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(54) Tunable bandpass filter

(57) The invention provides a tunable bandpass filter, comprising a plurality of resonator cavities (2) arranged serially along a first direction, each resonator cavity being equipped with a movable frequency tuning element (10) and a control mechanism having a movable control element (20), which are arranged such that an adjusting movement of the control element causes the tuning elements to be simultaneously displaced in dependence of the adjusting movement of the control element in order to adjust the centre frequencies of the resonator cavities.

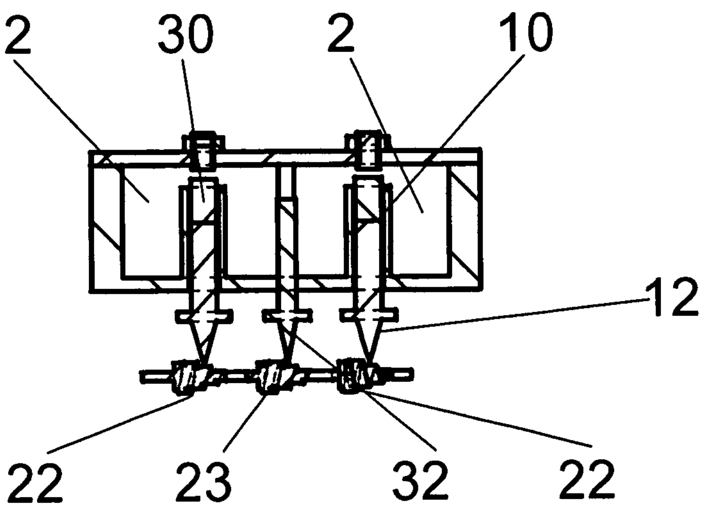

Fig.2

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Description

[0001] The present invention relates to tunable bandpass filters comprising a plurality of resonator cavities arranged serially along a first direction, each resonator cavity being equipped with a movable frequency tuning element extending in the cavity, and a control mechanism having a movable control element, wherein the tuning elements and the control element are arranged such that an adjusting movement of the movable control element causes the tuning elements to be simultaneously displaced within the resonator cavities in dependence of the adjusting movement of the control element in order to adjust the centre frequencies of the resonator cavities.

[0002] Such tunable bandpass filter is for example known from US 2005/0212623. In each resonator cavity a dielectric tuning element is located, which is guided for linear movement along the inner surface of the lid of the cavity resonator. The tuning element is connected to a control element located at the outer surface of the lid wall by a pin extending through an elongated slot in the lid wall. The control element is formed by a rod extending along the series of resonator cavities in a first direction. This rod carries a dielectric tuning element in each of the resonator cavities in the series of resonators, and by displacement of the rod along the first direction, a simultaneous displacement of the dielectric tuning element in the resonator cavities may be performed to allow a desired adjustment of the centre frequencies. However, this simultaneous adjustment of the frequency tuning elements does not allow a flexible design since the dielectric tuning elements are mechanically linked to each other, and therefore only a uniform displacement of all frequency tuning elements along the series of resonators is possible. Alternatively, it is suggested that individual adjustment of the respective frequency tuning elements may be achieved by providing each frequency tuning element with its own actuator which may be individually controlled. However, to provide an individual actuator for controlled displacement for each of the resonator cavities is a rather elaborate and complex approach which has disadvantages regarding manufacturing costs, reliable long-term operational safety and many other aspects, as for example the relative calibration of the actuators with respect to each other.

[0003] US 2006/0038640 A1 describes a cavity resonator (also for use in multiple resonator assemblies such as combline resonators) having an inner conductor with a movable end cap. The end cap is mounted on a central rod and is separated from the inner surface of the lid by a dielectric disc. The distance between lid surface and the end cap determines the capacitance of the capacitor formed by lid surface, dielectric disc and end cap. This capacitance in turn influences the resonator frequency. To adjust the position of the end cap an electromagnet is provided which drives the rod carrying the end cap against a biasing force to a desired position. Again, provision of an individual actuator (an electromagnetic or solenoid actuator in this case) for each resonator is an elaborate and complex approach.

[0004] Software-defined radio (SDR) is a rapidly evolving technology that is receiving widespread interest in the telecommunication industry. Over the last few years, analogue radio systems are being replaced by digital radio system for various radio applications in military, civilian and commercial spaces. In addition to this, programmable hardware modules are increasingly being used in digital radio systems. The aims of SDR are to define radio functions by software, and to configure a common hardware platform for a specific air interface by downloading software during operation or as part of the production cycle. To enable users to install such technology, tunable bandpass filters are needed. These filters have to be multi-standard filters and must be tunable over wide range.

[0005] It is an object of the present invention to provide a tunable bandpass filter including a series of resonator cavities which allows precise adjustment of the tuning elements of the resonators in a flexible and simple manner.

[0006] According to the invention a tunable bandpass filter is provided, comprising a plurality of resonator cavities arranged serially along a first direction, each resonator cavity being equipped with a movable frequency tuning element extending into the cavity, and a control mechanism having a movable control element, wherein the tuning elements and the control element are arranged such that an adjusting movement of the movable control element causes the tuning elements to be simultaneously displaced within the resonator cavities in dependence of the adjusting movement of the control element in order to adjust the centre frequencies of the resonator cavities, characterised in that

each frequency tuning element comprises a cam follower which is projecting from a wall of the respective resonator cavity to the outside and which is guided for shifting movement therein to allow to adjust the position of frequency tuning element by sliding the cam follower further inside or outside with respect to the resonator cavity wall;

the control element comprises a cam shaft extending in the first direction and having a plurality of cam sections along its length, each cam section comprising a cam track in the form of a conical spiral and each cam section being associated with a cam follower of a frequency tuning element such that the cam follower is in sliding contact with the cam track of the associated cam section, wherein the cam shaft is mounted for rotation in such a manner that it is axially shifted along the first direction in correspondence to the slope of the conical spirals of the cam sections;

a drive is provided to rotate the cam shaft to a desired adjusted position so that each of the frequency tuning elements is adjusted by movement of its cam follower as determined by the conical spiral cam track of its associated cam section at that adjusted rotational position of the cam shaft.

[0007] The cam segments provided on the cam shaft each provide a cam track showing a conical spiral for at least part of its length. By conical spiral in the sense of the present invention a function with varying radial distance from the central axis is meant which also proceeds in axial direction with each revolution; for example, the cam track may first, with each revolution around the central axis, increase its radial distance to the central axis, while at the same time proceeding in axial direction, wherein the slope of the conical spiral in axial direction is such that the axial advancement per revolution equals the width of the cam track in axial direction. The term "conical spiral" as used in the present application is not limited to three-dimensional spirals with strictly linear growth along the axial direction. Furthermore, it is not excluded that after a conical spiral portion with increasing radial distance with respect to the central axis that there may be a further portion in which the cam track returns to lower radial distances with respect to the central axis of the cam shaft again.

