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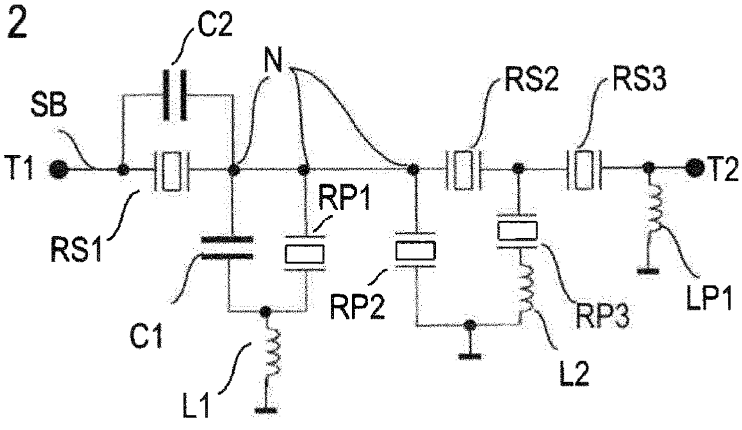
(54) Title: FILTER CIRCUIT WITH ADDITIONAL POLES OUTSIDE PASSBAND

Fig 2



(57) Abstract: In a ladder type two independently controllable transmission zeros can be achieved by a structure unit comprising a first parallel resonator (RP1) having a relatively high resonance frequency and a first inductor (L1) coupled in series between the fixed potential and the first parallel resonator.

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Description

Filter circuit with additional poles outside passband

The invention is related to a filter circuit as used in a passband filter for mobile communication. Such passband filters are mostly constructed from ladder type structures comprising a series arm with series resonators arranged therein. The series arm is coupled to ground via shunt arms, each shunt arm comprising a parallel resonator. Such a ladder type structure can easily be adapted to specific band requirements by simply adding more members to the filter structure or by varying the resonance frequency of the resonators properly. The resonators within a ladder type filter may be chosen from L,C elements, SAW filters (surface acoustic wave) or from BAW resonators (bulk acoustic wave). The latter ones are preferred if the filter is loaded with high power as it is usually the case in a transmission filter.

General requirements for passband filters are low loss in the passband, sufficient rejection in the stop band and often steep skirts of the passband to limit the passband against directly adjacent frequencies bands. Further goals can be low reflection within the passband and high reflection outside the passband, enhanced attenuation of specific bands, and good return loss.

For operating in currently used band B40, a conventional ladder type filter is known comprising BAW resonators. FIG. 1 shows the principle structure of this filter. The filter comprises four series resonators RS1 to RS4 and four shunt arms, each comprising a parallel resonator, such that parallel resonators RP1 to RP4 are present. Next to a terminal T1, the series arm is coupled to ground via an inductor LP1. Next to other terminal T2, the series arm is coupled to ground via a second parallel inductor LP2. The ground connection of the first two shunt arms is commonly coupled to ground via a third inductor LP3 while the third and the fourth shunt arm are commonly connected to ground via a fourth inductor LP4.

The main challenge for this B40 filter is to achieve a good insertion and return loss together with good rejection at the GPS WLAN frequencies as well as a good rejection of the second harmonic. The known filter fulfills the requirements but could be improved with respect to GPS rejection and WLAN rejection. Further, this filter comprises eight resonators that require substantial surface area on the filter chip.

It is an object of the invention to provide a passband filter having an improved topology with improved filter properties and which could be adapted to the requirements in given frequency bands, especially to the requirements of the B40 band.

These and other objects are solved by a filter circuit according to claim 1. Further advantages and embodiments are subject of the sub-claims.

The invention provides a new filter circuit having a series arm that is coupled between a first and a second terminal. Three or more shunt arms are coupled between a respective node in the series arm and a fixed potential that may be ground. Three or more series resonators are arranged between two adjacent nodes or between a node and one of the terminals within the series arm. In each of the shunt arms, a parallel resonator is arranged. A first capacitor may be circuited in parallel to a first parallel resonator. In series to either of the first parallel resonator and the first capacitor, a first inductor is coupled to the fixed potential.

Here and in the following numbering of elements like first resonator or any other first and second element does not represesent a sequence within the circuit but is only for distinguishing between different elements.

Although the arrangement of resonators alone is commonly known and already used in pass band filters, the inventive filter circuit is adapted to produce two new poles within the transfer function of the filter. One of these additional poles is due to the series resonance of the first parallel resonator now shifted to lower frequencies by the first inductor that is coupled in series to the first parallel resonator. More over the first parallel resonator is a series type resonator in view of its resonance frequency and thus, has a resonance frequency like a series resonator that is higher than that of the other parallel resonators. As a result, the above mentioned additional pole can be placed at a frequency below the passband at a substantial distance to the passband frequencies. First capacitor also controls/modulates the pole position and can thus be used to yield a higher degree of freedom when designing the filter topology.

The value of the first inductor can be set at a desired value and thus, can be used to control the frequency of this first additional pole. So it is possible to place the pole at a frequency that has to be suppressed by the filter circuit.

