

(19)



Europäisches Patentamt

European Patent Office

Office européen des brevets



(11)

EP 0 759 643 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
26.02.1997 Bulletin 1997/09

(51) Int Cl.⁶: **H01P 1/205**

(21) Application number: **96306059.5**

(22) Date of filing: **20.08.1996**

(84) Designated Contracting States:
CH DE DK FR GB IT LI SE

• **Loukkola, Jukka**
90440 Kempele (FI)

(30) Priority: **23.08.1995 FI 953962**

(74) Representative: **Slingsby, Philip Roy et al**
NOKIA MOBILE PHONES,
Patent Department,
St. Georges Court,
St. Georges Road,
9 High Street
Camberley, Surrey GU15 3QZ (GB)

(71) Applicant: **LK-PRODUCTS OY**
SF-90440 Kempele (FI)

(72) Inventors:
 • **Ala-Kojola, Jouni**
90440 Kempele (FI)

(54) **Mircowave filter**

(57) The invention relates to a radio frequency filter based on transmission line resonators and having adjustable frequency response characteristics. The invention relates particularly to a bandpass filter in which the transmission zero, or the highly-attenuated frequency area limiting the pass band can be switched between at least two frequency values. To affect the coupling between the transmission line resonators, an electrically

conductive regulating element and a switch are placed in their vicinity, and said regulating element can be connected to ground by means of said switch, thereby affecting either the capacitive or the inductive component of the coupling, depending on the location of the regulating element. Stepless adjustment can be realized by replacing the switch with a reactive component, advantageously a capacitance diode.

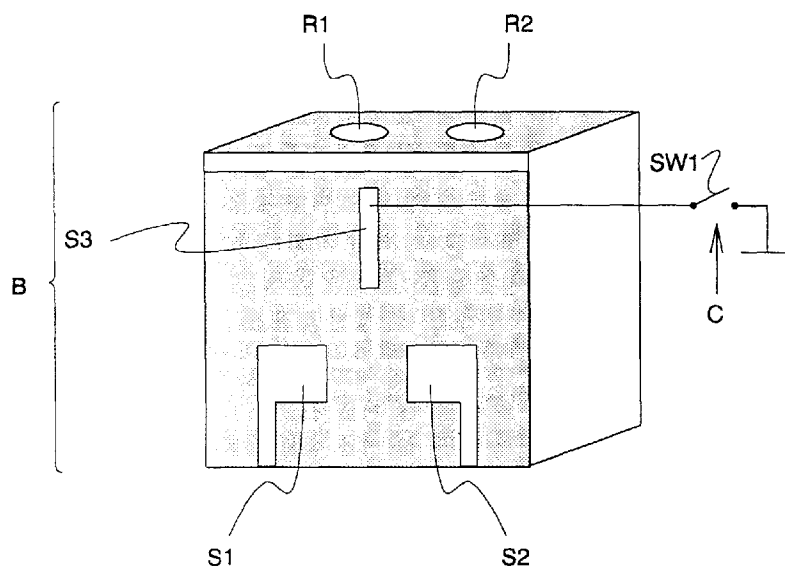


Fig. 2

Description

The present invention relates to a radio frequency filter comprising a first transmission line resonator and a second transmission line resonator.

Radio devices generally employ filters which are based on transmission line resonators with electromagnetic couplings between them. Between transmission line resonators coupled through an insulating material by means of electromagnetic fields there usually is both a capacitive and an inductive coupling, which together result in a certain frequency response in the filter constituted by the resonators. In particular, the capacitive and inductive couplings together cause in the frequency response of a bandpass filter a so-called transmission zero, or a certain relatively narrow frequency area which limits the pass band of the filter on one side and in which the attenuation of the filter is particularly high. In a filter based on so-called $\lambda/4$ resonators, ie. in which the electrical length of the resonators is substantially one fourth of the wavelength corresponding to the nominal frequency of the filter, the location of said transmission zero with respect to the pass band of the filter depends on the interrelation of the strengths of the capacitive and inductive couplings between the resonators. If the capacitive coupling is dominant, the transmission zero is located below the pass band, and if the inductive coupling is dominant, the transmission zero is located above the pass band.

The strength of the coupling between two resonators depends on the combined effect of the capacitive and inductive coupling between them. The phase difference between the capacitive and inductive coupling is 180 degrees, which means they have opposite signs and therefore tend to cancel each other. Because of this, both couplings in a bandpass filter can be made high enough for the zero of the frequency response to be located at a suitable distance from the pass band while the combined effect is small enough to realize the bandpass characteristic of the filter. If the absolute values of the inductive and capacitive couplings are identical, the total coupling between the resonators is zero, in which case they cannot be used to realize a bandpass filter.