[0008] This design of a conical spiral cam track, instead of a usual disc-like cam, allows that the displacement of the cam track surface occurs over several revolutions of the cam shaft, as opposed to a single revolution with a simple cam, which, when using drive means of the same precision, allows to achieve higher precision in the adjustment.

[0009] The cam follower of each frequency tuning element is in sliding contact with the cam track surface of the associated cam segment on the cam shaft. This sliding contact may be maintained either by gravitational force, in which case the elongated tuning elements must be positioned vertically and located in the bottom wall of the resonator cavities, or preferably by a biasing force, for example provided by a spring which urges the tuning element to its maximally extended position to the outside of the resonator cavity.

[0010] Each frequency tuning element may be moved to vary the position of the frequency tuning element with respect to the cavity and thus to vary the centre resonance frequency of the resonator. The positioning of each frequency tuning element is determined by the cam track surface against which its cam follower abuts, i.e. by the radial distance of the conical spiral from the central axis. The cam track surface has a predetermined radial distance from the central axis $r(\varphi) = r_0 + f(\varphi)$, wherein r_0 is a given initial value and $f(\varphi)$ is a given function of φ, wherein φ is the total revolution angle of the cam shaft, i.e. φ is increasing by 2π with every revolution; in one example $f(\varphi)$ may be a linear function of φ: $f(\varphi) = c \cdot \varphi$ with a constant c, in which case a "conical" spiral in a strict sense would be realised. In this manner, a predetermined contour of the cam track of each cam segment determines the pattern in which the frequency tuning elements are displaced when the cam shaft is rotated by the drive for a given angle. By providing cam segments having predetermined different conical spiral shapes along the cam shaft, in principle any predetermined pattern of frequency adjustments along the series of resonators may be accomplished by rotation of the cam shaft.

[0011] In a particularly preferred embodiment the cavity resonators have coupling openings between adjacent cavity resonators and have movable coupling tuning elements extending into the coupling openings. The coupling tuning elements are displaceable in the same manner as the frequency tuning elements. Also, there are associated cam segments for the coupling tuning elements, and associated cam segments and the coupling tuning elements have cam followers arranged such that the cam followers are in sliding contact with the associated cam segments on the cam shaft so that the rotation of the cam shaft determines, in addition to the positioning of the frequency tuning elements, the positioning of the coupling tuning elements. Thus, in this arrangement, it is possible to vary the centre frequencies of the individual resonators as well as the coupling of the individual resonators. Thus, it is possible to vary the centre frequency of the bandpass filter as well as its band width over a wide range.

[0012] In the following the invention will be described in connection with exemplary embodiments shown in the accompanying drawings, in which:

Figure 1 shows a cross-sectional view of a single cavity resonator which may be used in a filter according to the invention;

Figure 2 shows a cross-sectional view of two coupled resonator cavities which may be used in a filter according to the invention;

Figure 3 shows a schematical view of the bottom side of a filter having four coupled resonator cavities;

Figure 4 shows a cross-sectional view of the filter according to Figure 3;

Figure 5 shows a perspective view of the filter shown in Figures 3 and 4;

Figure 6 shows a schematical view of the bottom side of an alternative embodiment of a filter having four coupled resonator cavities.

Figure 7 shows a cross-sectional view of the filter of Figure 6;

Fig. 8 shows the centre frequency of a resonator as a function of the intruding length tf of the frequency tuning element into the cavity;

Fig. 9 shows a graph of the transmission S21 and the return loss S11 for an exemplary bandpass filter having five resonator cavities for three frequency tuning adjustments;

Fig. 10 shows a graph of the transmission S21 and the return loss S11 for an exemplary bandpass filter having five resonator cavities for three frequency tuning and coupling tuning adjustments;

Fig. 11 shows the variation of a coupling factor, in this example between first and second resonator, which is suitable to keep the bandwidth constant when the centre frequency of the bandpass filter is tuned through the frequency indicated on the x axis;

Fig. 12 shows the dependence of the coupling between two adjacent resonators on the adjustment tk (intruding length) of the coupling tuning element for three different settings of the intruding length tf of frequency tuning elements of the resonators;

Fig. 13 shows a single cavity resonator which may be used in a bandpass filter according to the invention.

[0013] In Figure 1 a cross-sectional view of a single cavity 2 resonator is shown. A frequency tuning element 10, in this case a dielectric ceramic body, extends in the resonator cavity 2 and is carried by a cam follower 12 which projects to the outside of the cavity. The cam followers 12 is guided for linear movement further into and out of the resonator cavity. The cam follower 12 is biased by a spring 16 to a maximally extended position (only in this Figure such bias spring is shown, whereas is has been omitted in the remaining Figures to simplify the graphical illustration).

[0014] Outside of the resonator cavity 2 a movable control element 20 is mounted. This control element 20 comprises a shaft which is provided with cam sections 22 along its length (in this view of a single resonator only one cam section 22 is shown which is associated with the frequency tuning element and the cam follower of this resonator). The cam section 22 has winding cam track which follows a path of a conical spiral, i.e. its radial distance to the longitudinal axis of the shaft is increasing over at least part of its length. The shaft is mounted in such a manner that it, upon rotation, advances in its longitudinal direction at a rate that corresponds to the slope of the conical spiral of the cam track. In this manner the cam follower 12 may follow the conically spiraling cam track when the shaft is rotating. The shaft may, for example be provided with an outer thread (not shown) at a certain portion which is engaging an inner thread of sleeve which is relatively fixed with respect to the filter. When the slope or pitch of the threads is identical to the slope of the conical spiral of the cam track, the shaft advances upon rotation in the desired manner.

[0015] In Figure 2 two coaxial resonators having resonator cavities 2 are shown; of course, in general a bandpass filter may have any number of resonators. As a general remark, it should also be noted that means for coupling electromagnetic energy to the filter and means for extracting it have been omitted in the drawings in order to simplify the graphical presentation.

[0016] In Figure 2 frequency tuning elements 10 extend in the resonator cavities 2 and are carried by cam followers 12 which project to the outside of the cavities. The cam segments 22 of the shaft are shaped in a predetermined manner such that by rotation of the shaft 20 the individual cam followers 12 and frequency tuning elements 10 are displaced in a predetermined manner given by the conical spiral shape of the cam segments. For controlled rotation of the shaft 20 a drive 24 (Fig. 1), for example a step motor, is provided.