A second additional pole results from a branch comprising the first parallel resonator, the first capacitor and the first inductor. The frequency of this second additional pole can be controlled by either the resonance frequency of the first parallel resonator, the first capacitor value and/or the first inductor value. The resulting second additional pole arises at a frequency above the passband and can be used to sharpen the upper passband edge or to produce a pole for suppressing a desired frequency of an adjacent band.

With the exception of the first parallel resonator, the rest of resonators comply with common ladder type design approach:

1. The resonance frequencies of the series resonators are set within passband.

2. The anti-resonance frequency of the parallel resonators are set within the passband but preferably at a different frequency than the resonance frequency of the series resonators

3. The anti-resonance frequency of the series resonators will define the upper band transmission zero and the right skirt position of the pass band

4. The resonance frequency of the parallel resonators will define the lower band transmission zero and left skirt position

According to a further embodiment, a second parallel resonator is coupled directly between a node of the series arm and the fixed potential. A second inductor is coupled in series between the fixed potential and a third parallel resonator. The resonance frequencies of the second and third parallel resonator are lower than the resonance frequency of the first parallel resonator. As the second and the third parallel resonators are different in their respective resonance frequencies, two poles are produced in the transfer function of the filter circuit. The poles are due to the resonance frequencies of the parallel resonators wherein the pole that is due to the resonance frequency of the third parallel resonator is shifted to a lower frequency because the second inductor is circuited in series to the third parallel resonator. Hence, this pole can be controlled by a proper selection of the value of the second inductor. It is mandatory that the poles caused by the parallel resonators are below the passband to have a filter-type response with this topology. The first inductor can only lower down the resonance frequency and, respectively the pole of the first parallel resonator, which by default in a classical ladder-type topology will be in the middle of the passband if shunt type resonators were used. So it is not possible to have this pole above the passband with this topology. Same reasoning applies for the third parallel resonator, where in that case without the second inductor the pole will already be below the band.

A fourth pole arises due to the anti-resonance frequency of the series resonators which may all have the same resonance frequency or a similar value each.

According to another embodiment, a second capacitor is coupled in parallel to a first series resonator in series between a first and a second node of the series arm. This second capacitor can be used to detune the transmission zero frequency of the first series resonator at a frequency right after the passband on the right-hand side of the passband. By default, the series resonators already have a transmission zero right after the passband on the right-hand side of the passband. The first capacitor is slightly detuning that frequency to create two transmission zeros and a steeper right hand side skirt of the passband. By this detuning, the trade-off between a minimal insertion loss and a steep skirt of the passband on the high frequency side is relaxed. Despite being named the first series resonator, this resonator need not be the first one following the sequence of resonators within the series arm. The same is true for the naming or numbering of the parallel resonators. The first parallel resonator need not be arranged in the first shunt arm that is next to one of the terminals the filter is coupled in-between. But preferably, the first parallel resonator is an outermost parallel resonator of the filter circuit. The arrangement of the two further parallel resonators (second and third parallel resonators) can mutually be exchanged such that an arbitrary sequence of the parallel resonators can be set.

In addition, the same type of response could be implemented without the use of the first capacitor. The first capacitor is just adding an additional degree of freedom to detune the poles of branch comprising first parallel resonator and first inductor, but it is not strictly necessary.

In addition, it is possible to couple said branch to an arbitrary node of the series branch such that an arbitrary sequence of the parallel arms can be achieved. This means that RS3 could be inserted in between RP1 and RP2 and same type of response could also be obtained.

The same is true for the position of the second capacitor circuited in parallel to the first series resonator. The first series resonator need not be placed in an outermost position of the series arm.

According to a further embodiment, the resonance frequency of the first parallel resonator complies with the resonance frequency of the series resonator. Depending on the resonance frequency of the first parallel resonator, the first inductor is chosen to form a first pole of enhanced attenuation of the filter circuit at a frequency below a passband of the filter.

According to a preferred embodiment, the first pole is set to a GPS frequency. The already mentioned second additional pole that is due to the branch comprising the first parallel resonator, the first capacitor and the first inductor is preferably set to a WLAN frequency. According to this embodiment, the passband of the filter circuit arranged between a GPS frequency and a WLAN frequency and, more preferably, at the frequencies of band B40.

According to another embodiment, the filter circuit comprises a shunt inductor coupled between an outermost node of the series arm and the fixed potential. This shunt inductor can be used to match the filter circuit to a desired impedance.

Depending on the desired power resistance of the filter circuit, one or more of the series resonators are embodied as a cascaded resonator. This means that one series resonator is substituted by a series circuit of two new series resonators, the two new series resonators having a static capacitance of about the double normal static capacitance and hence require a resonator area that is about double the area of the normal series resonator. Such a cascaded resonator is known from the art and can replace one or more of the series resonators. Further, a cascaded resonator can comprise n (n equal or greater than three) new resonators circuited in series to each other. In this case, the required resonator area on the chip is enlarged by a respective factor n.

A filter circuit as described above is perfectly suited to be used as a passband filter for band 40, for example.

