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(54) **Tunable cavity filter**

(57) A tunable cavity filter is proposed. The tunable cavity filter comprises a housing which is made of metal forming a cavity. Inside the cavity, a tunable element is attached to one side of the cavity. The tunable element is expandable or compressible using a control voltage, thus, if a control voltage is applied the tunable element expands or compresses itself.

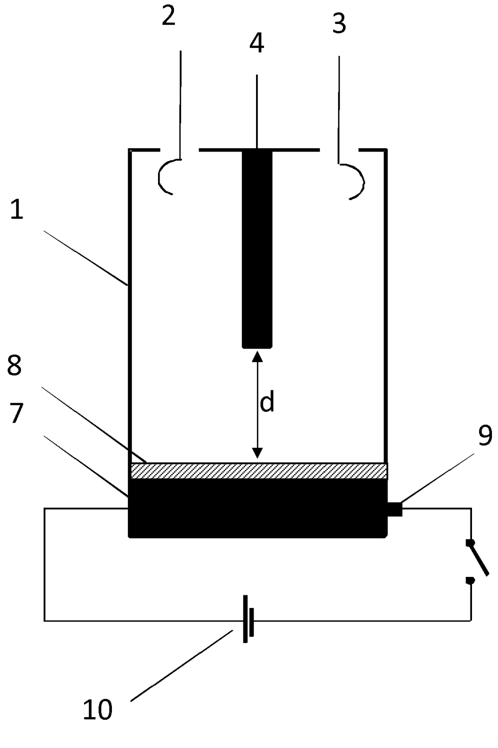

Fig. 2

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Description

FIELD OF THE INVENTION

[0001] The present invention relates to a tunable cavity filter.

BACKGROUND OF THE INVENTION

[0002] This section introduces aspects that may be helpful in facilitating a better understanding of the invention. Accordingly, the statements of this section are to be read in this light and are not to be understood as admission about what is in the prior art.

[0003] Today's mobile radio systems need to cover a wide range of the RF spectrum. Radio transmitter carrier frequencies in 4G and 5G wireless systems vary between 700 MHz and 4 GHz. For frequency filtering, cavity filters are used especially in case of high transmission power. Depending on the frequency band to be selected by the filter, the geometrical dimensions of the filter are defined by physical characteristics. The geometrical dimensions are often tuned in a complex process to meet the required performance.

[0004] Cavity filters may be tuned to the required frequency by mechanical adjustment, e.g. by turning a screw, in order to change the characteristic capacitances. This may be done once during or at the end of the manufacturing process. The adjustment is elaborative and is often not correctable or adjustable later on in the field.

[0005] Using servo/step motor drives to move tuning screws and thus to change the capacitances of the cavity is more flexible but at the cost of higher system complexity, cost and failure probability. Using the piezo-electrical effect by means of a piezoelectric drive suffers from the small deflection of the piezoelectric drive, thus providing only a small tuning range.

SUMMARY OF THE INVENTION

[0006] It is an object of the invention to propose a cavity filter which can easily be tuned over a wide tuning range.

[0007] According to one embodiment, a tunable cavity filter comprises a housing which is made of metal forming a cavity. Inside the cavity, a tunable element is attached to one side of the cavity. "Attached" is to be understood in that the tuning element is directly glued, screwed or otherwise mechanically attached to the inner surface of one side of the cavity. The tunable element is expandable or compressible using a control voltage, thus, if a control voltage is applied, the tunable element expands or compresses itself. The proposed cavity filter is advantageous, because such a structure can be manufactured more easily than other filters known in the prior art. Due to the low mechanical complexity, the manufacturing costs are kept low. The cavity filter is easily tunable, only by applying a control voltage and has a comparably large tuning range. Complex tuning processes as last step of the manufacturing process or during use for fine-tuning of the filter are omitted. In contrast, the filter specification can be adapted and tuned easily by applying the control voltage.

[0008] In one embodiment, the tunable cavity filter further comprises a control input for receiving the control voltage. In one embodiment, the control voltage is permanently applied to the control input. There is no or only few current dissipation through the tunable element when the tuning element does not change its geometry, though the power dissipation is negligible. Only when the control voltage is changed and the geometry of the tuning element changes, the power dissipation is non-negligible. In one embodiment, the control voltage is only applied to the control input during the tuning process and afterwards, the control voltage is switched off. The control input is electrically connected to the tunable element and is for applying the control voltage to the tunable element. In one embodiment, the control voltage is a DC voltage.