[0017] In the preferred embodiment there are furthermore coupling tuning elements 30 which extend into openings between adjacent resonator cavities 2. The coupling tuning elements 30 are mounted and guided in a similar manner as the frequency tuning elements. The outer ends of the coupling tuning elements 30 are likewise formed as cam followers 32 arranged to be in sliding contact with cam segments 23 of the control element 20. In this manner the positioning of the coupling tuning elements 30 may be varied in a predetermined way together with the adjustment of the centre frequencies of the resonators by the frequency tuning elements 20. Thus, in this arrangement, it is possible to vary the centre frequencies of the individual resonators as well as the coupling of the individual resonators. Thus, it is possible to vary the centre frequency of the bandpass filter as well as its bandwidth over a wide range.

[0018] Figures 3 to 5 show an embodiment of a filter comprising four coupled cavity resonators 2. Each cavity resonator comprises a frequency tuning element 10 carried by a cam follower 12 which rides on the cam track of an associated cam section 22 on a shaft 20. Likewise, coupling tuning elements 30 with cam followers 32 are adjusted by their associated cam segments 23. There are two shafts 20 with three cam sections 22, 23 each which are associated with the frequency tuning elements 10 of two adjacent resonator cavities and the coupling tuning element 30 between them. There is a further shaft 21 which is provided with one cam segment 23 which controls the positioning of an associated coupling tuning element. With this arrangement the frequency tuning elements and the coupling tuning element controlled by one shaft 20 are displaced in the same sense, i.e. if the frequency tuning elements 22 are displaced further inside into the resonator cavities, a movement in the same direction is performed by the coupling tuning element 30 in between the resonators. The shafts 20 and 21 may in principle be rotated independently. However, it is also possible to provide a single drive (not shown) and to provide transmissions to the three shafts 20, 21.

[0019] An alternative arrangement is shown in Figures 6 and 7 which in many aspects is similar to the filter of Figures 3 to 5, but comprises two additional shafts 21' which carry cam segments 23 which are associated with the coupling tuning elements 30 which determine the coupling of the resonators 2 which are associated with one shaft 20. In this arrangement it is possible to adjust the coupling tuning elements completely independent of the frequency tuning elements since the shafts 21, 21' may be rotated independently of the shafts 20.

[0020] Fig. 8 shows how the centre frequency of a single resonator of the type as shown in Fig. 1 is varying when the depth at which the frequency tuning element is intruding into the cavity is varied, this depth being designated as tf. At tf = -1 mm the frequency tuning element is still outside of the resonator cavity, at a depth tf = 0,0 mm the top surface of the frequency tuning element is flush with the inside wall of the resonator cavity. The variation of the centre frequency of the resonator is shown for three different cavity dimension, namely three different heights of the cavity hc.

[0021] In Fig. 9 the behaviour of an exemplary bandpass filter comprising five resonators is shown. Here the return loss S11 is shown in dashed lines and the transmission S21 in full lines. At a first adjustment of the filter the bandpass filter has a centre frequency of about 1400 MHz. In a second adjusted state the centre frequencies of the resonators are increased such that the centre frequency of the filter is about 2000 MHz. In a third adjustment the centre frequency of the filter is adjusted to 2600 MHz. This increase of the centre frequency is achieved by moving the frequency tuning elements to lower intrusion lengths into the cavities, i.e. by letting the cam followers 12 slide down the rotating cam segment 22 so that is moves closer to the central axis of shaft 20, for example by rotating the shaft 20 of Figure 1 in anti-clockwise direction. As can be seen from Fig. 9 the bandwidth of the filter is increasing with increasing centre frequencies. More precisely, the bandwidth of the filter is proportional to the centre frequency.

[0022] Fig. 12 shows that a variation of the centre frequency also leads to a variation in the coupling of resonators. As an example, Fig. 13 shows the coupling factor k (in units of 10^{-3}) of adjacent first and second cavity resonators as a function of the coupling tuning element adjustment length tk (intrusion length), for three different values of the intruding length tf of the frequency tuning elements into the resonators cavities. As can be seen, with decreasing intruding length tf and thus increasing centre frequency of the resonators, their coupling k is also increasing which contributes to the increasing bandwidth discussed above.

[0023] It may be desired to vary the centre frequency of the filter independently of the bandwidth, for example to vary the centre frequency while maintaining the bandwidth constant. This may be achieved when the coupling between adjacent resonators is lowered with increasing centre frequency.

[0024] In Fig. 10 a coupling between the first and second resonator of an exemplary filter is shown as decreasing with increasing centre frequency. By this decreasing coupling as illustrated it is accomplished to maintain the bandwidth of the filter constant with increasing centre frequency. This decreasing coupling may be achieved by displacing the coupling elements in a manner so that the coupling reduction as shown in Fig. 10 is achieved. The shape of the cam segments 23 effective for the cam followers 32 of the coupling tuning elements 30 may be chosen in relation to the cam sections 22 effective for the cam followers 12 of the frequency tuning elements 10 such that the bandwidth is maintained constant when the centre frequency of the band pass is adjusted. With such a coupling reduction it is possible to tune the bandpass centre frequency over a wide range while maintaining the bandwidth constant, as may be seen from Fig. 10 which shows the filter response for three centre frequency adjustments, with a bandwidth which is maintained constant.

[0025] In Fig. 13 a further schematical view of a single resonator which may be used in a filter according to the invention is shown. This resonator is shown to be equipped with a tuning screw 40. This tuning screw 40 may be useful in addition to the possible adjustment by way of the frequency tuning elements in order to allow to compensate for manufacturing tolerances in large scale production of filters. Thus, after manufacturing an initial fine-tuning may be accomplished whereafter the tuning may be performed using the cam surface, cam followers and tuning elements.

[0026] In an alternative arrangement of a cam follower and a frequency tuning element, the cam follower does not extend into the resonator cavity but only up to a flexible wall portion of the resonator cavity. By moving the flexible wall portion which forms the frequency tuning element, the centre frequency of the resonator is varied. The cam follower abuts against a cam segment on a shaft, and the position of the cam follower 12 may be adjusted by rotating the spiralling cam track of the cam segment so that a desired adjustment is achieved.

[0027] In the above described embodiments frequency and coupling tuning utilising the spiral cam track on a rotatable shaft have been described. It is evident that other tuning elements may be controlled and adjusted in the same manner for, example cross-coupling tuning element, tuning elements for coupling electromagnetic energy to the filter (input) or for extracting electromagnetic energy from the filter (output), etc.. It is noted that in general the input and output side of the filter is interchangeable depending on the intended operation.