Notwithstanding that, a filter circuit may comprise additional elements that are known per se from the art and thus, do not deviate from the principal idea of the invention. The selectivity of the filter circuit may be enhanced by adding a fourth or a higher series resonator and a fourth or a higher parallel resonator to the filter circuit. Further capacitances can be circuited in parallel and/or in series to either parallel resonator or series resonator. It is also possible to omit first and/or second capacitor circuited in series to the first parallel resonator and to the first series resonator.

Preferably, the resonators are BAW resonators formed on an acoustic mirror, on a substrate or on a membrane, the membrane extending and suspended over a recess in a substrate.

In a preferred embodiment, the resonators are BAW resonators and comprise a layer stack, the layer stack comprising at least two metal layers. An active region of the layer stack forming the resonator is called the resonator region where two electrode layers of the BAW resonator are overlapping each other. In a region different from the resonator region, the first and/or second capacitor can be implemented by removing one of the metal layers comprising the structure of BAW resonators. Alternatively the capacitor can be implemented by modifying one or some of the fabrication steps of BAW resonators. By doing this, manufacturing of the capacitor complies with the manufacturing step of the layer stack of the BAW resonator so that in the whole manufacturing process a manufacturing step is saved. This saves time and costs.

In a preferred embodiment, a parallel resonator different from the first and the third parallel resonator is coupled directly to the fixed potential. The resonance frequency of this second resonator is chosen to be the lowest of the total of the parallel resonators. Further, the anti-resonance frequency of the second parallel resonator is chosen lower than the resonance frequency of a series resonator. In addition, the assignment of a second additional frequency to the second parallel resonator is preferred but not mandatory. If a third frequency was not available, then the second parallel resonator could potentially use same frequency as the third parallel resonator.

Selected preferred embodiments of the invention will be explained in more detail with reference to the accompanied figures.

The figures are drawn schematically only and depict only selected embodiments.

FIG. 1 shows a filter circuit known from the art,

FIG. 2 shows a filter circuit according to an embodiment of the invention,

FIG. 3 shows the transfer function of the filter of FIG. 2 together with the admittance of a selected partial structure of this new filter,

FIG. 4 shows the result of a simulation of the transfer function and the reflection at the different terminals for an inventive filter in comparison with a filter circuit known from the art.

FIG. 1 shows a known filter that is already used for operation of band B40. The structure of this filter was already explained in the introduction section. The structure of this filter circuit is approximated to a symmetric structure and is able to form the desired passband with a low insertion loss and a sufficient stop band attenuation.

FIG. 2 shows an embodiment of the invention in a schematic block diagram. The filter circuit comprises a series branch SB coupled between a first terminal T1 and a second terminal T2. Within the series branch SB, three series resonators RS1 to RS3 are arranged. Between each couple of adjacent series resonators RS and between the outermost series resonators and the respective adjacent terminal are nodes N to which branches or elements may be coupled.

Three shunt arms, each comprising a parallel resonator RP1 to RP3 is coupled to a respective one of the nodes N in the series branch SB. Each node represents a branching point in the series or any shunt arm. For clarity reasons only few nodes are provided with reference sign N. Each shunt arm is coupled between this node and a fixed potential. A first inductor is arranged in the first shunt arm between the first parallel resonator and the fixed potential. In parallel to the first parallel resonator, a first capacitor C1 is coupled such that a series circuit of the first capacitor and the first inductor is formed. The first parallel resonator RP1 and first capacitor C1 are directy connected coupled to a common node on the ground side, the common node being coupled to the fixed potential/ground via the first inductor L1.

A second capacitor C2 is circuited parallel to a first series resonator RS1. Hence, this second capacitor C2 is coupled between a node N on the left side of the first series resonator and another node N on the right-hand side of the first series resonator RS1.

A third parallel resonator RP3 that may be arranged in the third shunt arm is connected between a node N in the series branch SB and the fixed potential and is further circuited in series to a second inductor L2 that is coupled between the third parallel resonator RP3 and the fixed potential.

As a further element, the filter circuit comprises a third inductor LP1 circuited between an outermost node N of the series branch SB and the fixed potential.

The second parallel resonator RP2 and the ground side of the second inductor L2 may be connected to a further common node before being connected to the fixed potential. But it is possible, too, that the two shunt arms where the second and the third parallel resonator RP2, RP3 are arranged in have separate ground connections.

A filter circuit as shown in FIG. 2 can be optimized to operate band 40 frequencies. As explained above, by a proper selection of values for first inductor, first parallel resonator and first capacitor, two additional poles can be created in the transfer function of the filter circuit and set at frequencies to be suppressed or filtered out by the filter circuit. Preferably, the first additional pole is set at the GPS frequency while the second additional pole is set at a WLAN frequency.