[0009] In one embodiment, the tunable cavity filter further comprises a resonator within the cavity. In one embodiment, the resonator is defined by an axial rod attached to one side of the cavity and extending into the cavity. In one embodiment, the axial rod is made of metal or is metalized. The frequency of the cavity filter is amongst others defined by the distance between the end of the axial rod and the tunable element. This is advantageous as this distance is easily adjustable by expanding and compressing the tunable element.

[0010] In one embodiment, a metallization layer is attached to the inner side of the tunable element. Thus, the tunable element is covered by a metallization. Inner side of the tunable element means the side which is not in direct contact with the cavity. Thus, in the embodiment with the axial rod, the inner side of the tunable element is the side which is closest to the axial rod. Metalizing the top of the tunable element has the advantage that a cavity is built which has a variable size by moving the metallization layer up and down by expanding and compressing the tunable element. In one embodiment, the metallization layer on the inner side of the tunable element and the side walls of the cavity are arranged without space between them such that the edges of the metallization layer and the side walls of the cavity are electrically connected.

[0011] In one embodiment, an isolation layer is included between the metallization layer and the inner side of the tunable element. Thus, the metallization layer and the tunable element are not electrically connected. In one embodiment, isolation layers are included between the cavity and the tunable element. Thus the tunable element and the cavity are not electrically connected.

[0012] In one embodiment, the tunable element of the tunable cavity filter is expanded when a suitably polarized control voltage is attached. The tunable element of the tunable cavity filter is compressed when the polarity of the control voltage is reversed. In one embodiment, the degree of expansion and the degree of compression corresponds to the absolute value of the applied control voltage and to the sign of the applied control voltage. In one embodiment, when applying a voltage above a certain threshold, the tunable element is expanded to the maximum value and when applying a voltage below this certain threshold, the tunable element is not expanded at all. Thus, the expansion is performed stepwise.

[0013] In one embodiment, the tunable element is an ionic electroactive polymer. Ionic electroactive polymers are for example ionic gels, ionic polymer-metal composites, stimuli-responsive gels or the like. Ionic electroactive polymers have the advantage that only a low voltage, e. g. a few volts are necessary to control them.

[0014] In one embodiment, the tunable element is made of a dielectric electroactive polymer. Dielectric electroactive polymers are for example ferroelectric polymers, electrostrictive graft polymers, liquid crystalline polymers or the like. Dielectric electroactive polymers are controlled by a voltage which is applied and almost no current is needed. One group of dielectric electroactive polymers are dielectric elastomers, which provide a large strain and are thus dedicated for the use in a cavity filter as tuning element. A large tuning range of the cavity filter is realized with such dielectric elastomers.

[0015] In one embodiment, the tunable element keeps its expansion state when the control voltage is switched off. Thus, only when tuning the cavity filter, a control voltage needs to be applied to the tuning element in order to tune the tuning element. After the cavity filter has been tuned, the control voltage is switched off and no further power needs to be applied. Thus, power is saved and after tuning the cavity filter does not consume any power.

[0016] In one embodiment, the cavity includes an input port and an output port at a first side of the cavity. The resonator defining element is attached to this first side of the cavity and the tunable element is attached to a second side of the cavity which is the side opposite to the first side of the cavity.

[0017] In one embodiment, further metalized tunable elements are attached to further sides of the cavity. Such tunable elements are attached to the side walls of the cavity. This has the advantage that more degrees of freedom are available to fine tune the cavity filter.

[0018] In one embodiment, a duplex filter for a reception path and for a transmission path is made of at least one tunable cavity filter in the transmission path and at least one tunable cavity filter in the reception path.

[0019] In one embodiment, two or more tunable cavity filters, each one made of a housing forming a cavity, are coupled such that they form a multi-pole filter. In one embodiment, two tunable cavity filters are coupled such that they form a dipole filter.

[0020] In one embodiment, a transceiver device for mobile communication is proposed which comprises at least one tunable cavity filter.