As known, it is possible to influence the strength of an inductive and capacitive coupling by choosing suitable dimensions for the filter structure. A method is known from U.S. Patent No. 5,239,279 in which the couplings are influenced by creating in the vicinity of the resonators strip-like areas of a conducting material, which, depending on their location and manner of implementation, either strengthen or weaken the electric and/or magnetic field which acts as a medium of coupling between the resonators.

In the prior art solutions there is a drawback that once a filter has been manufactured according to certain dimensions and possibly fine-tuned by mechanically working the strip elements affecting the coupling, its frequency response cannot be altered during use, at least

not in a simple manner.

According to the present invention there is provided a radio frequency filter comprising a first transmission line resonator and a second transmission line resonator and an electromagnetic coupling between the first and second transmission line resonators, which coupling comprises a capacitive and inductive portion, characterized in that the radio frequency filter includes means for changing the capacitive and/or inductive portion of said coupling to affect the frequency response of the radio frequency filter, said means comprising an electrically conductive element and means for changing the potential of the conductive element.

Advantageously the potential of the conductive element is changed on the basis of a signal, ideally an electric signal.

Exemplary embodiments in accordance with the invention may provide a radio frequency filter based on transmission line resonators the frequency response of which can be changed electrically. Also exemplary embodiments in accordance with the invention may provide a bandpass filter operating at radio frequencies in which the location on the frequency axis of the frequency response zero limiting the pass band can be altered electrically. Furthermore exemplary embodiments in accordance with the invention may provide a filter as described above in which the frequency response adjustment is realized in a simple manner.

Embodiments in accordance with the invention may be achieved by adding an electrically controllable switch or an electrically adjustable reactive component between a prior-art passive regulating element located in the vicinity of the resonators and the ground potential of the filter to change the reactance between said regulating element and the filter ground plane.

Embodiments in accordance with the invention may relate to the adjustment of the frequency response of a filter, based on transmission line resonators and operating at radio frequencies. In a filter in accordance with the invention, the adjustment may be directed especially to the location on the frequency axis of the so-called transmission zero, or the attenuation peak limiting the pass band of a bandpass filter. In some applications it would be advantageous that the frequency response of the filter, particularly the location of the transmission zero, or the frequency response zero, could be altered using an external control voltage or current.

Embodiments in accordance with the invention may be based on the idea that when examining a prior-art passive regulating element located in the vicinity of resonators, we can see that its regulating characteristics are affected, in addition to its location and conductivity properties, by its potential which can be electrically altered using the method in accordance with the invention. In practice, this means that an electrically controlled switch, advantageously a PIN diode, field-effect transistor or other voltage- and/or current-controlled semiconductor switch known to one skilled in the art or an elec-

trically variable reactive element, advantageously a capacitance diode, or a varactor, may be placed between said regulating element, which can be e.g. a metal strip, and the ground potential. A semiconductor switch made of gallium arsenide (GaAs) is fast and reliable, whereby the frequency response of a filter can be changed very quickly between two different states. Adding more regulating elements and more switches one can implement adjustment arrangements with more steps. By placing a variable reactive component, such as a capacitance diode, between the regulating element and the ground potential of the filter instead of a switch, one can have an arrangement in which the frequency response of the filter can be steplessly adjusted by means of a control voltage and/or current.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which

- Fig. 1a illustrates diagrammatically a filter in accordance with the invention,
- Fig. 1b is a circuit diagram of a filter in accordance with the invention,
- Fig. 2 shows an advantageous embodiment in accordance with the invention,
- Fig. 3 shows a second advantageous embodiment in accordance with the invention,
- Fig. 4 is a graph showing qualitatively the frequency response characteristics achieved with the embodiments shown in Figs. 2 and 3,
- Fig. 5 is a graph showing qualitatively the frequency response characteristics achieved with a third embodiment in accordance with the invention,
- Fig. 6a is a circuit diagram of a fourth embodiment in accordance with the invention,
- Fig. 6b is a circuit diagram of a fifth embodiment in accordance with the invention,
- Fig. 7 is a circuit diagram of a sixth embodiment in accordance with the invention, and
- Fig. 8 is a graph showing the frequency response characteristics achieved with the embodiment shown in Fig. 7.

According to Fig. 1a, there is a coupling K between two transmission line resonators R1, R2, which can be influenced with a control signal C. The practical implementation of Fig. 1a can be realized in many ways by embodiments in accordance with the present invention. Fig. 1b shows a circuit diagram of an advantageous embodiment wherein an electrically conducting regulating element S3, which affects the coupling between resonators R1 and R2, can be grounded by means of switch SW1 when desired. Next, we will discuss the technical implementation of this embodiment.