Claims

1. Tunable bandpass filter, comprising a plurality of resonator cavities (2) arranged serially along a first direction, each resonator cavity being equipped with a movable frequency tuning element (10) extending in the cavity, and a control mechanism having a movable control element (20), wherein the tuning elements (10) and the control element (20) are arranged such that an adjusting movement of the movable control element causes the tuning elements to be simultaneously displaced within the resonator cavi-

ties in dependence of the adjusting movement of the control element in order to adjust the centre frequencies of the resonator cavities, **characterised in that** each frequency tuning (10) element comprises a cam follower (12) which is projecting from a wall of the respective resonator cavity (2) to the outside and which is guided for shifting movement therein to allow to adjust the position of frequency tuning element (10) by sliding the cam follower (12) further inside or outside with respect to the resonator cavity wall;
the control element comprises a cam shaft (20) extending in the first direction and having a plurality of cam sections (22) along its length, each cam section (22) comprising a cam track in the form of a conical spiral and each cam section being associated with a cam follower (12) of a frequency tuning element such that the cam follower is in sliding contact with the cam track of the associated cam section, wherein the cam shaft is mounted for rotation in such a manner that it is axially shifted along the first direction in correspondence to the slope of the conical spirals of the cam sections;
a drive (24) is provided to rotate the cam shaft to a desired adjusted rotated position so that each of the frequency tuning elements (10) is adjusted by movement of its cam follower (12) as determined by the conical spiral cam track of its associated cam section (22) at that adjusted rotational position of the cam shaft.

2. Tunable bandpass filter according to claim 1 **characterised in that** the drive (24) comprises a step motor.

3. Tunable bandpass filter according to any preceding claim, wherein additional cam shafts and drives are provided to control the adjustment of the frequency tuning elements of additional resonator cavities.

4. Tunable bandpass filter according to any preceding claim, wherein cavity resonators are coupled by coupling openings between adjacent cavity resonators (2), and wherein movable coupling tuning elements (30) extend into the coupling openings, wherein the coupling tuning elements (30) have cam followers (32) and are displaceable in the same direction as the frequency tuning elements (10) and wherein an associated cam segment (23) is provided on the cam shaft for each coupling tuning element (30), wherein each associated cam section (23) comprises a cam track in the form of a conical spiral and wherein the cam follower (32) of each coupling tuning element (30) is in sliding contact with the cam track of its associated cam section so that each of the coupling tuning elements (30) is adjustable as determined by the conical spiral cam track of the associated cam section (23).

5. Tunable bandpass filter according to any of the preceding claims, wherein a cross-coupling path is provided between two of the cavity resonators, and wherein a movable cross-coupling tuning element is provided which extends in the cross-coupling path, wherein the cross-coupling tuning element comprises cam follower which is projecting to the outside and which is displaceable in the same manner as the cam followers (12) of the frequency tuning elements (10), and wherein the control element and cam follower of the cross-coupling tuning element are arranged such that the cam follower is in sliding contact with an associated cam section comprising a cam track in the form of a conical spiral track of the shaft or one of the shafts so that the rotational positioning of the cam segment determines positioning of the cross-coupling tuning element.

6. Tunable bandpass filter according to any of the preceding claims, wherein a path for inputting electromagnetic energy into the bandpass filter is provided with a movable input tuning element which extends in the input path, wherein the input tuning element comprises cam follower which is projecting to the outside and which is displaceable in the same manner as the cam followers (12) of the frequency tuning elements (10), and wherein the control element and cam follower of the input tuning element are arranged such that the cam follower is in sliding contact with an associated cam section comprising a cam track in the form of a conical spiral track of the shaft or one of the shafts so that the rotational positioning of the cam segment determines positioning of the input tuning element.

7. Tunable bandpass filter according to any of the preceding claims, wherein a path for outputting electromagnetic energy from the bandpass filter is provided with a movable output tuning element which extends in the output path, wherein the output tuning element comprises cam follower which is projecting to the outside and which is displaceable in the same manner as the cam followers (12) of the frequency tuning elements (10), and wherein the control element and cam follower of the output tuning element are arranged such that the cam follower is in sliding contact with an associated cam section comprising a cam track in the form of a conical spiral track of the shaft or one of the shafts so that the rotational positioning of the cam segment determines positioning of the output tuning element.