By proper selection of elements for the topology shown in FIG. 2, key parameters of the B40 band can be matched and improved simultaneously. Then, such a circuit shows improved insertion loss, improved return loss, and GPS and WLAN rejection as well. The attenuation of the second harmonic is achieved by means of L2 inductor, which creates a controllable additional pole above the band, which in this case is placed at the second harmonic. Then, such a circuit shows improved insertion loss, improved return loss, and GPS and WLAN rejection as well. The attenuation of the second harmonic is achieved by means of inductor L2, which creates a controllable additional pole above the band, which in this case is placed at the second harmonic. Thereby, the fifth key parameter, that is attenuation of the second harmonic is kept at the same level as prior art topology like that one shown in FIG. 1 and fully satisfies the requirements.

On the other hand, with the topology shown in FIG. 2, a tradeoff of said key parameters with wideband rejection is achieved. So it is possible to use the topology for other applications where a very high wide-band rejection is not a requirement.

When using the topology of the filter circuit shown in FIG. 2 for creating a filter for band B40, three different types of parallel resonators are used wherein the types differ by the range of the possible resonance frequencies.

A first type of parallel resonator as used for the first parallel resonator RP1 has a resonance frequency of a common series resonator.

A second type of parallel resonator is used for the second and the third parallel resonator RP2,RP3 that has a "normal" resonance frequency as commonly used in ladder type structures known from the art. This means the resonance frequency of this normal parallel resonator is just below the passband of the filter. But preferably both parallel resonators RP2 and RP3 have different frequencies as it is usual for common ladder type topologies.

The two additional capacitors C2, C1 used in the filter circuit of FIG. 2 are added to detune transmission zeros of the filter that are due to respective resonator resonances of first series resonator RS1 and first parallel resonator RP1. Further, the second capacitor C2 is used to further control the steepness of the right skirt of the filter passband and to allow a better tradeoff between insertion loss and WLAN rejection. The first capacitor C1 adds a higher freedom for the selection of the two additional poles and the matching of the passband. According to one embodiment, both capacitors C1, C2 are realized with capacitances of about 0.8 pF.

In order to prove the advantage of the new topology approach over conventional ladder type structures, two designs based on the two circuits of FIG. 1 and FIG. 2 are simulated at circuit level using a Butterworth van Dike (BVD) model with same parameter properties. Both parameter sets are optimized aiming to reach at best insertion/return loss and WLAN/GPS/second harmonic rejection.

FIGs. 4A to 4E each show a comparison of the two simulated circuits by depicting the respective transfer function S21 and the return loss S11 and S22. FIG. 4A shows the transfer function of the two circuits in the passband region. Curve C1 is assigned to the inventive topology of FIG. 2, while curve C2 shows the respective simulation result of the known structure according to FIG. 1. What can be seen is that the maximum insertion loss is reduced by about 1.2 dB. The smallest insertion loss, too, is reduced from 1.7 dB to 1.0 dB. This shows a clear improvement of the inventive filter circuit over prior art.

FIG. 4B shows two curves C1 and C2 for the transfer function for a narrow band region near the passband. What can be seen is that the left passband skirt of curve C1 according to Fig. 2 is shifted to lower frequencies, thereby resulting in a greater bandwidth. On the low frequency side, the attenuation near the passband is a bit lower while being improved on the high frequency side of the passband at WLAN frequencies between 2423 and 2480 MHz. In Fig. 4B the range of the WLAN frequencies is bounded on both sides by dashed lines.

FIG. 4C shows the return loss (S11) for the two simulations and confirms the improvement resulting in a better insertion loss in the passband for the inventive topology.

Curve C1 of FIG. 4D shows the return loss on the output side (S22) for the invention compared with curve C2 and according to the known structure. The improvement in the return loss amounts to 7 dB.

FIG. 4E shows the transfer function in a wideband area and makes clear that relevant frequencies for GPS (reaching from 1574 to 1680 MHz) undergoes greatly improved attenuation while frequencies between the dashed lines in the range of the second harmonics (reaching from 4600 to 4800 MHz) show sufficient attenuation in the order of the known filter circuit. This means that the inventive filter circuit according to the curve C1 can better filter out GPS and WLAN frequencies out of the spectrum when used for operation in band B40 in a trade-off with wide-band rejection.

It is shown that the most improvement of the invention is due to the structure comprising first parallel resonator, first capacitor and first inductor. FIG. 3 shows the transfer function where the effects of this structure unit are marked together with other typical transmission zeros. Further, a simulation of the admittance of this structure unit is presented by curve 1 in FIG. 3. The transfer function of the filter structure according to curve 2 in FIG. 3 shows four typical transmission zeros where the transmission zeros A and D are due to the discussed structure unit. The first transmission zero according to the minimum in the region A is due to the resonance frequency of the RP1/L1 resonance of first parallel resonator and first inductor that arises at the GPS frequencies, which frequency position was also modulated by C1. The circuit achieves a shift of this transmission zero with respect to the normal resonance frequency of the first parallel resonator RP1 due to the series circuit of this resonator with first parallel inductor L1.

The admittance of said separated structure unit shows another transmission zero at frequencies in the region D that are located in the WLAN frequency area. This transmission zero is due to a resonance produced by the co-operation of elements first parallel resonator RP1, first capacitor C1 and first inductor L1.

