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(54) **Rectangular waveguide filter with extracted poles**

(57) A band pass rectangular waveguide H-plane configuration (no variation in waveguide height) filter for implementing a transfer function with finite real-frequency transmission zeros which is composed by the cascade connection of a plurality of inductive coupling resonant cavities (C2, C3) and a plurality of cavities (C1,

C4) with a double electrical behaviour. Symmetrical or asymmetrical out of band very high rejections are obtained if the positions of zeros are suitably chosen. In addition, pseudo low-pass and pseudo high-pass filters can be designed if all the transmission zeros are located in the same side out of the band pass

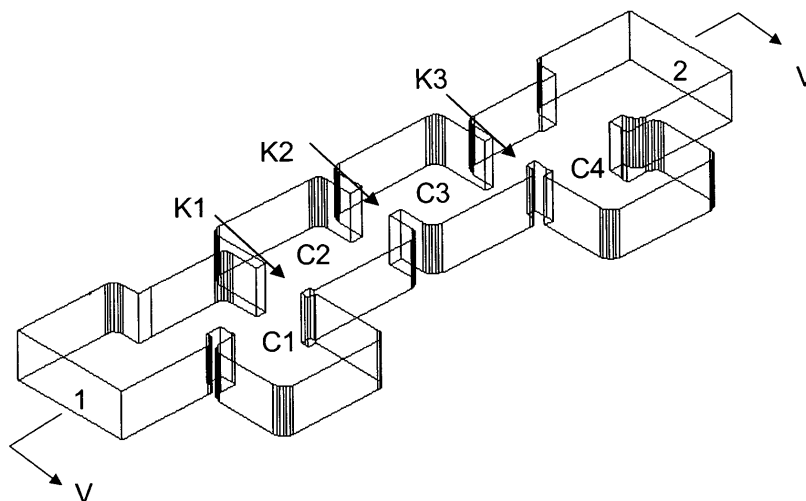


Fig. 4

Description**OBJECT OF THE INVENTION**

[0001] The present invention relates to a new structure for high-power and low insertion losses microwave filters with symmetrical or asymmetrical transfer function response to implement in rectangular waveguide H-plane configuration.

STATE OF THE ART

[0002] The increase in capacity, complexity, and RF power employed in satellite communications and broadcast repeaters, has forced the use of sophisticated filter transfer functions. Regarding the out of band rejection a more and more demanding specification is required at present for innovative applications. In the same way, to save mass and volume it is mandatory not to use high degree filters to fit these specifications. Therefore the inclusion of transmission zeros at real finites frequencies is essential.

[0003] It is known from US5926079 of MOTOROLA a ceramic filter that introduces finite frequency transmission zeroes in a filter's transfer function. Drawbacks in this case are that only two transmission zeroes could be implemented, another one being that two additional cavities must be added to the N cavities that implement the N degree transfer function in order to implement the transmission zeroes, thus increasing mass and dimensions.

[0004] It is known from US4360793 of RHODES and CAMERON an extracted pole filter that allows to implement a transfer function with finite real-frequency transmission zeroes, but it presents several drawbacks: main drawback is that phase shifting waveguide sections have to be introduced, which makes a complex filter layout and increases mass and size, another drawback being that only symmetrical responses are possible, finally, mechanisms must be included in order to eliminate degenerate modes that are present because of the electromagnetic mode of operation. Furthermore another disadvantage is a costly manufacturing process.

[0005] The basic synthesis theory of filters with extracted poles for symmetrical responses was developed in J. D. RHODES, R.J. CAMERON.: 'General extracted pole synthesis technique with applications to low-loss TE₀₁₁ mode filters', IEEE Trans. Microwave Tech., Sep. 1980, vol. 28, n°9, pp. 1018-1028; and later on generalized in R. J. Cameron.: 'General Prototype Network-Synthesis Methods for Microwave Filters', ESA Journal, 1982, vol.6, pp. 193-206 for asymmetrical responses. In J.R. Montejo-Garai.: 'Synthesis of N-Order Filters with N Transmission Zeros at Real Frequencies by means of Extracted Poles', Electronics Letters, Jan. 2003, vol.39, n°2,pp. 182-183, an extension is developed in order to extract the maximum number of transmission zeros in N-degree filters with either symmetrical or asymmetrical

responses.