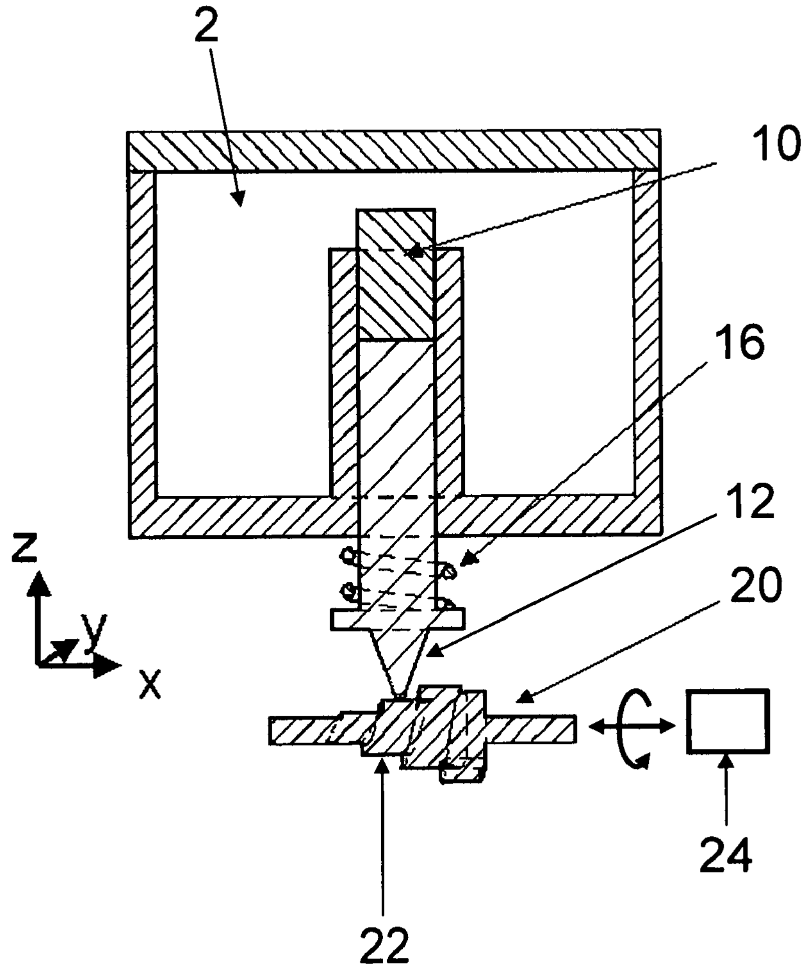

Fig. 1

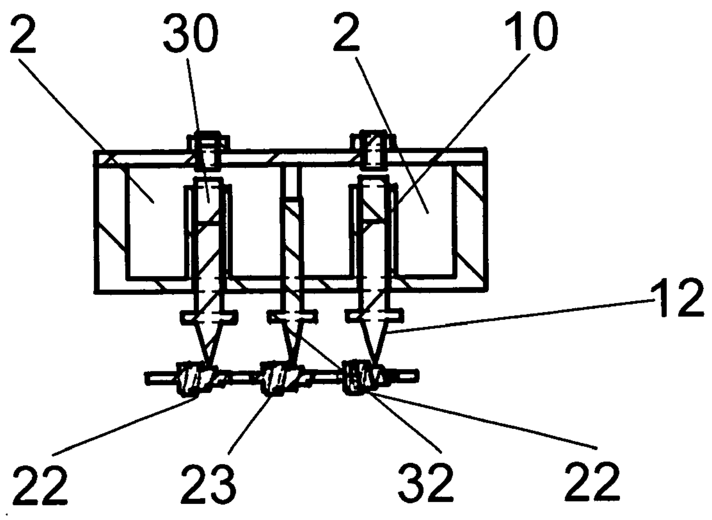

Fig.2

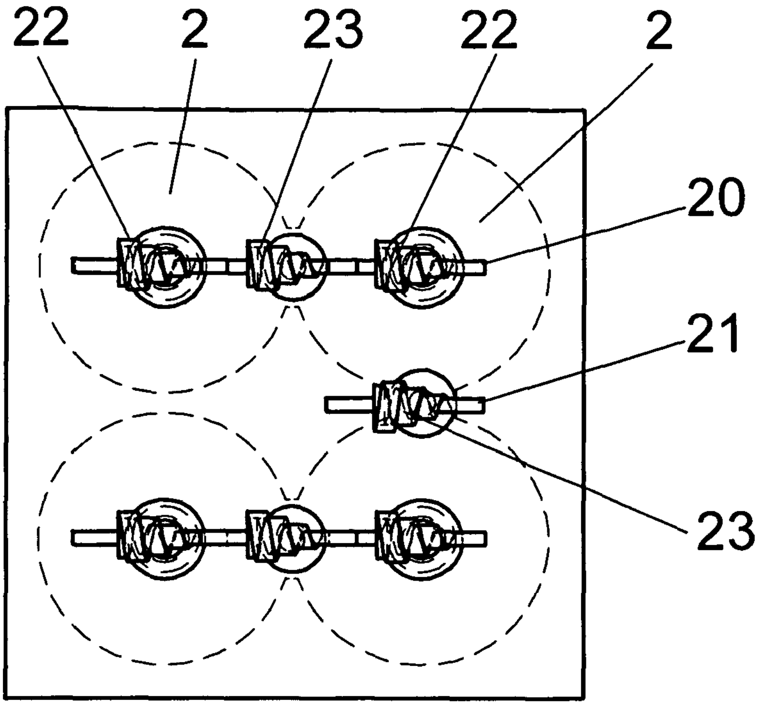

Fig. 3

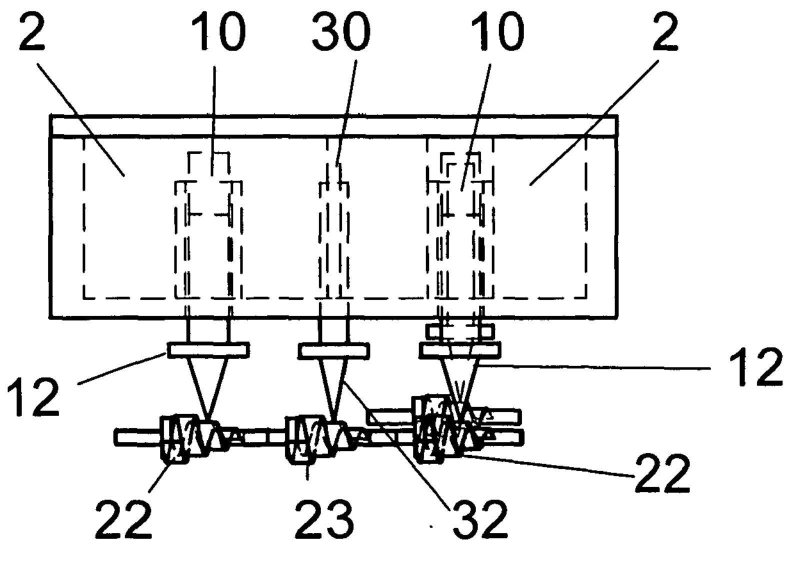

Fig. 4

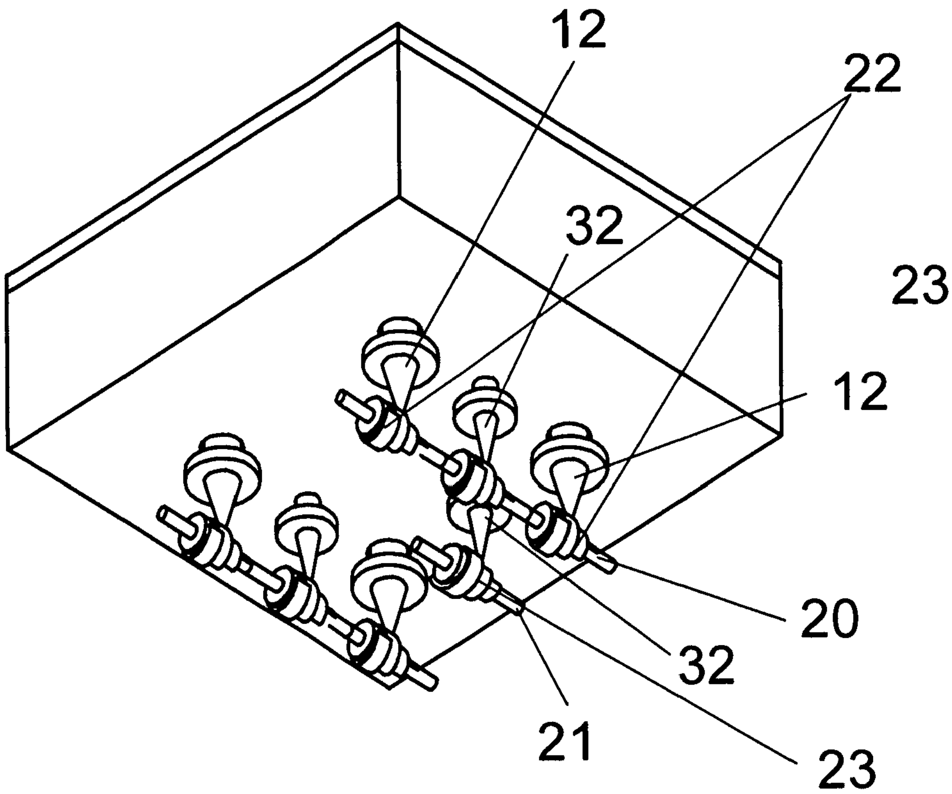