Fig. 2 shows a dielectric filter made of one piece (so-called monoblock) comprising two transmission line resonators R1, R2. The manufacture of this kind of filter

will not be described since it is known to one skilled in the art. The dielectric block B which constitutes the body of the filter is advantageously of ceramic material, and the resonators R1 and R2 are cylindrical holes in the block, extending from the lower surface of the block to the upper surface (the top surface in the figure) of the block, and the walls of the holes are coated with a conductive material. Most of the side surfaces of the block B are also coated with a conductive material, which is indicated by white colour in the figure. The front side shown in Fig. 2 is not entirely coated, but strip-like conductive patterns S1, S2 and S3 are formed on it. The top side shown in Fig. 2 is uncoated. The uncoated ceramic material is shown as gray in the figure. The two widest conductive patterns S1 and S2 constitute the input and output port of the filter, ie. they provide the coupling interface to the resonators R1 and R2. The third conductive pattern S3 is a regulating element known in the prior art which, as such, strengthens in a known manner the capacitive coupling between the resonators R1 and R2. The alternative embodiment shown in Fig. 3 is also a dielectric filter which differs from the embodiment in Fig. 2 in that there the front side is coated with a conductive material and the conductive patterns S1, S2 and S3 are formed on the top surface which is uncoated except for the conductive patterns.

In accordance with the invention, the embodiments shown in Figs. 1b, 2 and 3 include a switch SW1, which is shown in the figures only diagrammatically, but which is realized by a PIN diode, field-effect transistor or other semiconductor switch in a manner which is known to one skilled in the art. In the implementation, the switch component is coupled e.g. by soldering to connection pads (not shown in the figures) which are formed on the surface of the dielectric block B in the same way as the other conductive patterns S1, S2 and S3. Also a control signal C, which opens and closes the switch SW1, is coupled to said switch component by means of strip lines (not shown) formed on the surface of the dielectric.

In the position shown in Figs. 1b, 2 and 3, the switch SW1 is open, whereby there is no significant effect on the operation of the filter. As the switch SW1 is closed it couples the regulating element S3 to the ground potential, whereby the grounded regulating element S3 weakens the capacitive coupling between the resonators R1 and R2. According to the principle discussed above in conjunction with the description of the prior art, weakening the capacitive coupling strengthens the relative portion of the inductive coupling, which in turn shifts the transmission zero of the frequency response of the filter upwards on the frequency axis. Fig. 4 shows a qualitative representation of a real frequency response measurement, in which the frequency response of a filter according to the embodiment shown in Fig. 2 is measured with the switch SW1 open (solid line) and closed (dashed line). Fig. 4 shows clearly that closing the switch SW1, ie. grounding the regulating element S3, shifts the transmission zero in the frequency re-

sponse upwards on the frequency axis, or, in Fig. 4, to the right, from position O1 to position O1'. In addition, the pass band of the filter, or the frequency area with the lowest attenuation, becomes somewhat narrower when the switch SW1 is closed, because the absolute value of the combined effect of the capacitive and inductive coupling becomes smaller.

Fig. 5 is a simplified illustration of a frequency response measurement for the frequency response of a third embodiment of the invention. Since the transmission zero is in this case above the pass band, ie. on the right-hand side in the figure, the inductive coupling is dominant in a filter according to the third embodiment. It is clear to one skilled in the art how to implement a filter the frequency response of which qualitatively corresponds to the solid-line curve using known methods discussed above in conjunction with the description of the prior art, advantageously a regulating element made of a conductive material. When such a regulating element is grounded according to the invention, the relative portion of the inductive coupling increases compared to the capacitive coupling, whereby the transmission zero is shifted upwards on the frequency axis, ie. in Fig. 5, to the right, from position O2 to position O2'. At the same time the pass band of the filter becomes somewhat wider, because the absolute value of the combined effect of the capacitive and inductive coupling becomes greater.

Above it was discussed how to switch the transmission zero of a bandpass filter between two frequency values. In some cases it is advantageous that the location of the transmission zero can be switched between more values. Then, more regulating elements and corresponding ground switches can be included in the filter, thereby broadening the adjustment range respectively. This fourth embodiment of the invention is shown as a circuit diagram in Fig. 6a including regulating elements S3 and S4, which advantageously are strip lines, and corresponding switches SW1 and SW2. According to their location shown in Fig. 6a the regulating element S3 primarily affects the capacitive coupling between the resonators R1 and R2, and the regulating element S4 primarily affects the inductive coupling between the resonators R1 and R2. The switches are controlled by separate control signals C and C'. A further alternative is to use, instead of the aforementioned simple two-state switch SW1, a switch SW3 with three or more states which is included in the fifth embodiment of the invention as shown in the circuit diagram of Fig. 6b. The implementation of such a switch using e.g. PIN diodes is known to a person skilled in the art. Advantageously, the switch SW3 could be open in its first state, connect the regulating element S3 directly to the ground in the second state and, in the third state, ground the regulating element S3 through a transmission line SL1 which advantageously could be a strip line similar to the other strip lines in the filter structure. Grounding through a transmission line SL1 would affect the resonance char-

acteristics of the regulating element S3 differently than direct grounding, whereby the effect on the frequency response would be different. Various other embodiments may be realised within the scope of the inventive idea disclosed here.