[0021] Further advantageous features of the embodiments of the invention are defined and are described in the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] Some embodiments of apparatus and methods in accordance with embodiments of the present invention are now described, by way of examples only, and with reference to the accompanying drawings, in which:

Fig. 1 shows a cavity filter known in the art

Fig. 2 shows a cavity filter according to the invention in a first filter state

Fig. 3 shows a cavity filter according to the invention in a second filter state

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0023] The description and drawings merely illustrate the principles of the invention. It will thus be appreciated that those skilled in the art will be able to devise various arrangements that, although not explicitly described or shown herein, embody the principles of the invention and are included within its spirit and scope. Furthermore, all examples recited herein are principally intended expressly to be only for pedagogical purposes to aid the reader in understanding the principles of the invention and the concepts contributed by the inventors to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions. Moreover, all statements herein reciting principles, aspects, and embodiments of the invention, as well as specific examples thereof, are intended to encompass equivalents thereof.

[0024] Fig. 1 depicts a cavity filter as known in the art. The cavity filter comprises a cavity 1, which is metalized. Two RF input/output connectors 2, 3 are located in the upper side of the cavity 1. A resonator defining element 4 ("resonator") is attached to the upper side of the cavity 1 inside the cavity 1. The resonator 4 is attached in the center of one side of the cavity as shown in Fig. 1. In one embodiment, the resonator is attached beside the center of one side of the cavity. The resonator 4 includes a tuning element 5 which is movable and expands the resonator 4 by a length depending on movement of the tuning element 5. A tuning screw 6 is provided to move the tuning element 5. The resonant frequency is depending, amongst others, on the free space distance d between the tuning element 5 and the below boundary of the cavity 1.

[0025] Fig.2 and Fig. 3 show a cavity filter according to the invention. The cavity filter comprises a cavity 1, which is metalized. Two RF input/output connectors 2, 3 are located in the upper side of the cavity 1. A resonator defining element 4 ("resonator") is attached to the upper side of the cavity 1 inside the cavity 1. A tunable element

7 is included in the cavity 1 and is attached on the lower side of the cavity 1. The tunable element 7 is attached by gluing, screwing or otherwise mechanically attaching it to the surface of the lower side of the cavity 1. In one embodiment, on top of the tuning element, a metallization layer 8 is attached. The metallization layer 8 is electrically connected to the cavity walls. In one embodiment, an isolation layer is included between the tunable element 7 and the metallization layer 8. In the embodiments with the metallization layer 8, an inner cavity is built which is completely metalized providing a filter cavity. In another embodiment, no metallization layer 8 is attached. The filter frequency is then influenced by the thickness of the tunable element 7, the geometry of the assembly, and the dielectric constant of the tunable element 7. This means, the space between the resonator 4 and the opposing wall of the cavity 1 is partially filled with the tunable element 7 and with air or a gas within the cavity 1. The ratio between the space filled with the tunable element 7 and the space filled with air or gas between the resonator 4 and the opposing wall of the cavity 1 as well as the geometry of the assembly determines the filter frequency. A further parameter influencing the filter frequency is the difference between the dielectric constant of the tunable element 7 and the dielectric constant of the material in the cavity, i.e. air. A control input 9 is provided for receiving a control voltage 10 and for applying the control voltage 10 to the tunable element 7. In one embodiment, the control input 9 is connected to the tunable element 7 by means of highly conductive adhesive. In one embodiment, a part of a side wall or the bottom wall is used as a control input 9. Depending on the control voltage 10 received at the control input 9, the tunable element expands or compresses its size and thus, the upper edge of the tunable element 7 moves up and down. In case a metallization layer 8 is attached on top of the tunable element, the distance d between the resonator and the metallization layer 8 increases or decreases in dependence of the applied control voltage 10. This distance d influences as a main factor the resonant frequency of the cavity 1 and thus, tuning of the cavity filter is made by applying a corresponding control voltage 10. In case no metallization layer 8 is provided on top of the tunable element 7, the distance between the resonator 4 and the upper edge of the tunable element 7 increases or decreases in dependence of the applied control voltage 10. This distance is a main factor defining the resonant frequency of the cavity. In addition, by expanding and compressing the tunable element 7, the ratio between the part below the resonator 4 which is filled with air and the part which is filled with a material with a higher dielectric constant than air, namely the tunable element 7, which has a dielectric constant depending on its material, is changing and influences significantly the resonant frequency. Thus, the characteristic of the dielectric constant between the resonator 4 and the opposing wall follows a step function, which influences the resonant frequency significantly. In both embodiments, by applying a control voltage, the resonant frequency is tuned. Fig. 2 depicts a state of the embodiment when a control voltage 10 is applied such that the tunable element 7 is compressed. Fig. 3 depicts a state of the embodiment when a control voltage 10 is applied such that the tunable element 7 is expanded.