The further transmission zeros in the areas B and C are caused by other elements of the filter circuit. These two transmission zeros below the band in the region B are due to the conventional series resonance of third parallel resonators RP3 and PR2. These zeros appear at different frequencies due to the different resonance frequencies of the two parallel resonators RP3 and RP2.

A transmission zero in the region C above the band is due to the conventional series resonator’s anti-resonance. In this area, the impedance of the branch tends to infinity. As a result, the transmission curve 2 has an absolute minimum at C which is responsible for a very steep right passband skirt.

While FIG. 3 just shows an embodiment optimized for operation of the filter circuit in band B40, the transmission zeros can be shifted by the respective control elements, especially by first and second inductor L1, L2.

The improved attenuation at the WLAN frequencies are best seen in FIG. 4B. This region is in the two dashed lines reaching from 2 423 to 2 480 MHz.

Regarding attenuation of the second harmonics a similar rejection is obtained thanks to the additional pole provided by L2 inductor.

When realizing the filter circuit according to FIG. 2, different kind of passive elements like inductors or capacitors can be used. The third inductor L3 requires the highest quality and is preferably realized as a discrete SMD component. The second inductor L2 has the lowest inductance and can be realized as a parasitic inductance caused by a given length of the conductor coupling the third parallel resonator to ground. The first inductor is also realized as a high-quality inductor like the third inductor LP1 and realized in an SMD device. The capacitors can be realized as discrete elements. Preferably, they are formed as a layer sequence metal 1/isolator/metal 2 and are integrated in the manufacturing process of the resonators as far as bulk acoustic wave resonators are used as resonators. As already explained, a BAW resonator comprises a sequence of layers, at least two of them being metal layers. At least one of these metal layers can be used as an electrode for forming capacitors C1 and/or C2.

In a further embodiment, one or two of the capacitors C1, C2 can be omitted when a tuning of the respective poles due to the first shunt resonator RP1 and inductor L1 is not required. According to customer specification requirements, the filter circuit can also have additional stages producing a better rejection. This means that the filter circuit comprises additional sections of series resonators and parallel resonators. By doing this, the capacitor C2 can be moved to another series resonator or even be removed if the additional stages already provide the required performance.

As the invention has been explained by means of a few embodiments and the respective figures only, the invention is not restricted to the depicted embodiments. The invention is best defined by the wording of the claims when interpreted in their broadest scope.

Claims

1. A filter circuit, comprising
   - a series branch (SB) coupled between a first and a second terminal (T1,T2)
   - three shunt arms coupled between a respective node (N) in the series branch and a fixed potential
   - three series resonators (RS1,RS2,RS3), each being arranged between two adjacent nodes or between a node and one of the terminals
   - a parallel resonator (RP) arranged in each of the shunt arms
   - a first inductor (L1) coupled in series between the fixed potential and a first parallel resonator (RP1)

   wherein
   - the resonance frequency of the first parallel resonator complies with a resonance frequency of a series resonator
   - Wherein the first parallel resonator and the first inductor are chosen to form a first and a second pole of enhanced attenuation of the filter circuit, a first pole at a frequency below a passband of the filter and a second pole at a frequency above the passband.

2. The filter circuit of claim 1, wherein
   - a first capacitor (C1) circuited in parallel to the first parallel resonator (RP1)

3. The filter circuit of claim 1 or 2, wherein

- a second parallel resonator (RP2) is coupled directly between a node (N) of the series branch (SB) and the fixed potential,
- a second inductor (L2) is coupled in series between the fixed potential and a third parallel resonator (RP3), and
- the resonance frequency of the second parallel resonator (RP2) being lower than the resonance frequency of the third parallel resonator (RP3).

4. The filter circuit of one of the foregoing claims, comprising a second capacitor (C2) coupled in parallel to a first series resonator.

5. The filter circuit of the foregoing claim, wherein the first pole is set to a GPS frequency and the second pole is set to a WLAN frequency.

6. The filter circuit of one of the foregoing claims, further comprising a shunt inductor coupled between an outermost node of the series arm and the fixed potential.

7. The filter circuit of one of the foregoing claims, wherein one or more of the series resonators are embodied as a cascaded resonator.

8. The filter circuit of one of the foregoing claims, comprising four or more series resonators and four or more parallel resonators.

9. The filter circuit of one of the foregoing claims, wherein the resonators are BAW resonators formed on an acoustic mirror on a substrate or on a membrane extending and suspended over a recess in a substrate.

10. The filter circuit of the foregoing claims, wherein the resonators are formed as a layer stack comprising at least two metal layer
wherein in a region different from a resonator region a metal layer is removed or a fabrication step is changed to form a capacitor electrode of the first and/or the second capacitor.

11. The filter circuit of one of the foregoing claims, wherein a parallel resonator different from first and third parallel resonator is coupled directly to the fixed potential, has the lowest resonance frequency of all parallel resonators, and has an anti-resonance frequency lower than the resonance frequency of a series resonator.