Fig. 5

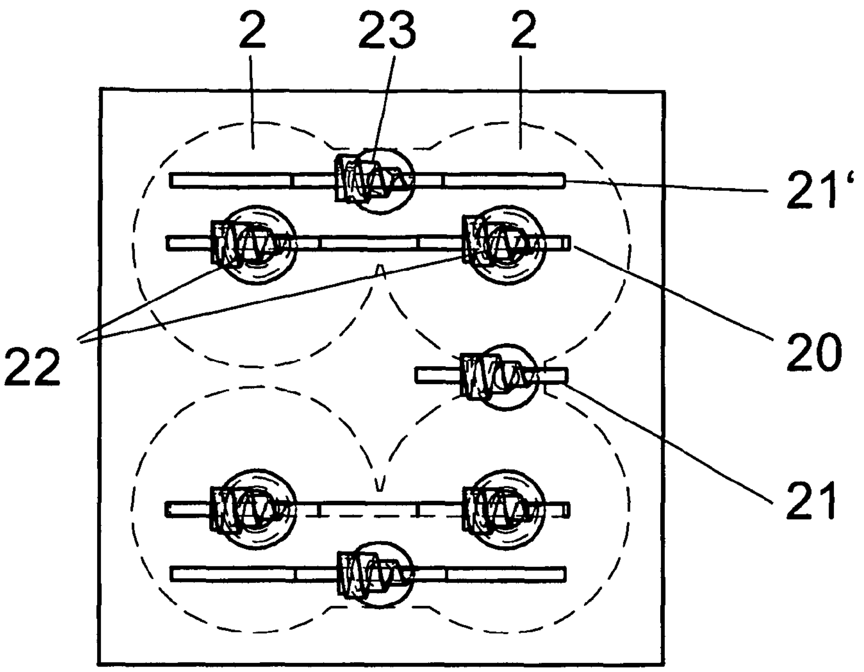

Fig. 6

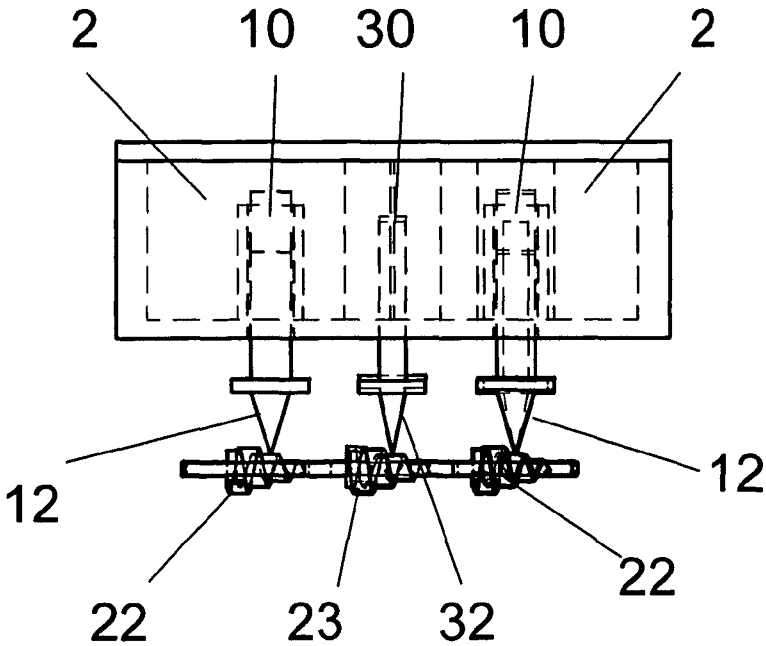

Fig. 7

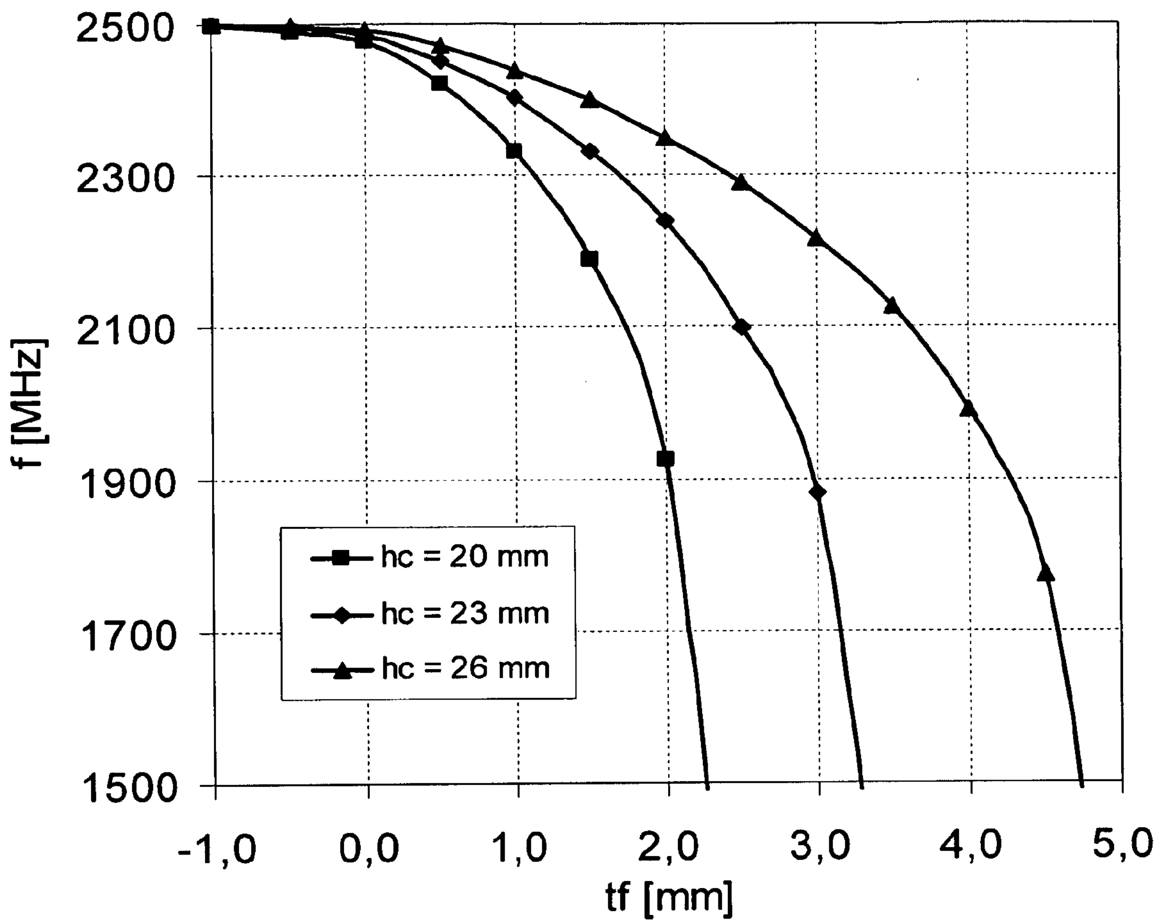
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Fig. 8