[0026] The functions of the various elements shown in the Figures, including any functional blocks, may be provided through the use of dedicated hardware as well as hardware capable of executing software in association with appropriate software. When provided by a processor, the functions may be provided by a single dedicated processor, by a single shared processor, or by a plurality of individual processors, some of which may be shared. Moreover, the functions may be provided, without limitation, by digital signal processor (DSP) hardware, network processor, application specific integrated circuit (ASIC), field programmable gate array (FPGA), read only memory (ROM) for storing software, random access memory (RAM), and non volatile storage. Other hardware, conventional and/or custom, may also be included.

Claims

1. A tunable cavity filter comprising:

- a housing (1) forming a cavity (1),
- a tunable element (7) inside the cavity (1) being attached to one side of the cavity (1),

characterized in that the tunable element (7) is expanded or compressed if a control voltage (10) is applied.

2. A tunable cavity filter according to claim 1, further comprising a control input (9) for receiving the control voltage (10), the control input (9) is connected to the tunable element (7) and is for applying the control voltage (9) to the tunable element (7).

3. A tunable cavity filter according to one of claims 1 or 2, further comprising a resonator (4) within the cavity (1).

4. A tunable cavity filter according to one of claims 1 to 3, wherein a metallization layer (8) is attached to the inner side of the tunable element (7).

5. A tunable cavity filter according to one of claims 1 to 4, wherein an isolation layer is included between the metallization layer (8) and the inner side of the tunable element (7).

6. A tunable cavity filter according to one of claims 1 to 5, wherein the tunable element (7) is expanded if a suitably polarized control voltage (10) is applied and the tunable element (7) is compressed if a the polarization of the control voltage (10) is reversed.

7. A tunable cavity filter according to one of claims 1 to 6, wherein the tunable element (7) is made by ionic electroactive polymer.

8. A tunable cavity filter according to one of claims 1 to 7, wherein the tunable element (7) is made by a dielectric electroactive polymer.

9. A tunable cavity filter according to claim 8, wherein the tunable element (7) keeps its expansion state when the control voltage (10) is switched off.

10. A tunable cavity filter according to one of claims 3 to 9, wherein the cavity includes an input port (2) and an output port (3) at a first side of the cavity (1), wherein the resonator (4) is attached to this first side of the cavity (1) and the tunable element (7) is attached to a second side of the cavity (1) which is the side opposite to the first side of the cavity (1).

11. A tunable cavity filter according to one of claims 1 to 10, wherein further tunable elements are attached to further sides of the cavity (1).

12. A tunable cavity filter according to one of claims 1 to 11, comprising two housings forming cavities according to one of claims 1 to 11, the two housings forming a duplexfilter for a transmission path and a reception path.

13. A tunable cavity filter according to one of claims 1 to 12, comprising more than one housings forming cavities according to one of claims 1 to 12, the more than one housings forming a multi-pole filter.

14. A transceiver device for mobile communication, comprising at least one tunable cavity filter according to one of claims 1 to 13.