Fig 1
(State of the art)

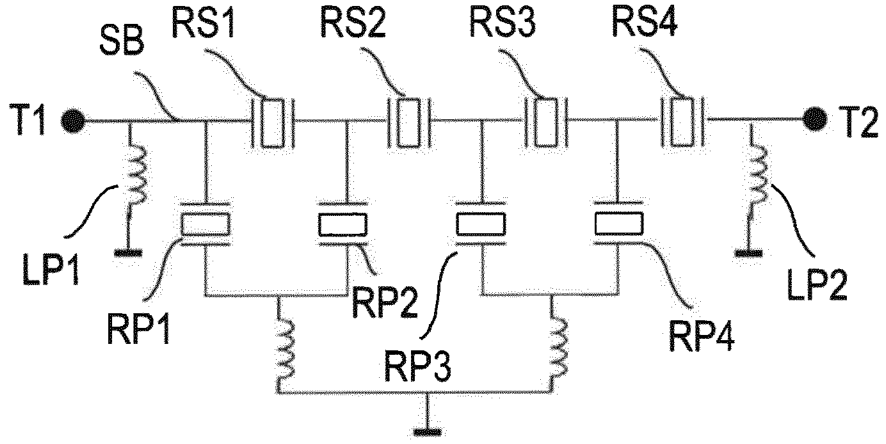


Fig 2

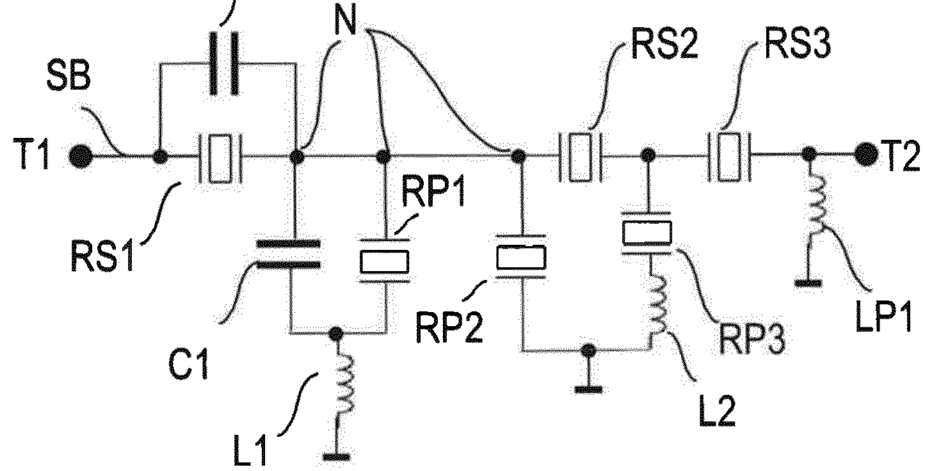
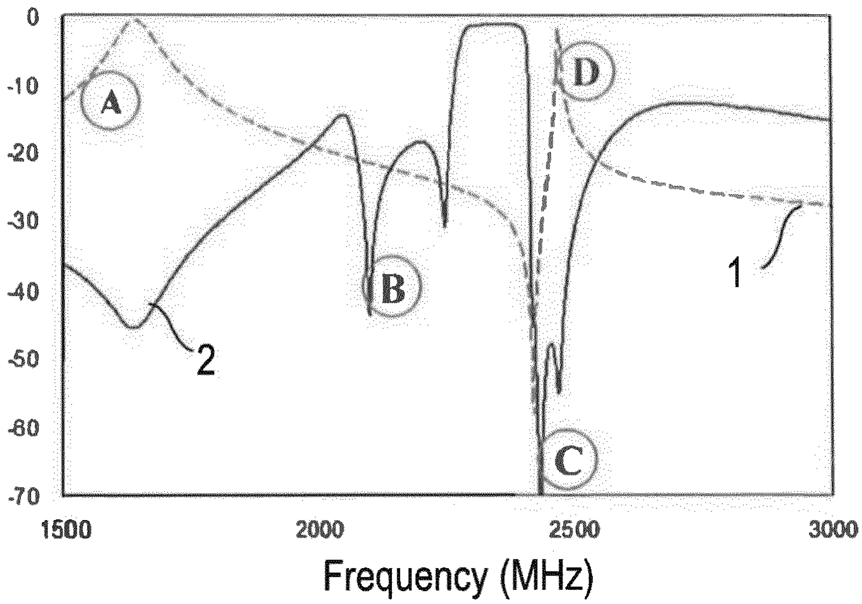


