonator being electrically coupled to at least one other resonator;

each resonator having an equivalent circuit comprising a short circuited stub in parallel with a capacitor

the plurality of resonators having an equivalent electrical circuit comprising the equivalent circuits for each resonator, the equivalent circuit for each resonator being connected in

cascade by first and second signal lines to the equivalent circuit for at least one other resonator, the first signal line comprising a further short circuited stub;

each short circuited stub being dimensioned such that its electrical length θ varies between $2\pi/9$ and $13\pi/36$ or a portion of that range across the tuneable band.

10. A tuneable microwave filter as claimed in any one of claims 1 to 9, further comprising at least one matching circuit, the matching circuit being connected to one of the resonators.
11. A tuneable microwave filter as claimed in claim 10, comprising an input matching circuit connected to one resonator and an output matching circuit connected to a different resonator.
12. A tuneable microwave filter as claimed in claim 10 wherein the resistive part of the admittance of the matching circuit varies as $1/f(\theta)$ with $f(\theta)$ increasing with θ across the tuneable band.
13. A tuneable microwave filter as claimed in claim 12, wherein the resistive part of the admittance of the matching circuit varies as $1/\tan \theta$ across the tuneable band.
14. A tuneable microwave filter as claimed in claim 12, wherein $f(\theta)$ is a polynomial in θ .
15. A tuneable microwave filter as claimed in claim 12, wherein $f(\theta)$ is a polynomial in $\tan \theta$.
16. A tuneable microwave filter as claimed in claim 10, when dependent on claim 7, wherein the matching circuit comprises an inductor connected to the resonant body of the resonator and extending out of the resonator cavity.

17. A tuneable microwave filter as claimed in claim 16, wherein the inductance L of the inductor is calculated from

$$F(\theta_1) = F(\theta_2)$$

where

$$F(\theta) = \frac{\tan \theta}{1 + A^2 \theta^2}$$

and θ_1 and θ_2 are the values of the electrical length at spaced apart points of the tuneable band and with a unitary resistive load connected between the inductor and earth; and,

where $A\theta = L\omega$, where $\omega = 2\pi f$, and f is the frequency of the signal.

18. A tuneable microwave filter as claimed in claim 10, when dependent on claim 7, wherein the matching circuit comprises an electrically conducting impedance matching bar arranged within the resonator cavity of the resonator spaced apart from the resonator body and extending from the first end face part way towards the second end face; and, a signal line extending from the impedance matching bar out of the resonator cavity.

19. A tuneable microwave filter as claimed in claim 18, wherein the value of the characteristic impedance Z of the matching bar is calculated from

$$F(\theta_1) = F(\theta_2)$$

where

$$F(\theta) = \frac{\tan \theta}{1 + Z^2 \tan^2 \theta}$$

and θ_1 and θ_2 are the values of the electrical length at spaced apart points of the tuneable band with a unitary resistive load connected between the signal line and earth.

20. A tuneable microwave filter as claimed in any one of claims 1 to 9, comprising a plurality of groups of resonators, the resonators within each group being electrically coupled together;

an input matching circuit connected to a resonator of each group; and
 an output matching circuit connected to a different resonator of each group.

21. A tuneable microwave multiplexer comprising
 a plurality of tuneable microwave filters as claimed in any one of claims 1 to 9; and,
 a matching circuit connected to a resonator of each filter.
22. A tuneable microwave multiplexer as claimed in claim 21, wherein the real part of the admittance of the matching circuit varies substantially as $1/\tan \theta$ across the tuneable band.
23. A tuneable microwave multiplexer as claimed in either of claims 21 or 22, wherein the matching circuit comprises a plurality of inductors,
 the inductors being arranged such that each filter has one inductor connected to the resonator body of one of its resonators, the inductors being connected together at a common node
24. A tuneable microwave multiplexer as claimed in claim 23 wherein the multiplexer is a diplexer and wherein the inductance L of each inductor is calculated from

$$F(\theta_1) = F(\theta_2)$$

where

$$F(\theta) = \frac{\tan \theta}{4 + A^2 \theta^2}$$

and θ_1 and θ_2 are the values of the electrical length at spaced apart points of the tuneable band with a unitary resistive load connected between the common node and earth; and $A\theta = L\omega$, where $\omega = 2\pi f$, where f is the frequency of the signal.

25. A tuneable microwave multiplexer as claimed in either of claims 21 or 22, wherein each of the resonators to which the matching circuit is connected share a common resonant cavity, the matching circuit comprising an electrically conducting matching bar arranged in the resonator cavity and spaced apart from the resonator bodies and extending from the first end face part way to the second end face; and, a signal line extending from the matching bar out of the resonator cavity.

26. A tuneable microwave multiplexer as claimed in claim 25, wherein the multiplexer is a diplexer and the value of the characteristic impedance Z of the matching is calculated from

$$F(\theta_1) = F(\theta_2)$$

where

$$F(\theta) = \frac{\tan \theta}{4 + Z^2 \tan^2 \theta}$$

and θ_1 and θ_2 are the values of the electrical length at spaced apart points of the tuneable band and where a unitary resistive load is connected between the signal line and earth.

27. A tuneable microwave multiplexer as claimed in any one of claims 21 to 26, further comprising a plurality of output matching circuits, the number of output matching circuits being equal to the number of filters, a resonator of each filter having an output matching circuit connected thereto.