The above description concerned switching the transmission zero in the frequency response of a bandpass filter between two or more discrete frequency values. In some cases it is advantageous that the location on the frequency axis of the transmission zero can be switched steplessly within a frequency range limited by certain limit values. Such a coupling is implemented by replacing the switch SW1 mentioned above with a reactive component, advantageously a capacitance diode, or varactor D controlled with a voltage and/or current signal, as shown in the circuit diagram of Fig. 7 illustrating a sixth embodiment of the invention. The reactance of the capacitance diode can be steplessly adjusted by changing the voltage serving as control signal C". Fig. 8 is a simplified representation of a frequency response measurement in which the frequency response of a filter according to the embodiment shown in Fig. 7 is measured with three different values of the control voltage C". Each curve represents a certain value of the control voltage C".

In a bandpass filter in accordance with the invention the shifting of the transmission zero is easy and quick, and only one switch and a suitable ground strip line need be added to a filter according to the prior art. The invention is in no way limited to bandpass filters only but it can be generalized to apply to other transmission line resonators when their frequency response characteristics need be electrically changed. Neither is the invention limited to dielectric filters, but it can be applied in all filter structures which are based on transmission line resonators and in which the coupling between the resonators can be affected with a conductive regulating element. Another example of a possible filter structure is a helix filter based on cylindrical coil conductors, known e.g. from Finnish Patent FI-90157, wherein the regulating elements according to the invention can be manufactured as strip lines in the same way as in the embodiments described above. Filters according to the invention can be advantageously used in small radio communication devices, such as mobile phones.

Claims

1. A radio frequency filter comprising a first transmission line resonator (R1) and a second transmission line resonator (R2) and an electromagnetic coupling (K) between the first and second transmission line resonators, which coupling comprises a capacitive and inductive portion, **characterized** in that the radio frequency filter includes means (S3; S4; SW1; SW2; SW3; SL1; D) for changing the capacitive and/or inductive portion of said coupling (K) to affect

the frequency response of the radio frequency filter, said means comprising an electrically conductive element (S3; S4) and means (SW1; SW2; SW3; D) for changing the potential of the conductive element.

2. The radio frequency filter of claim 1, wherein the filter includes an electrically conductive first regulating element (S3) and first switching means (SW1; SW3) to change the potential of said first regulating element (S3) with an electric signal (C; C") between at least two values in order to affect the frequency response of said radio frequency filter. 10
3. The radio frequency filter of claim 1 or 2, wherein said first switching means include a first switch (SW1) between said first regulating element (S3) and the ground potential, and the switch (SW1) has two states and in the first state the switch is open and in the second state the switch connects said first regulating element (S3) to ground. 20
4. The radio frequency filter of any one of the preceding claims, wherein said first regulating element (S3) is a strip line. 25
5. The radio frequency filter of any one of the preceding claims, wherein said first regulating element (S3) is arranged to affect the electromagnetic coupling between said transmission line resonators when said first regulating element (S3) is not connected to any particular potential. 30
6. The radio frequency filter of claim 1, 2, 4 or 5, wherein the filter includes a transmission line (SL1) for indirect grounding of said first regulating element (S3), and said first switching means include a second switch (SW3) between said regulating element (S3) and the ground potential, and the switch (SW3) has at least three states and in the first state the switch (SW3) is open, in the second state the switch (SW3) connects said first regulating element (S3) directly to the ground, and in the third state the switch (SW3) connects said first regulating element (S3) to the ground via said transmission line (SL1). 45
7. The radio frequency filter of any one of the preceding claims, wherein said first switch (SW1) and second switch (SW3) are PIN diodes or field-effect transistors. 50
8. The radio frequency filter of claim 1, wherein the filter includes an electrically conductive first regulating element (S3) and first reactive means (D) for steplessly changing the potential of said first regulating element (S3) with an electric signal (C") in order to affect the frequency response of said radio frequency filter. 55
9. The radio frequency filter of claim 8, wherein said first reactive means (D) comprises a capacitance diode (D) between said first regulating element (S3) and the ground potential, and said electric signal (C") is a voltage signal arranged to bias said capacitance diode. 5
10. The radio frequency filter of any one of the preceding claims, wherein the filter also includes a second electrically conductive regulating element (S4) to affect said coupling (K), and a second switching means (SW2) to change the potential of said second regulating element with an electric signal (C") between at least two values in order to affect the frequency response characteristics of said radio frequency filter.
11. The radio frequency filter of any one of the preceding claims, wherein the filter is a bandpass filter.