Fig 3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-20
-30
-40
-50
-60
-70
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B
C
D
1
2
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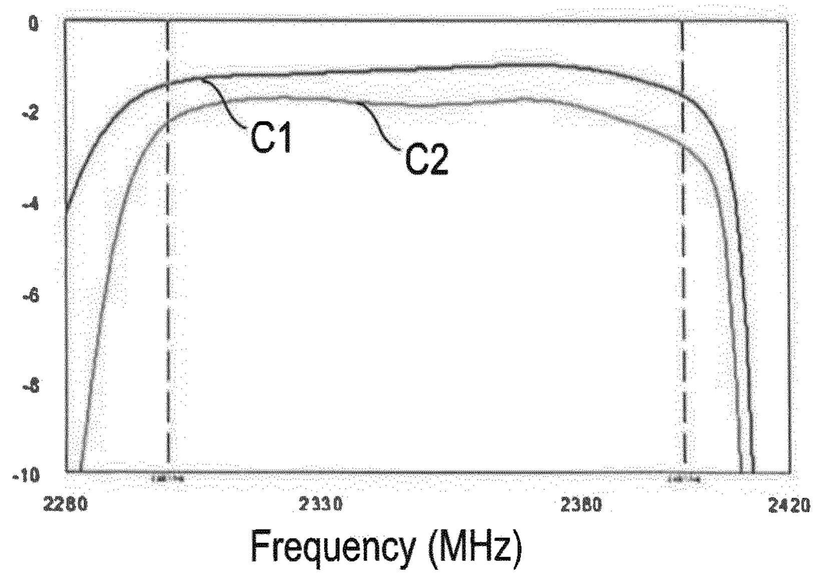
2000
2500
3000
Frequency (MHz)

Fig 4A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-6
-8
-10
C1
C2
2280
2330
2380
2420
Frequency (MHz)

Fig 4B

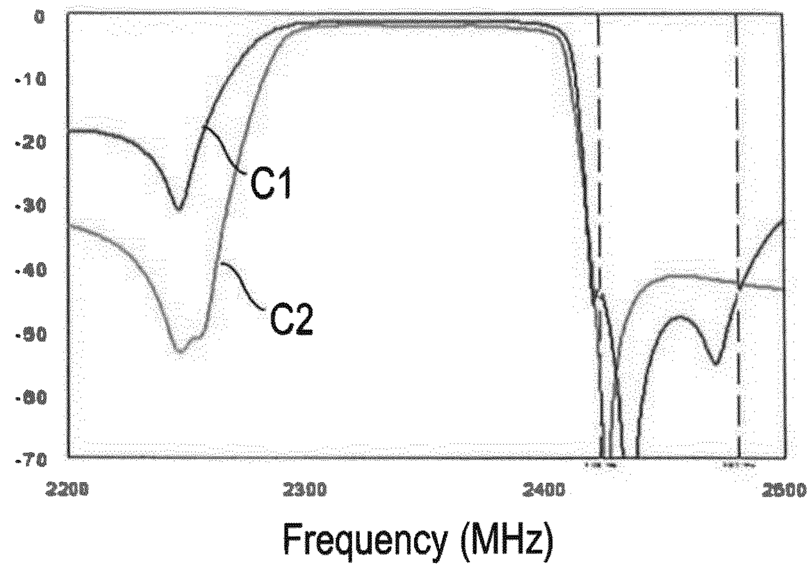

0
-10
-20
-30
-40
-50
-60
-70
C1
C2
2200
2300
2400
2500
Frequency (MHz)

Fig 4C

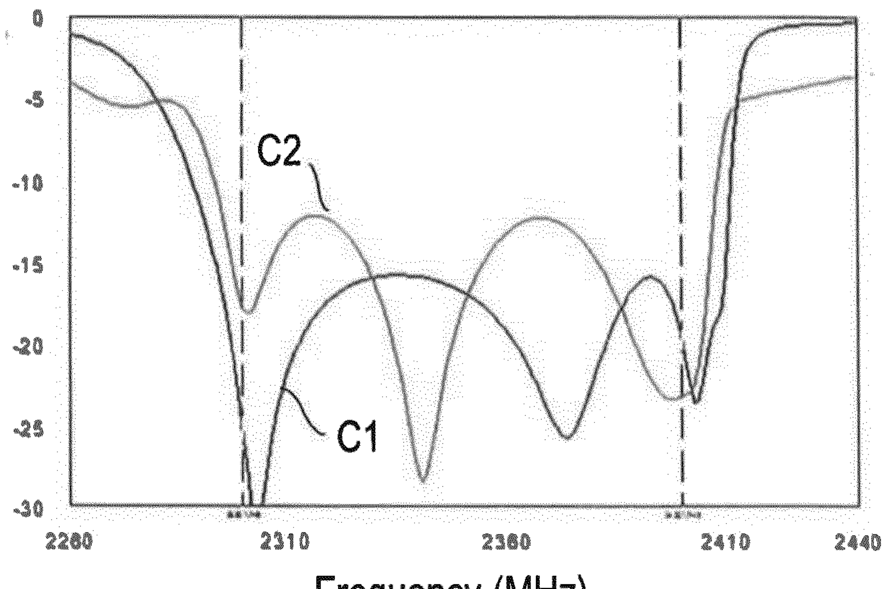

0
-5
-10
-15
-20
-25
-30
C2
C1
2260
2310
2360
2410
2440
Frequency (MHz)