28. A tuneable microwave filter substantially as hereinbefore described.

29. A tuneable microwave diplexer substantially as hereinbefore described.

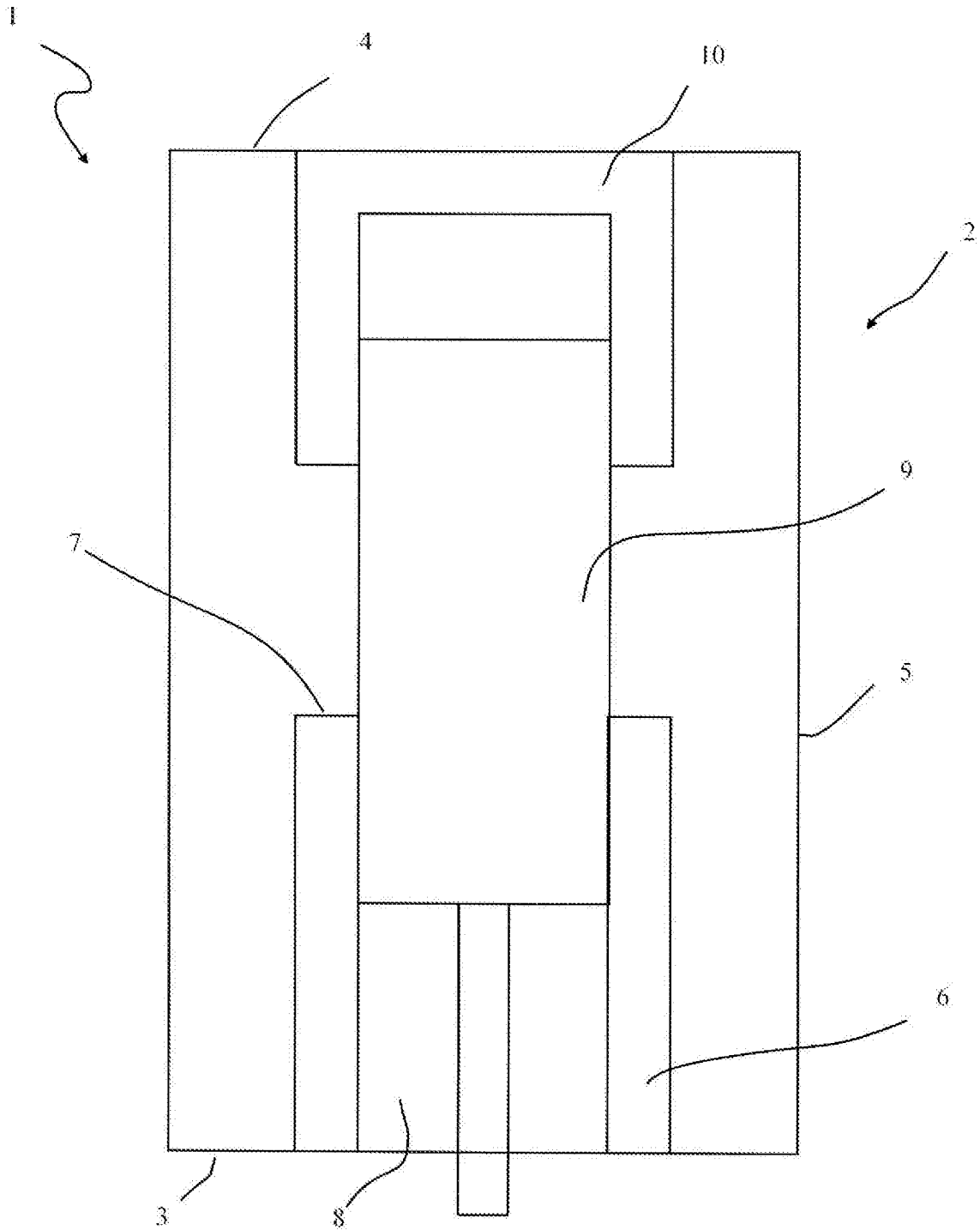


Figure 1

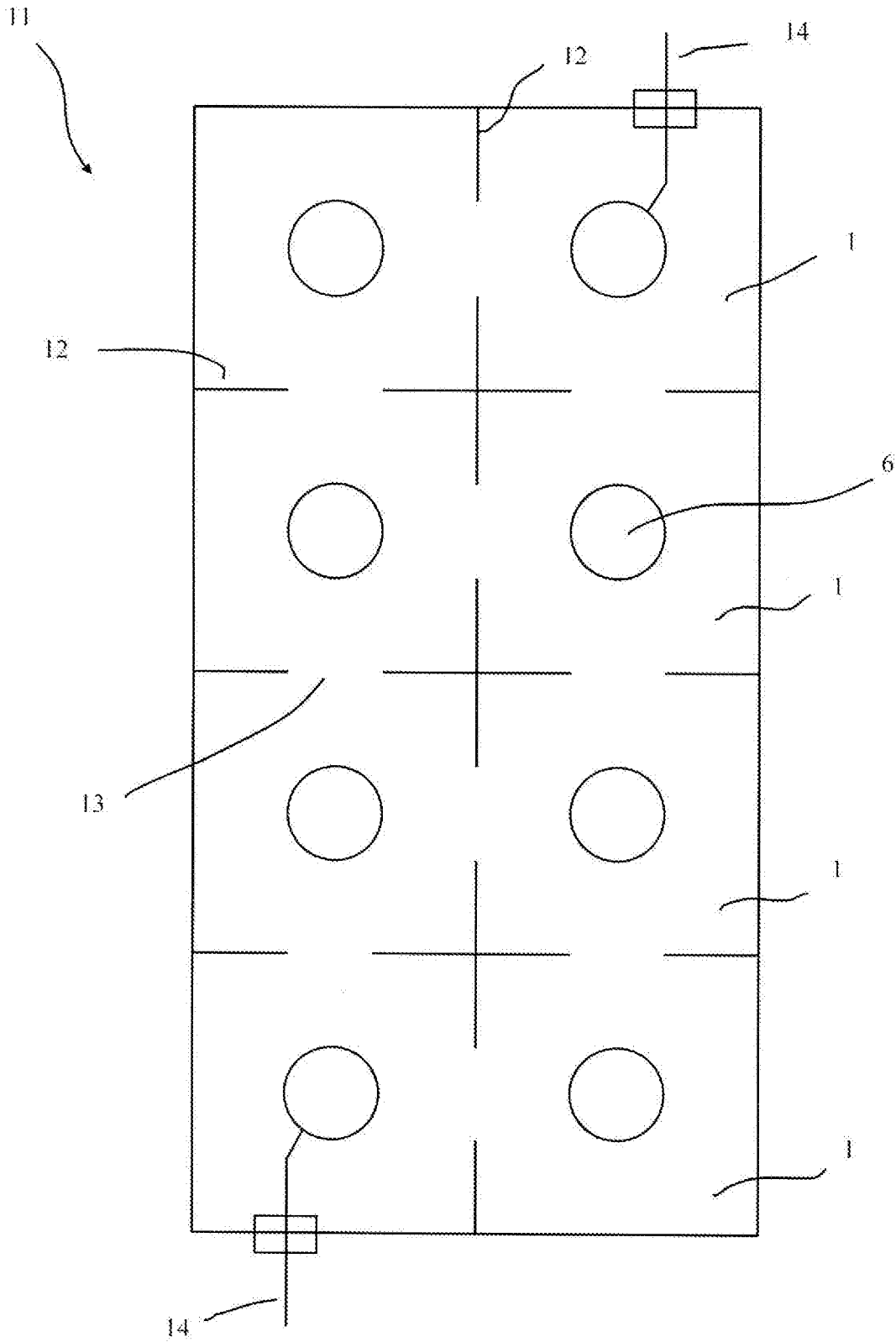


Figure 2a

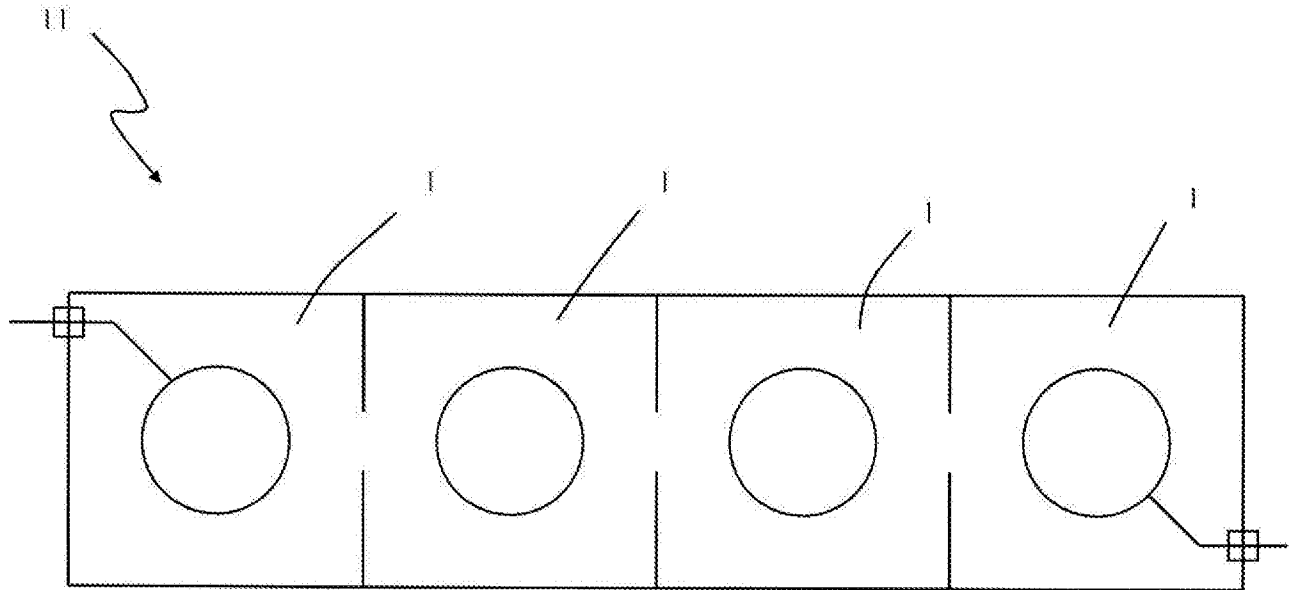


Figure 2b