CHARACTERISATION OF THE INVENTION

5 [0006] The present invention seeks to overcome or reduce one or more of the above problems by means of an electric transmission structure for implementing a transfer function of N degree that can incorporate finite real-frequency transmission zeros, the structure comprising: a main rectangular waveguide without change in height (H-plane configuration) wherein the body of the structure comprises a plurality of resonant cavities placed adjacent to each other and connected with inductive irises and at least one cavity with a double electrical behaviour, i.e. operating as a resonant cavity in transmission at central frequency of the passband and simultaneously introducing a controlled transmission zero out of the passband.

10 [0007] A further object of the present invention is to provide a new structure for cavity filters assuring a drastic reduction in mass and volume in comparison with the all-pole transfer functions with the same rejection specification.

15 [0008] Another object of this invention is to provide a new cavity arrangement with a double controlled electrical behaviour that allows to introduce transmission zeros at finite real frequencies.

20 [0009] Yet another object of the invention is a synthesis technique for the synthesis of N-degree filters with N-transmission zeros at real frequencies by means of extracted poles.

25 [0010] In accordance with the invention there is provided an electric transmission structure in rectangular waveguide for implementing a transfer function with transmission zeros at finite real frequencies. This structure comprises a plurality of resonant cavities placed adjacent to each other with inductive irises between adjacent cavities, and at least one cavity with a double controlled electrical behaviour connected to the "classical" resonant cavities by means of inductive irises.

30 [0011] The structure according to the invention has the advantage of allowing the filter to be mechanized in a simple and very compact construction without slots or critical dimensions to ensure a high RF power handling capability, increasing the multipactor margin in space applications. In addition, the cost and the manufacturing dimensional tolerance sensitivity are reduced. This construction allows using large cavities to increase the Q in order to maintain low insertion losses at high frequencies.

35 [0012] A further advantage of the invention is that fine adjustment of all elements, i.e., cavities and coupling between them, is possible by means of tuning screws. These are not part of the structure but elements to compensate for the mechanical tolerances.

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BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The characteristics and advantages of the invention will become more clear with a detailed description thereof, taken together with the attached drawings, in which:

- Figure 1 shows the low pass prototype filter of 3th degree with 3 transmission zeros at finite real frequencies according to the invention,
- Figure 2 shows the low pass prototype filter of 4th degree with 2 transmission zeros at finite real frequencies according to the invention,
- Figure 3 shows the band pass prototype filter of 4th degree with 2 transmission zeros at finite real frequencies corresponding to low pass prototype in figure 2,
- Figure 4 is a view of an exemplary rectangular waveguide realization of the network shown in figure 3,
- Figure 5 is a longitudinal view along line VV in figure 4,
- Figure 6 shows an example of insertion (A) and return losses (B) of a filter with the characteristics described in figures 2 and 3.

DESCRIPTION OF THE INVENTION

[0014] In order to verify a band pass filter rejection specifications, the first task is to generate the transfer function that in the more general case can be always expressed as the ratio of two finite-degree polynomials with complex coefficients (from here on, the degree of the transfer function is the degree of the numerator polynomial). The evaluation of this mathematical response must fit with the out of band rejection specifications and the return losses in the passband.