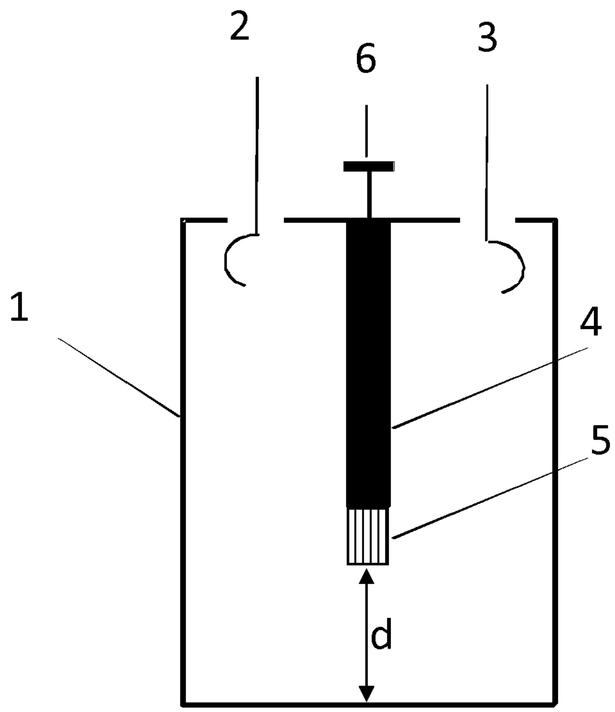

Fig. 1

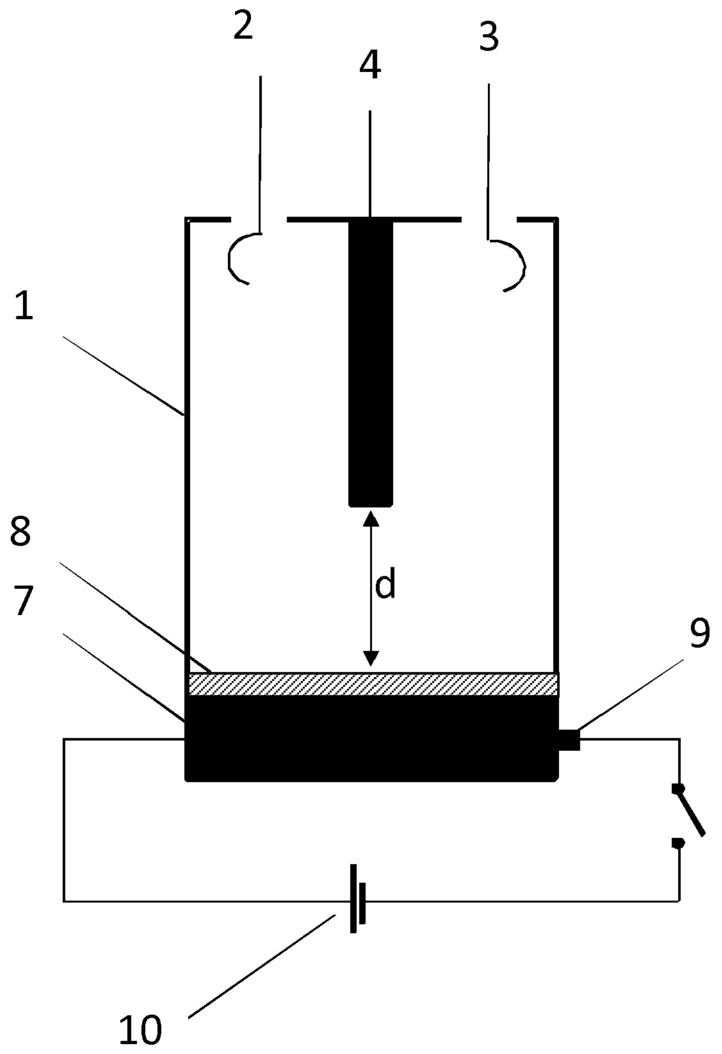

Fig. 2

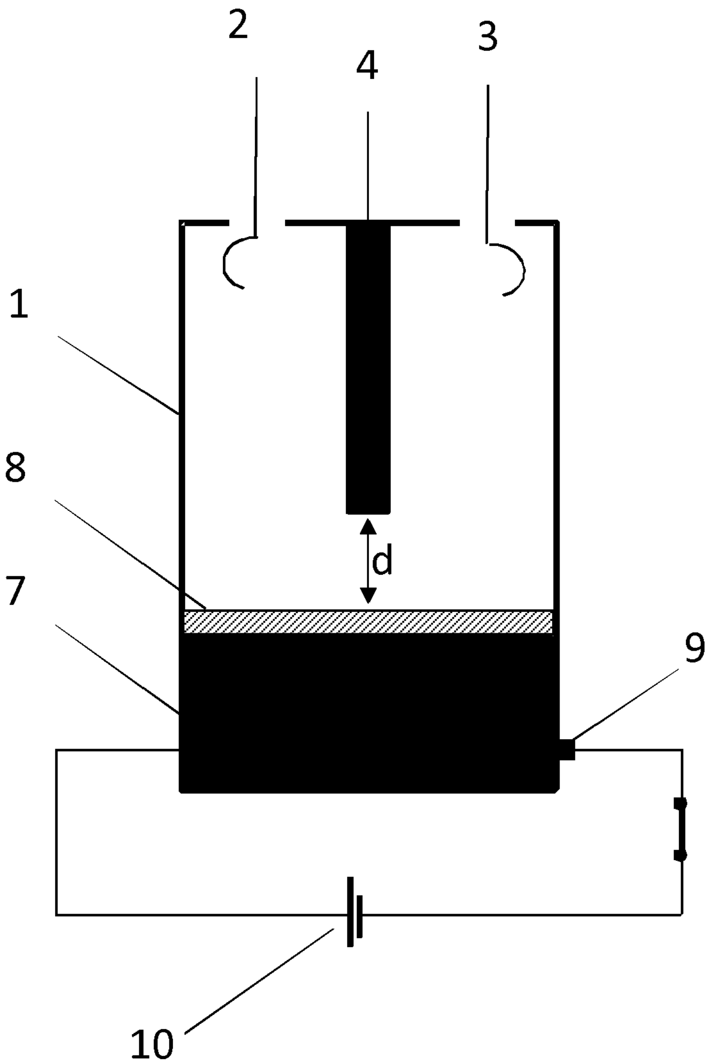

Fig. 3

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EUROPEAN SEARCH REPORT

Application Number
EP 13 30 6741

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X Y	US 3 471 811 A (KLOTZ ROBERT E) 7 October 1969 (1969-10-07) * column 2, line 14 - column 4, line 9; figure 1 *	1,2,4,6, 9,11-14 7,8	INV. H01P1/205 H01P1/208 H01P7/06 H01P7/04
X Y	US 2010/007442 A1 (NARHI HARRI [FI]) 14 January 2010 (2010-01-14) * paragraph [0027] - paragraph [0031]; figures 3a,3b,4 *	1-6,9-14 7,8	
Y	US 2004/212457 A1 (EDEN RICHARD C [US] ET AL) 28 October 2004 (2004-10-28) * paragraph [0016] * * paragraph [0035]; figures 1a, 1b *	7,8	
Y	US 2010/127953 A1 (WIK DANIEL [SE]) 27 May 2010 (2010-05-27) * paragraph [0018]; figure 3 *	7,8	
Y	EP 2 555 322 A2 (DIEHL BGT DEFENCE GMBH & CO KG [DE]) 6 February 2013 (2013-02-06) * paragraph [0005] - paragraph [0009]; figures 1a,1b *	7,8	TECHNICAL FIELDS SEARCHED (IPC) H01P
A	US 8 598 969 B1 (WALKER ANDERS P [US] ET AL) 3 December 2013 (2013-12-03) * column 4, line 39 - column 5, line 58; figures 2,3 *	1-14	

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The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
Munich	2 May 2014	La Casta Muñoa, S

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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EUROPEAN SEARCH REPORT

Application Number