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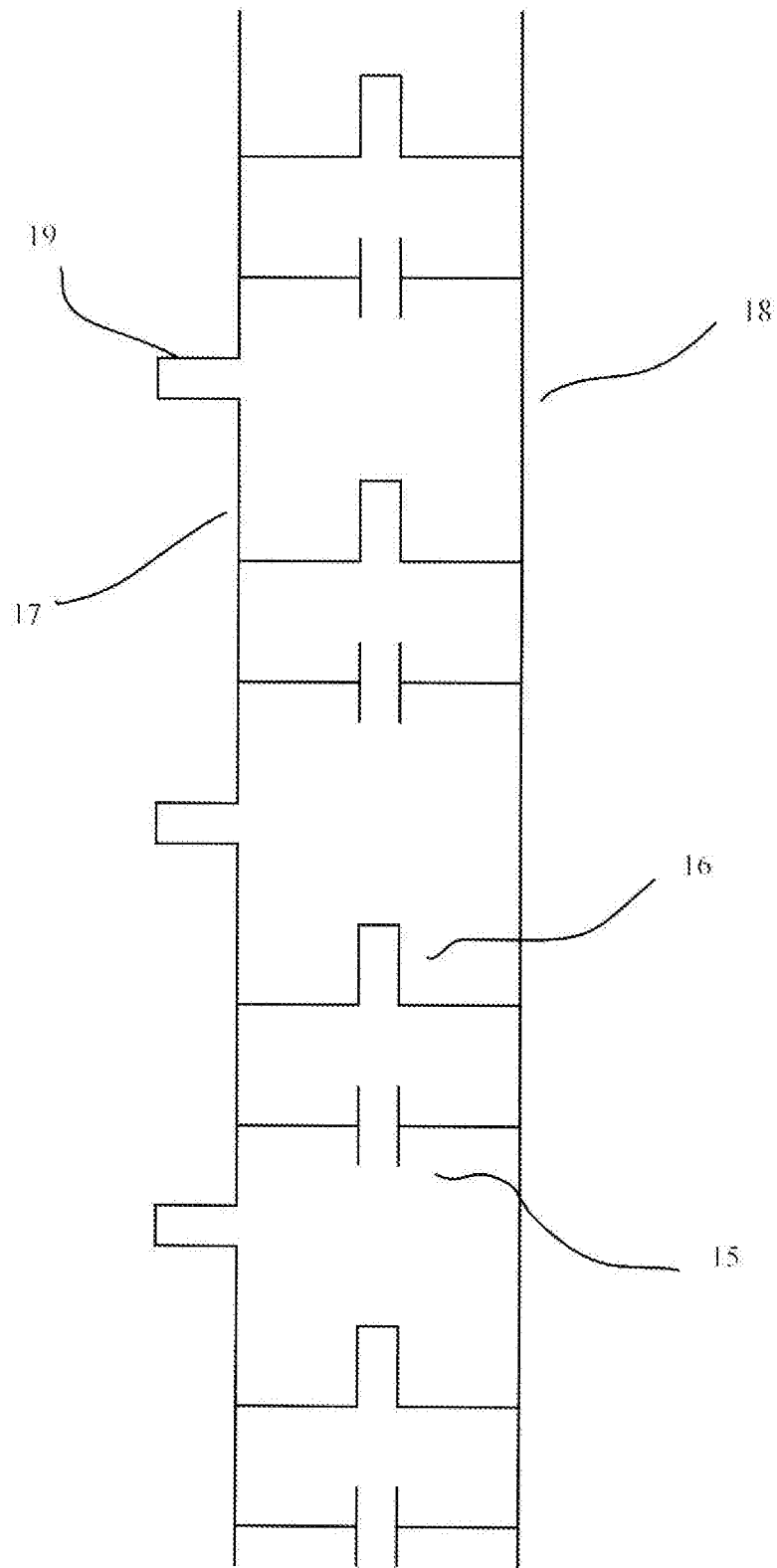


Figure 3

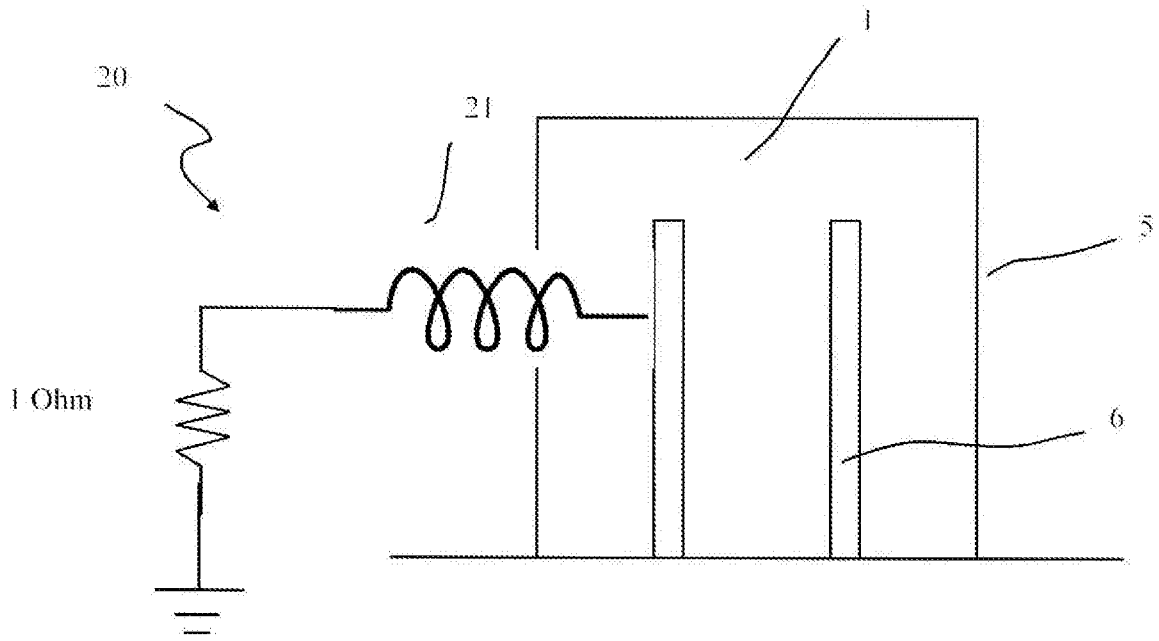


Figure 4(a)