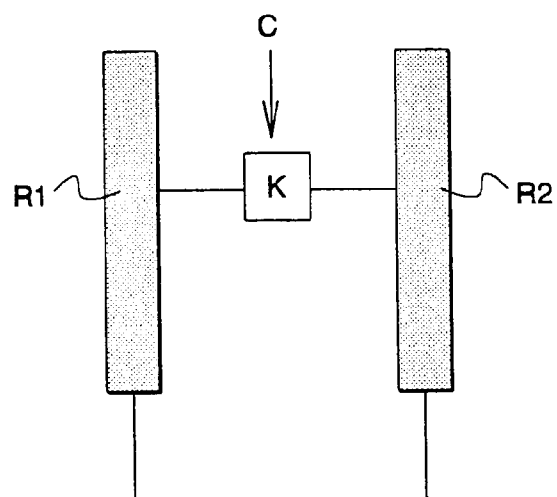


Fig. 1a

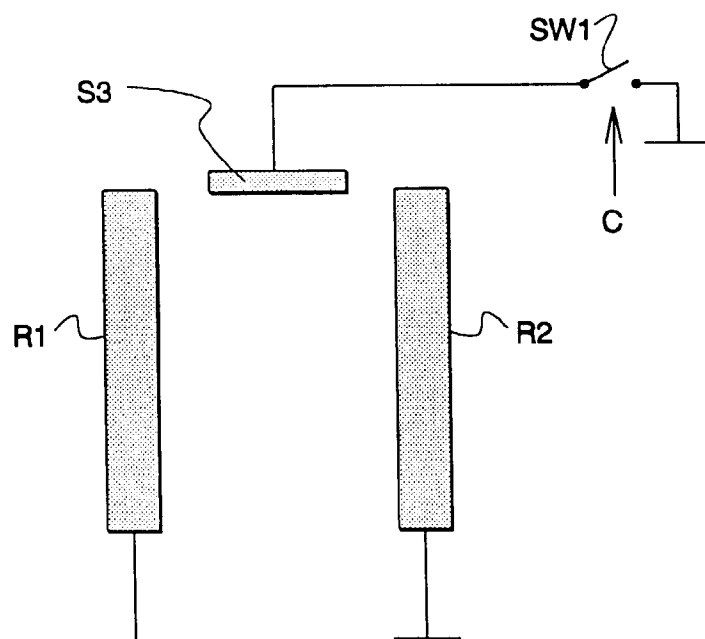


Fig. 1b

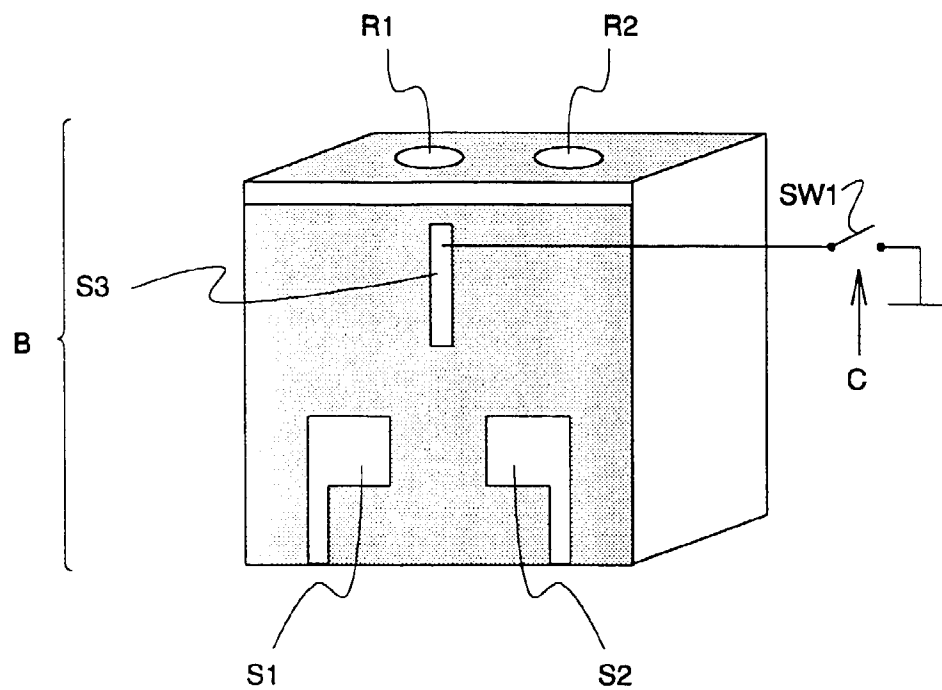


Fig. 2

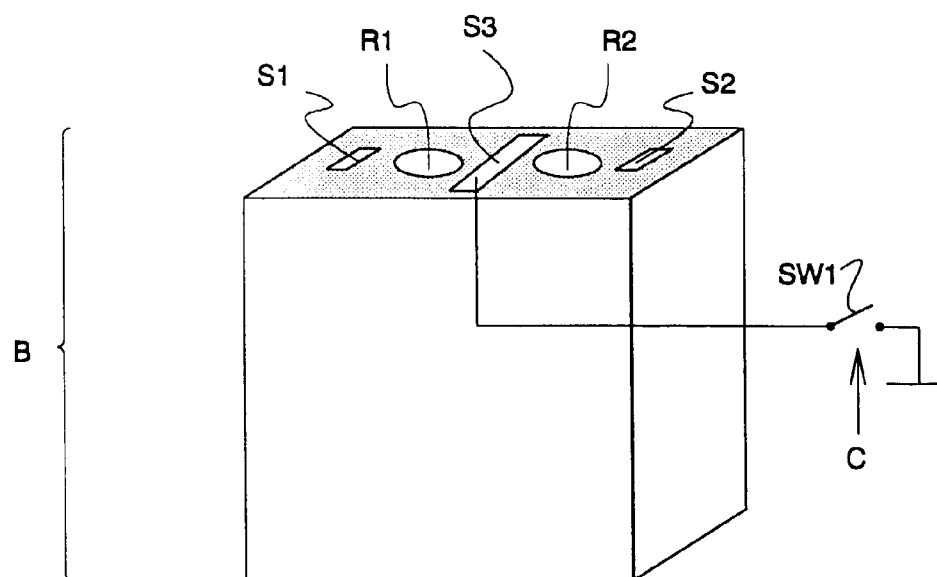


Fig. 3

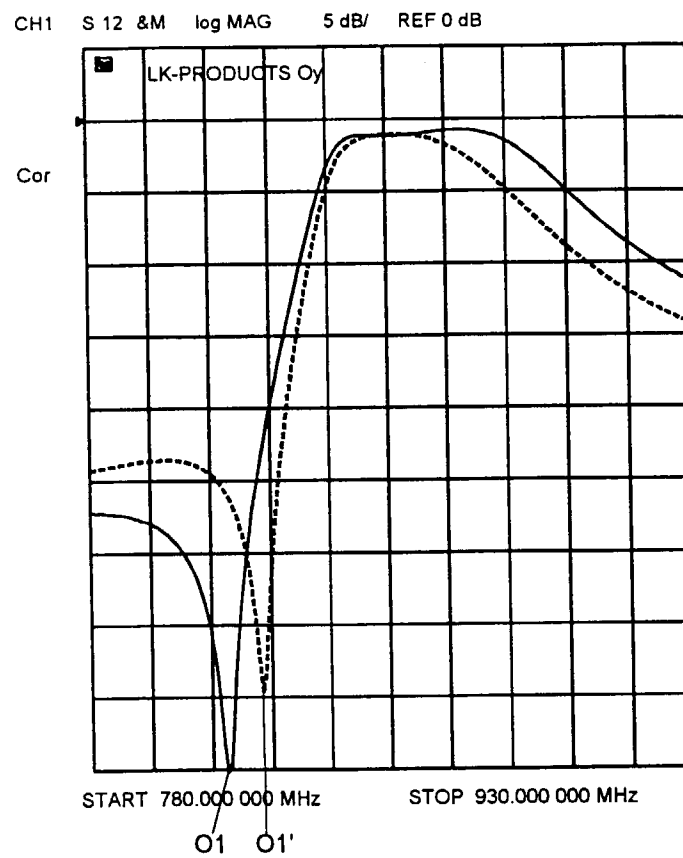


Fig. 4

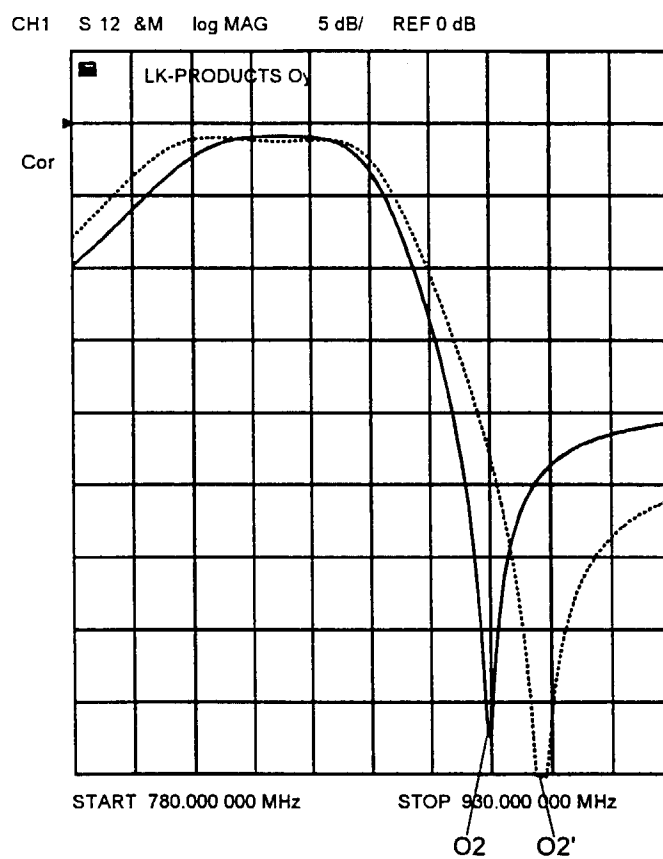


Fig. 5