Fig 4D

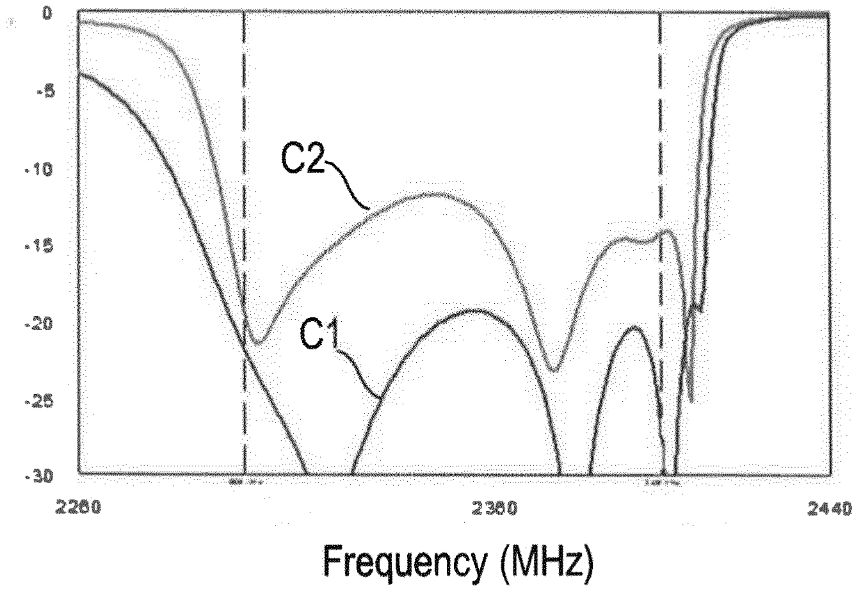
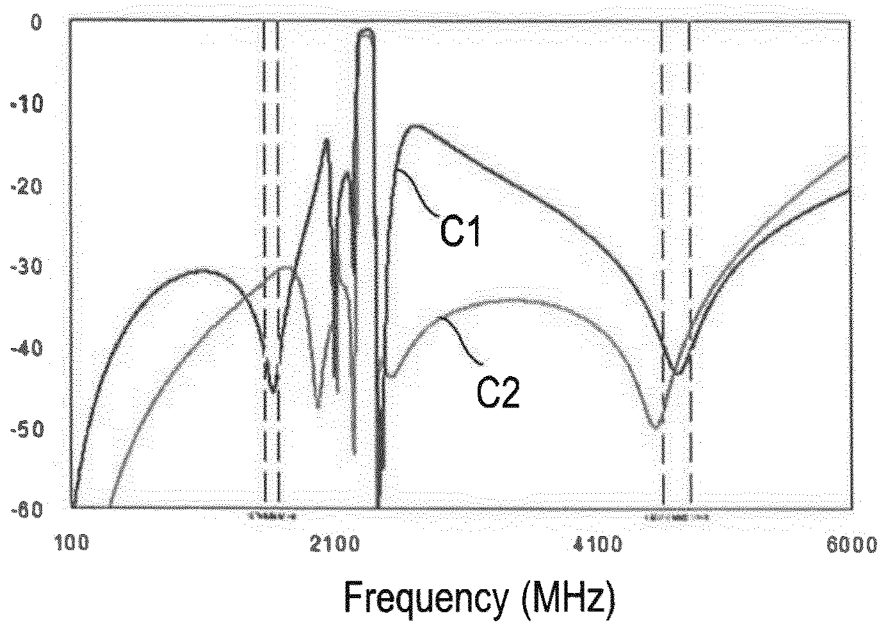

0
-5
-10
-15
-20
-25
-30
2260
2360
2440
C2
C1
Frequency (MHz)

Fig 4E


0
-10
-20
-30
-40
-50
-60
100
2100
4100
6000
C1
C2
Frequency (MHz)

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/076551

A. CLASSIFICATION OF SUBJECT MATTER
INV. H03H9/54 H03H9/56 H03H9/60 H03H9/64 H03H7/075
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H03H

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

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

EPO-Internal, WPI Data, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012/293277 A1 (HARA MOTOAKI [JP] ET AL) 22 November 2012 (2012-11-22) paragraph [0062] - paragraph [0066]; figures 5 - 7 paragraph [0073] - paragraph [0074]; figure 9 paragraph [0076] - paragraph [0077]; figures 11, 12 -----	1-11

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 January 2017	31/01/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Trafidlo, Renata

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2012/286895 A1 (HARA MOTOAKI [JP] ET AL) 15 November 2012 (2012-11-15) paragraph [0045] - paragraph [0056]; figures 4 - 7 paragraph [0063] - paragraph [0071]; figures 11 - 14 paragraph [0084] - paragraph [0086]; figure 18 paragraph [0101] - paragraph [0116]; figures 23, 24 -----	1-11
A	US 2006/139125 A1 (SHIGA-KEN SHIGEYUKI [JP] ET AL) 29 June 2006 (2006-06-29) paragraph [0054] - paragraph [0056]; figure 1 paragraph [0070] - paragraph [0078]; figures 5 - 7; table 1 -----	1-11
A	WO 2014/108254 A1 (EPCOS AG [DE]) 17 July 2014 (2014-07-17) page 15, line 23 - page 16, line 7; figure 3 page 18, line 25 - page 23, line 6; figures 7 - 9 -----	1-11

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2016/076551

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