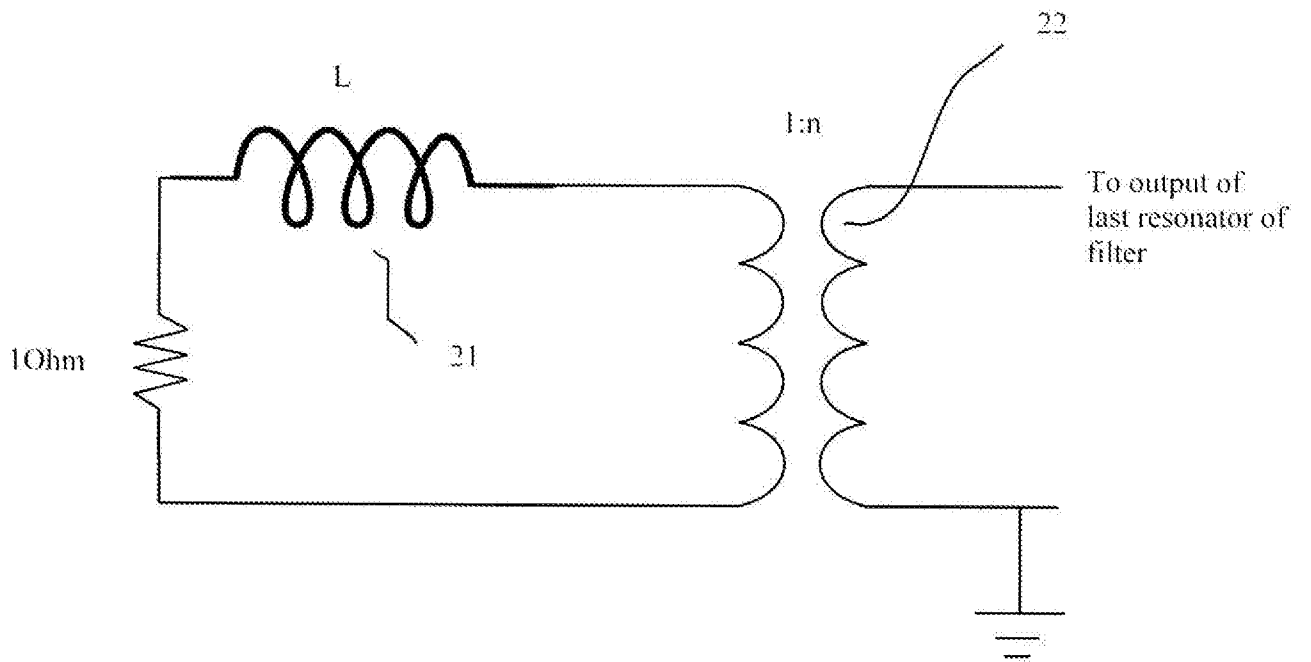


Figure 4(b)

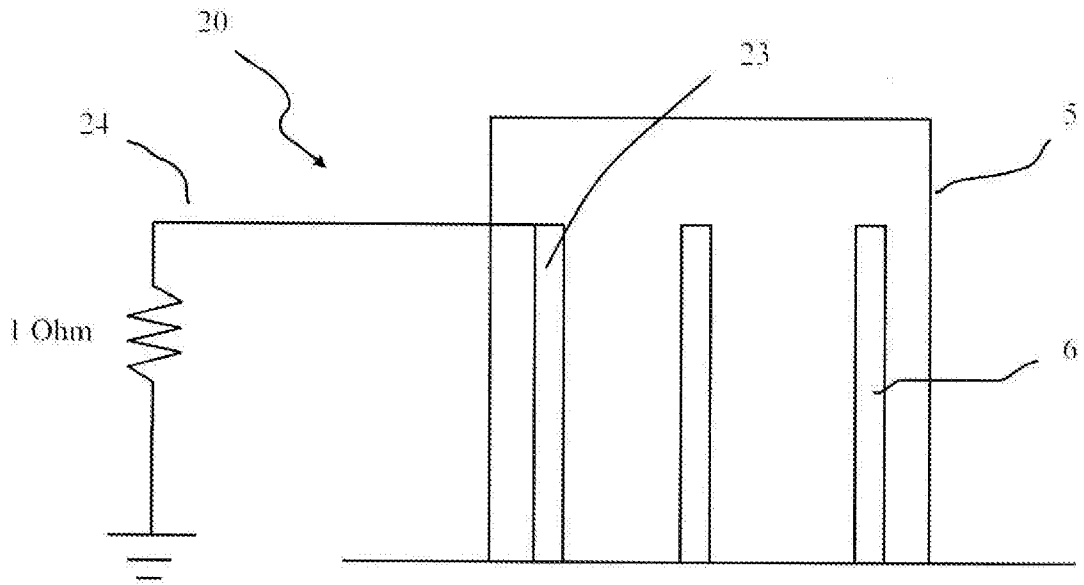


Figure 5 (a)