EP 13 30 6741

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	DUBOIS P ET AL: "Voltage Control of the Resonance Frequency of Dielectric Electroactive Polymer (DEAP) Membranes", JOURNAL OF MICROELECTROMECHANICAL SYSTEMS, IEEE SERVICE CENTER, US, vol. 17, no. 5, 1 October 2008 (2008-10-01), pages 1072-1081, XP011231987, ISSN: 1057-7157, DOI: 10.1109/JMEMS.2008.927741 * abstract; figures 1,2 * -----	1-14	
			TECHNICAL FIELDS SEARCHED (IPC)

2

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	2 May 2014	La Casta Muñoa, S

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02-05-2014

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 3471811 A	07-10-1969	FR 1570690 A	13-06-1969
		GB 1187572 A	08-04-1970
		SE 334184 B	19-04-1971
		US 3471811 A	07-10-1969
US 2010007442 A1	14-01-2010	BR PI0710366 A2	16-08-2011
		CN 101438457 A	20-05-2009
		EP 2013939 A1	14-01-2009
		FI 20065272 A	28-10-2007
		US 2010007442 A1	14-01-2010
		WO 2007125161 A1	08-11-2007
US 2004212457 A1	28-10-2004	CA 2368260 A1	21-09-2000
		EP 1177593 A1	06-02-2002
		JP 2002539702 A	19-11-2002
		US 6347237 B1	12-02-2002
		US 2003125214 A1	03-07-2003
		US 2004212457 A1	28-10-2004
		WO 0055936 A1	21-09-2000
US 2010127953 A1	27-05-2010	CN 102224636 A	19-10-2011
		EP 2353206 A1	10-08-2011
		TW 201042832 A	01-12-2010
		US 2010127953 A1	27-05-2010
		WO 2010060656 A1	03-06-2010
EP 2555322 A2	06-02-2013	NONE	
US 8598969 B1	03-12-2013	NONE	

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