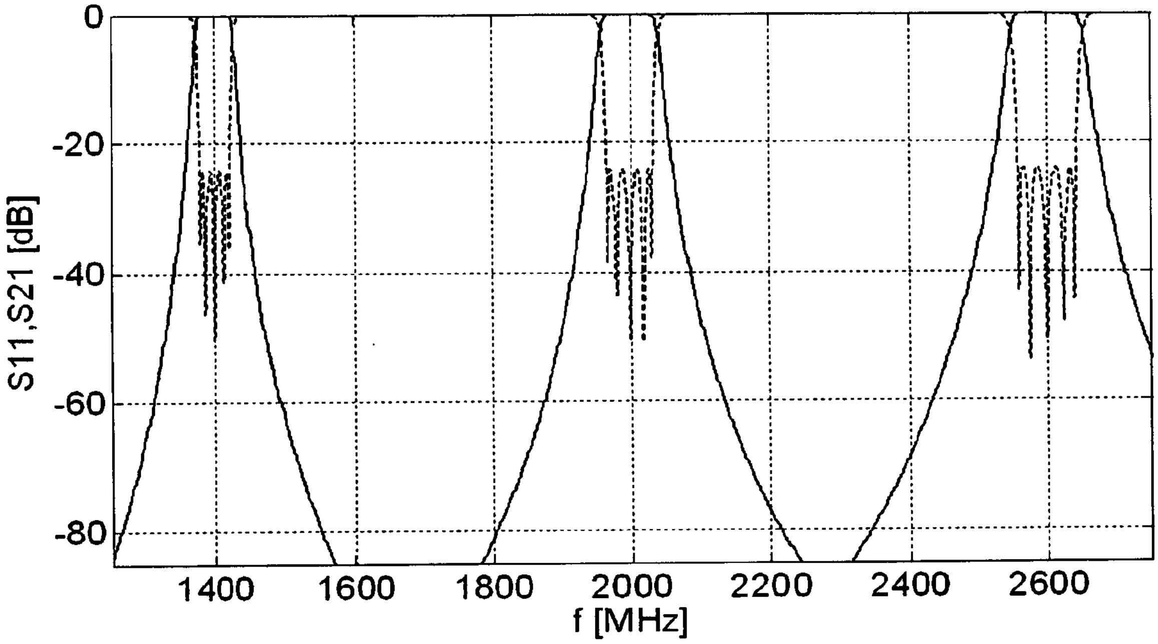

Fig. 9

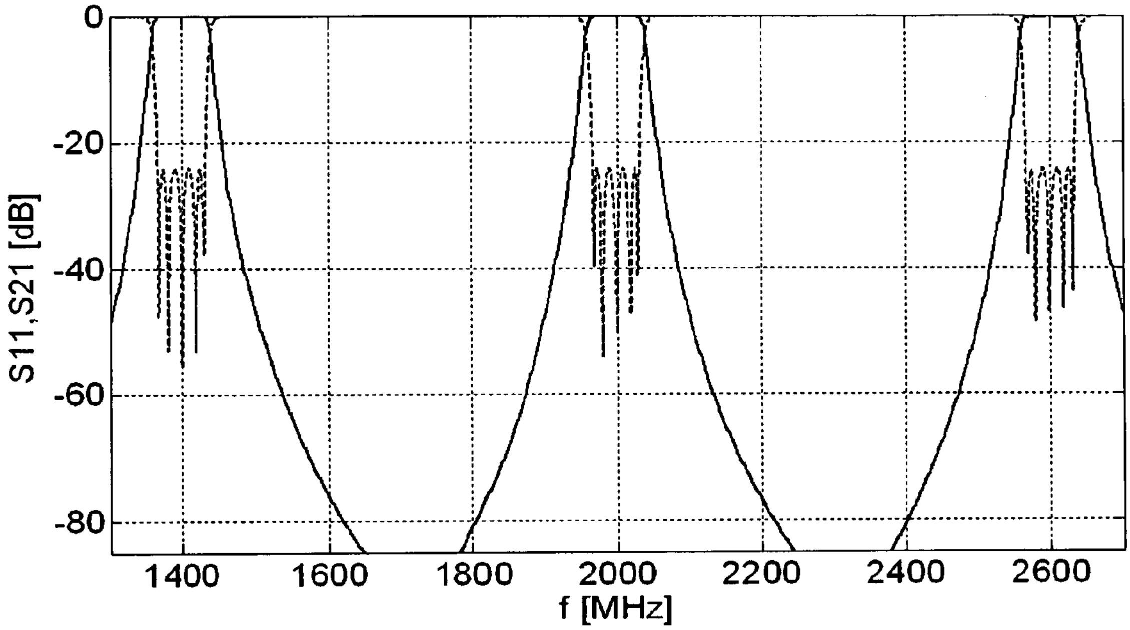

Fig. 10

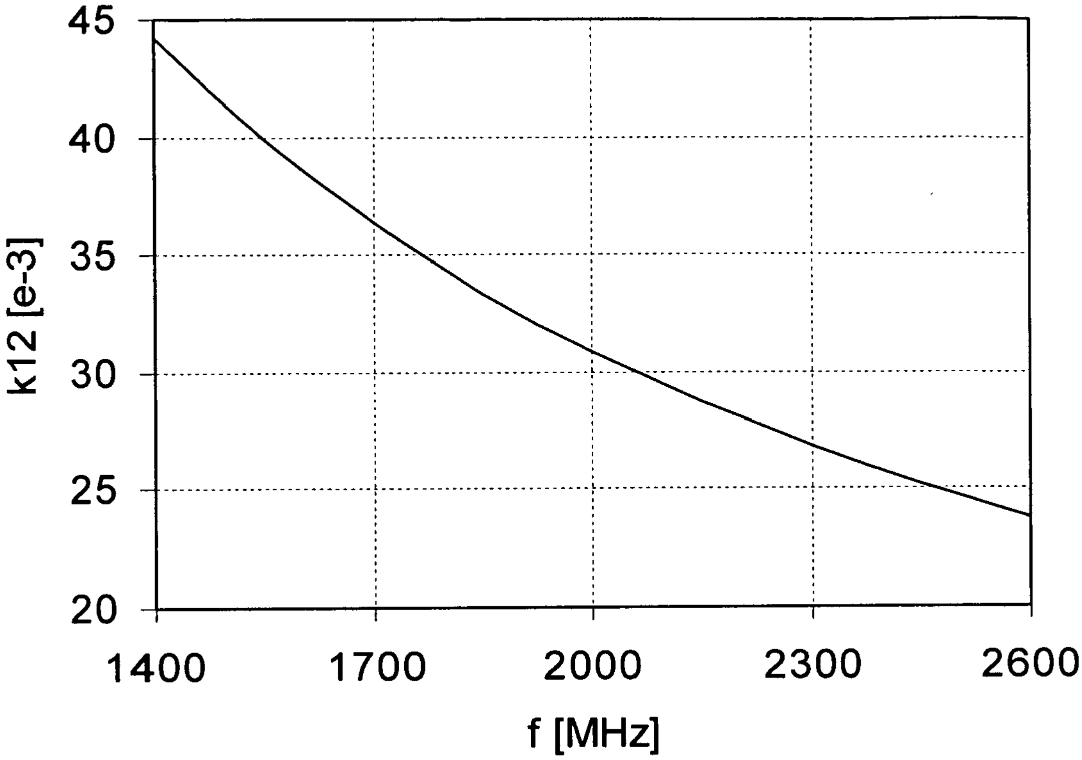

Fig. 11

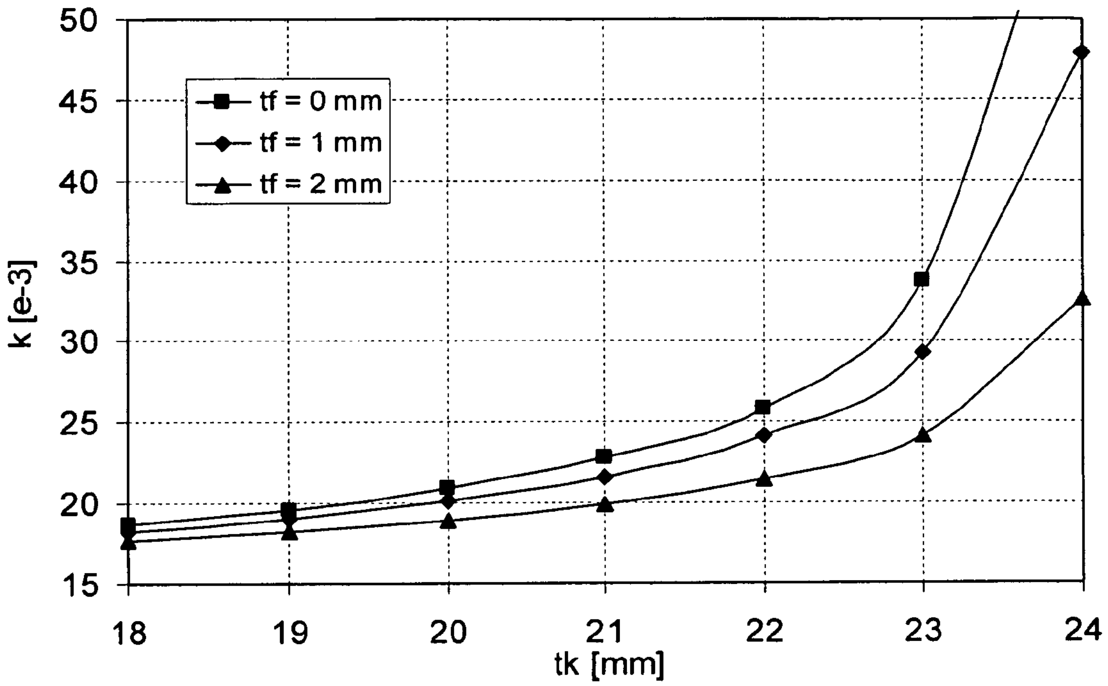
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Fig. 12

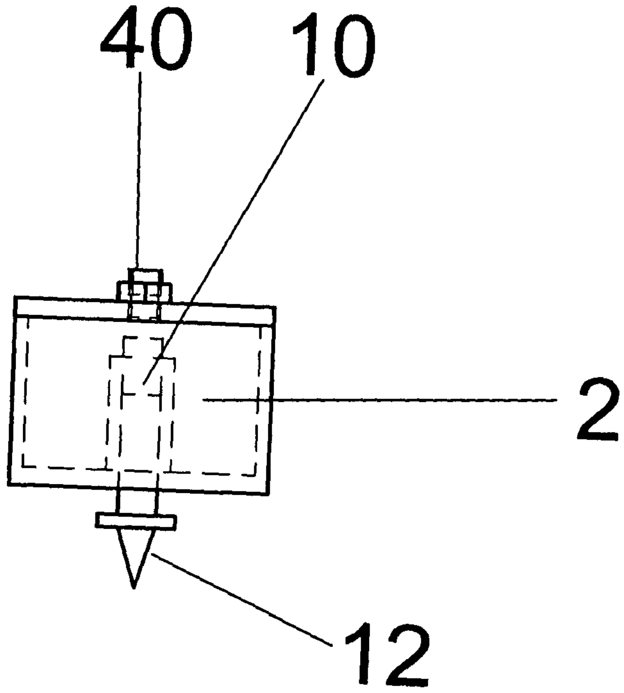

Fig. 13

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 06 01 5382

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
D,A	US 2005/212623 A1 (ALA-KOJOLA JOUNI [FI]) 29 September 2005 (2005-09-29) * abstract; figures 1-14 * -----	1-7	INV. H01P1/205
A	EP 1 258 941 A2 (COMTECH S R L [IT]) 20 November 2002 (2002-11-20) * paragraph [0015]; figures 1,2 * -----	1-7	
A	DE 196 02 815 A1 (ISRAEL STATE [IL]) 8 August 1996 (1996-08-08) * abstract; figures 1,2 * -----	1-7	
A	US 3 516 030 A (BRUMBELOW JOSEPH S) 2 June 1970 (1970-06-02) * column 2, lines 12-39; figure 1 * -----	1-7	
D,A	WO 2006/012055 A2 (MICROWAVE CIRCUITS INC [US]; D OSTILIO JAMES P [US]) 2 February 2006 (2006-02-02) * abstract * -----	1-7	
			TECHNICAL FIELDS SEARCHED (IPC)
			H01P

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	23 November 2006	van Norel, Jan

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CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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