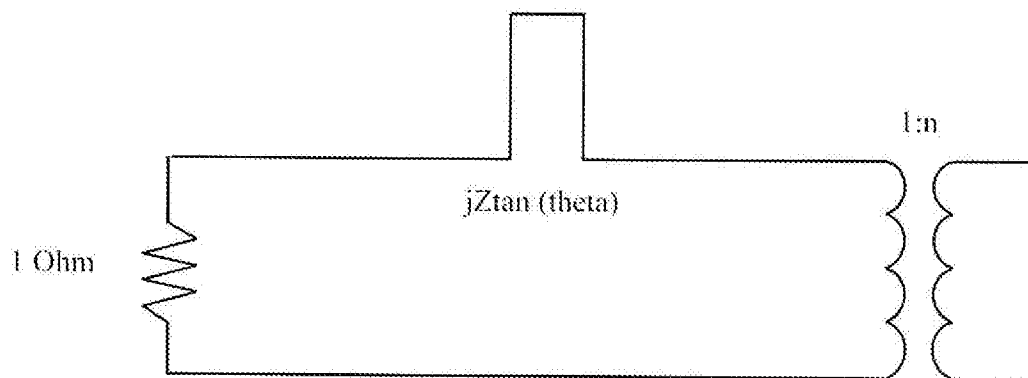


Figure 5 (b)

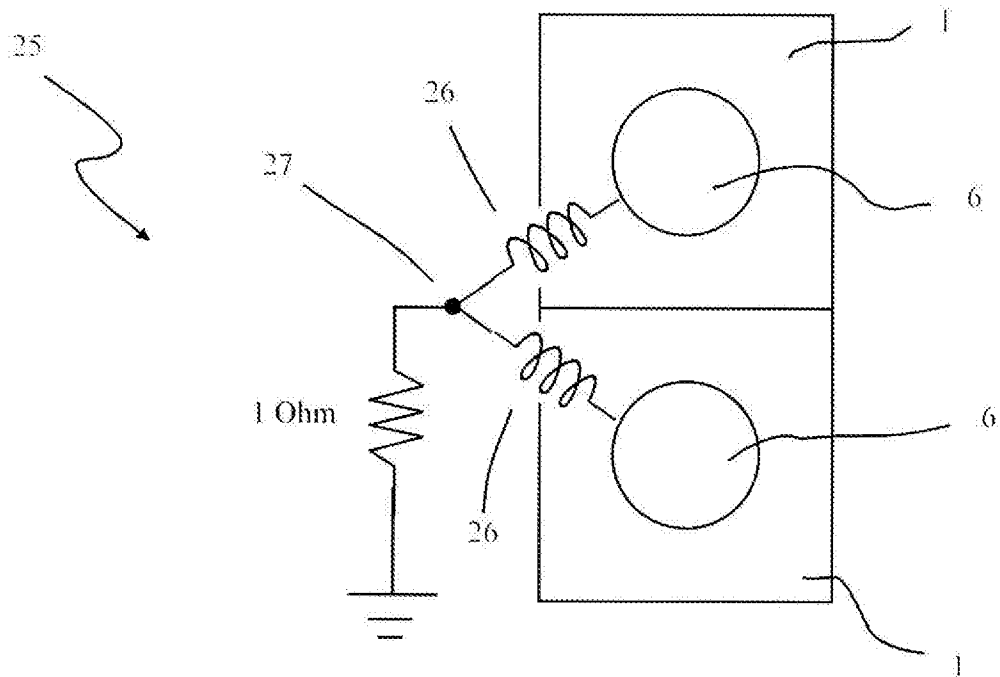


Figure 6(a)

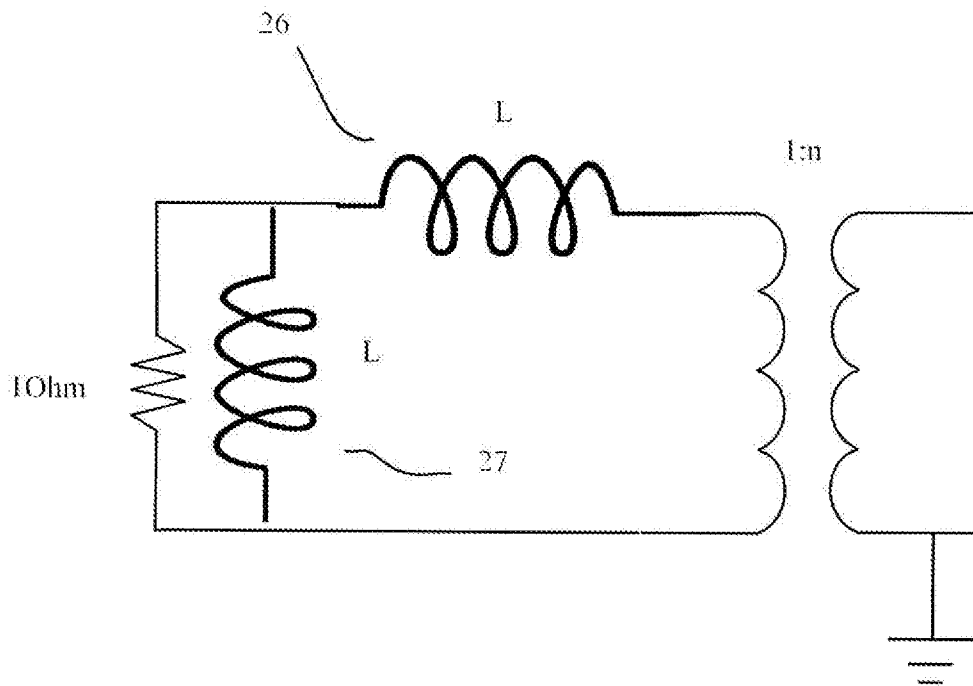


Figure 6(b)