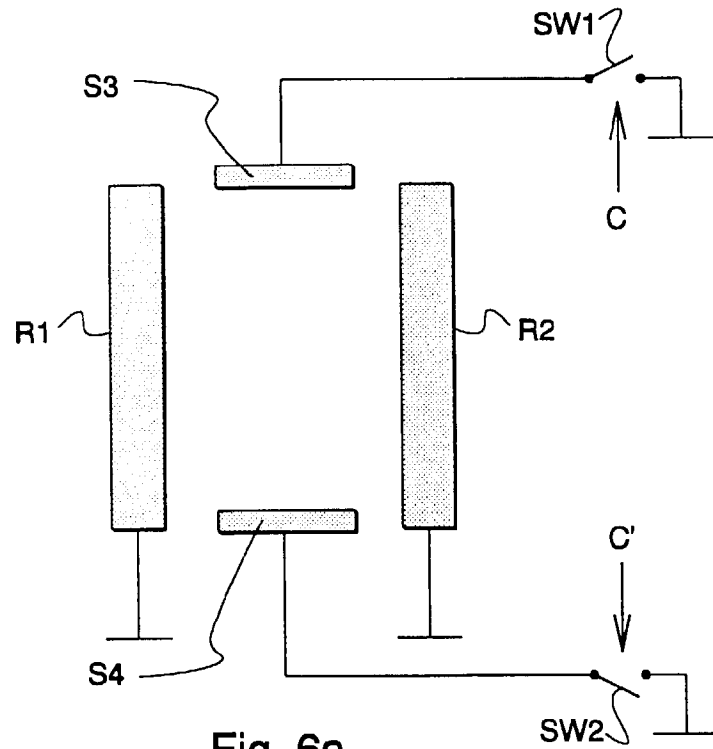


Fig. 6a

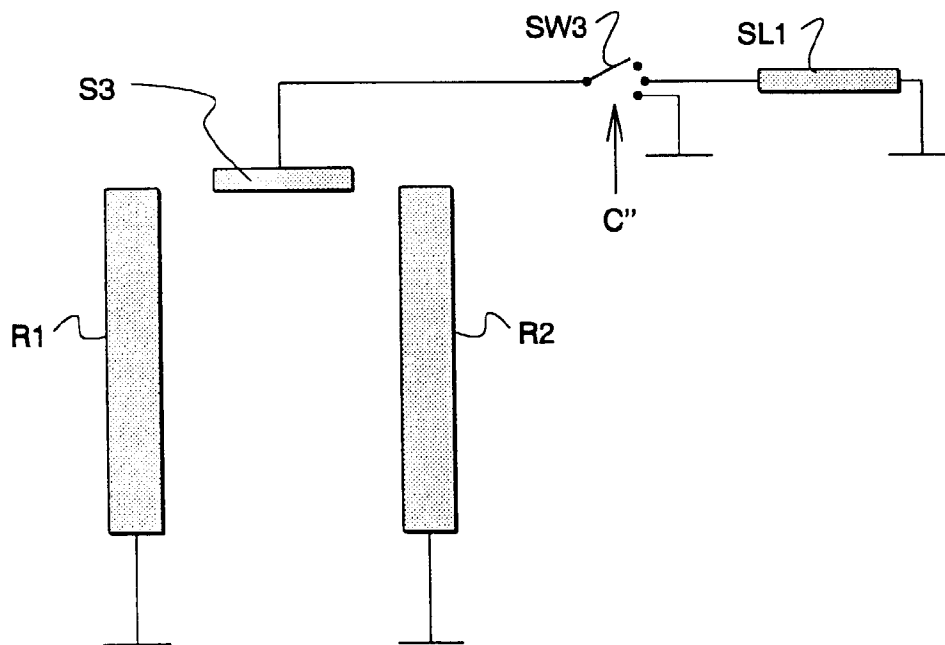


Fig. 6b

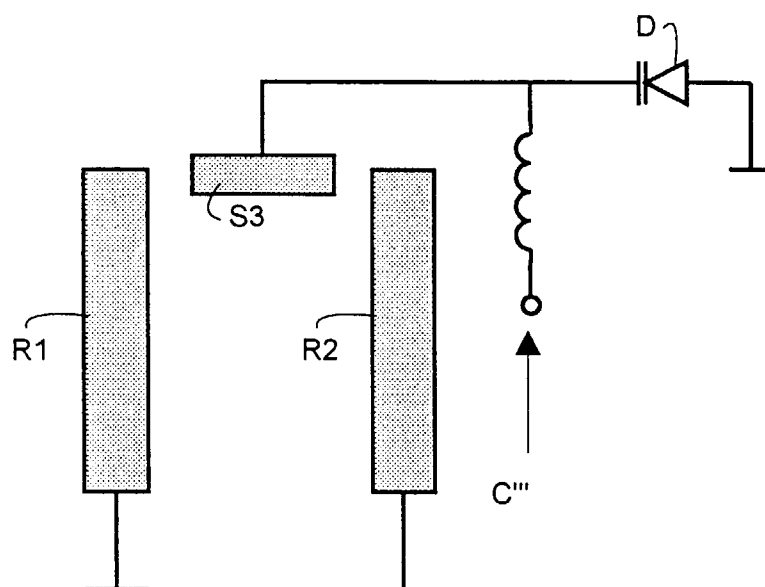


Fig. 7

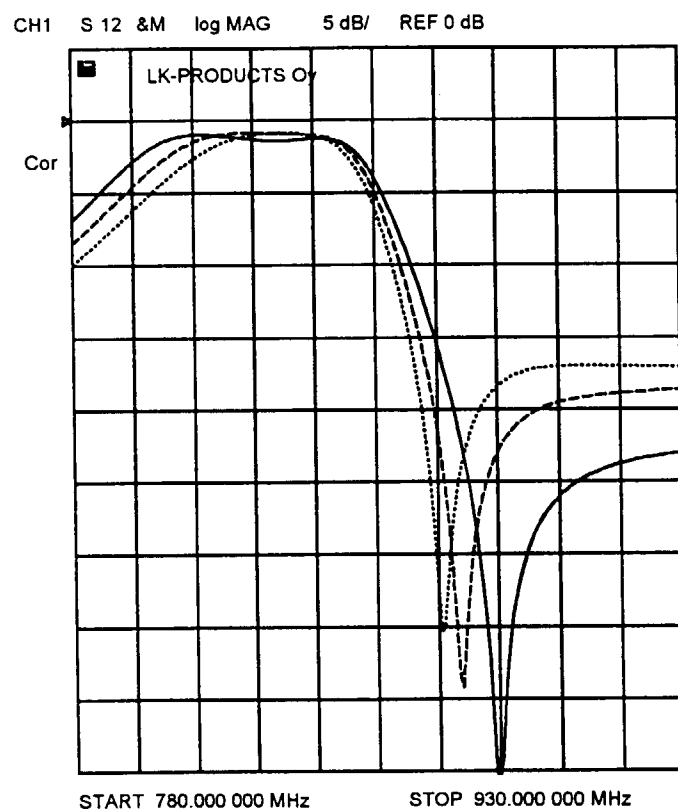


Fig. 8



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 96 30 6059

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	US-A-5 055 808 (WALKER ET AL.) * column 2, line 53 - column 3, line 39; figures 3A,3B *	1-5,7,11	H01P1/205
Y	---	6,8,9	
Y	EP-A-0 520 641 (LK-PRODUCTS OY) * column 5, line 31 - column 6, line 16 * * column 8, line 48 - line 53 * * column 9, line 5 - column 10, line 5; figures 2,3B,7 *	6,8,9	
A	EP-A-0 481 607 (HEWLETT-PACKARD COMPANY) * column 3, line 14 - column 4, line 10; figure 1 * -----	1	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			H01P H03J
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
THE HAGUE		12 November 1996	Den Otter, A
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

EPO FORM 1503 03.92 (P04C01)