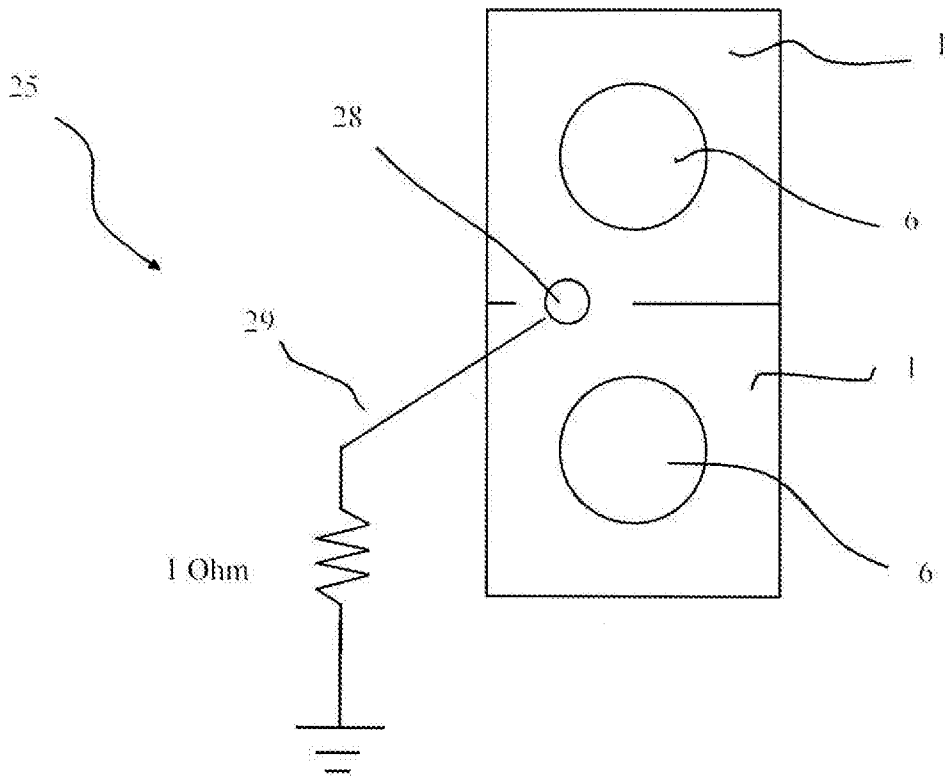


Figure 7(a)

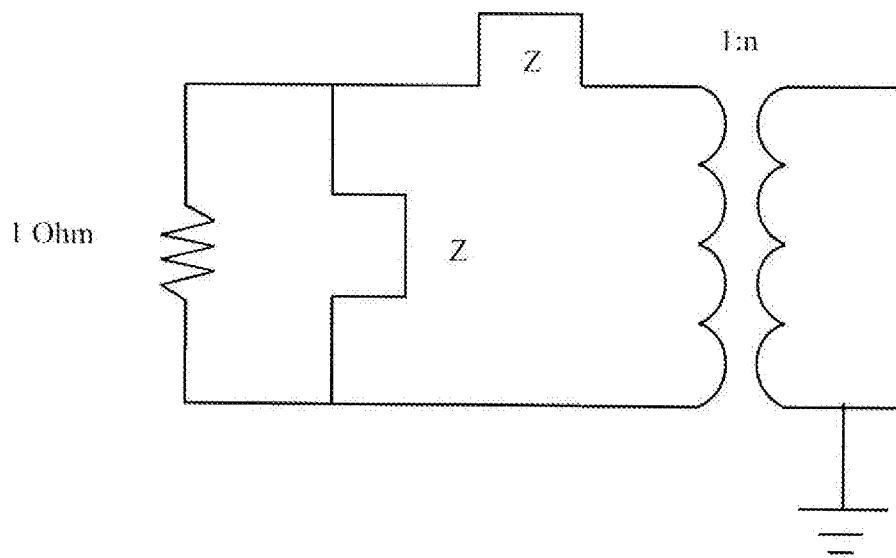


Figure 7(b)

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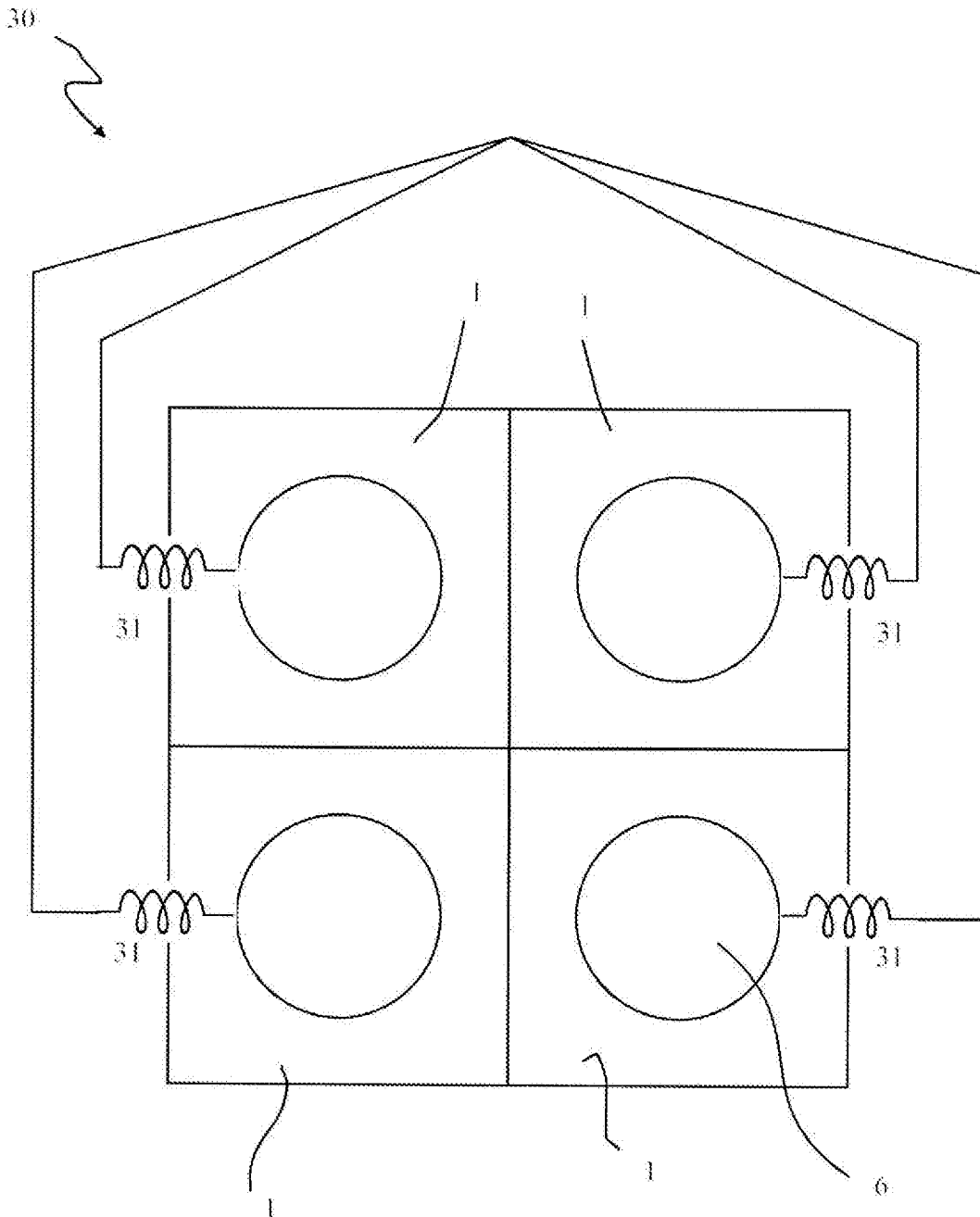


Figure 8

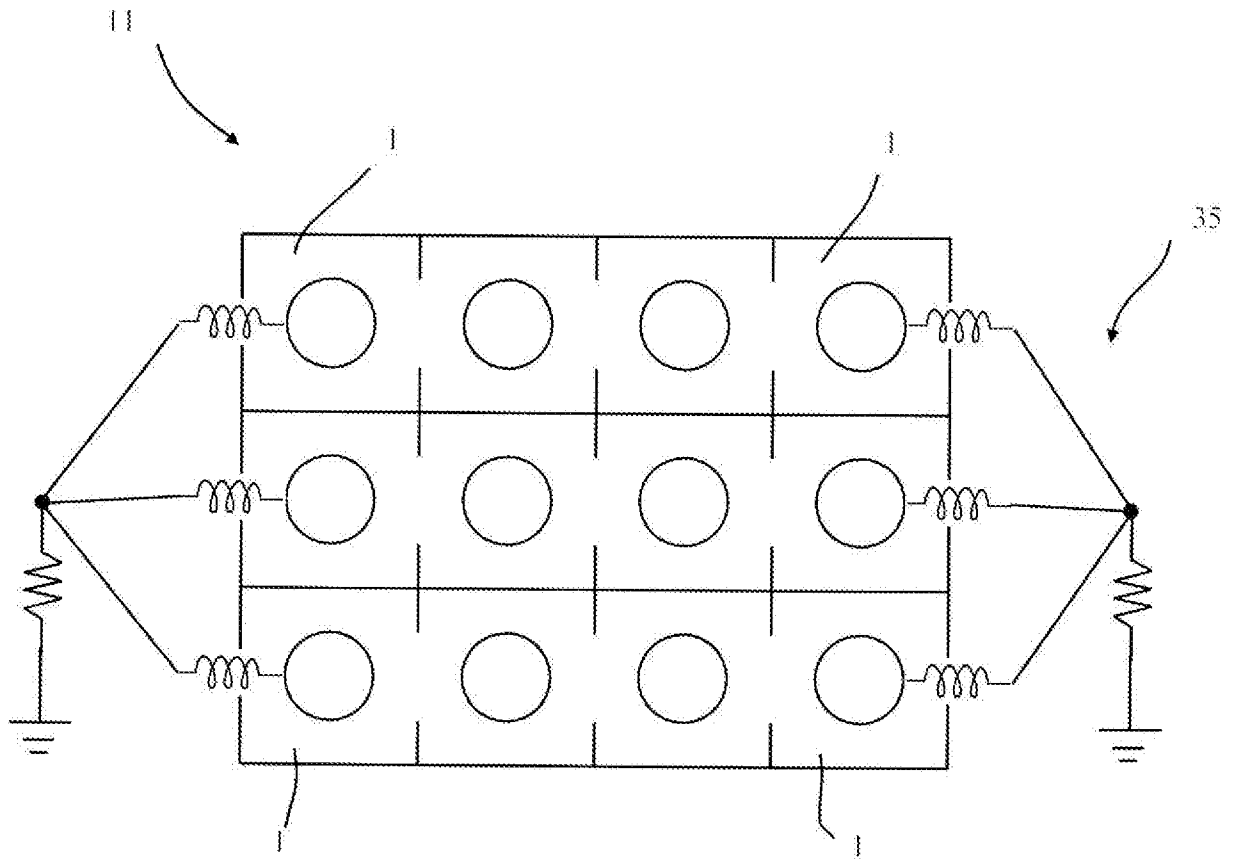


Figure 10