[0015] Once this task has been carried out, the next step is to synthesize a low-pass prototype network, i.e., to obtain the values of the electrical components such as capacitors, inductors, admittance/impedance inverters, frequency invariant reactances/susceptances and transmission lines. The response of this electrical network must be the same as that of the mathematical transfer function. For the case of band pass filters a transformation is necessary to translate the low-pass response to the considered frequency band. Equally important, since mechanical structure is the rectangular waveguide, a one-to-one correspondence between the electrical circuit elements and the physical resonant cavities and irises is necessary.

[0016] FIG. 1 shows as an example, the low pass prototype of a 3th degree network with 3 transmission zeros

in the real frequency axis, wherein ψ_1 , ψ_2 , ψ_3 , ψ_4 and ψ_5 represent electrical lengths corresponding to transmission lines, K is an admittance inverter, 1 is a unity inverter, L1, L2, and L3 are inductors, and jX_1 , jX_2 , and jX_3 are frequency invariant reactances.

[0017] FIG. 2 shows another example, the low pass prototype of a 4th degree network with 2 transmission zeros in the real frequency axis, wherein ψ_1 , ψ_2 , ψ_3 and ψ_4 represent electrical length corresponding to transmission lines, C1 and C2 are capacitors, L1 and L2 are inductors, jX_1 and jX_2 are frequency invariant reactances and jB_1 and jB_2 are frequency invariant susceptances.

[0018] FIG. 3 shows the equivalent rectangular waveguide H-plane structure to implement the network corresponding to FIG. 2, wherein ψ_2^* and ψ_3^* represent electrical length corresponding to transmission lines, K1, K2 and K3 are admittance inverters, C1 and C4 are the equivalent circuit elements of the cavities with double electrical behaviour, C2 and C3 are the equivalent circuit elements of the classical resonant cavities. FIG. 4 is a view of an exemplary rectangular waveguide realization of the network shown in FIG. 3 according to the invention. 1 and 2 are the input and output of the structure respectively. C1 and C4 are cavities with double electrical behaviour. C2 and C3 are resonant cavities. K1, K2 and K3 are inductive irises for coupling adjacent cavities.

[0019] FIG. 5 is a perspective representation of a cross section along the line VV of the rectangular waveguide of FIG. 4 wherein the position of the cavities can be clearly observed.

[0020] Note that this structure is composed by two different types of resonant cavities; C2 and C3 are two inductive coupled (shunt reactive iris K2) transmission cavities. C1 and C4 are a new structure having a double controlled electrical behaviour; each one operates as a resonant cavity in transmission at central frequency of the passband and simultaneously introduces a controlled transmission zero out of the band. C1 and C4 are inductive coupled to C2 and C3 by means of shunt reactive irises K1 and K3 respectively. Therefore, it is possible to guarantee the required return losses and at the same time to introduce a transmission zero in the desired position. If the rectangular waveguide elements are correctly dimensioned the electrical response of the structure will be very similar to that predicted by the mathematical filtering function. However, in the synthesis process an attention will be paid to the circuitual values, in order to obtain the most adequate results because of the mechanical constraints.

[0021] The dimensions of the cavities with double behaviour can therefore be obtained by way electromagnetic simulation in conjunction with optimisation of their structure. This simulation can provide different dimensions depending on the requirements of the design in each particular case. In the example of figures 4 and 5 these double behaviour cavities C1 and C4 are shown

to represent an extension to a side of the filter structure, clearly being different from the rest of the cavities, e.g. C2 and C3.

[0022] Based on design parameters, the cavities with double behaviour may adopt a variety of structures, for example instead of being extended to a side of the waveguide, i.e. having a width larger than the general width of the waveguide structure as shown in figures 4 and 5, they could have a width being smaller than the general width of the rectangular waveguide (not shown).

[0023] The use of minimum phase networks like the one shown above, is more desirable because element-value sensitivity is less and network complexity is reduced. If cross-couplings are employed, the designer does not have specific control over the positions of the zeros because there is not a one to one correspondence between zeros and cross-couplings. For this reason such kind of structures are very sensitive and difficult to adjust. However, by implementing the extracted-pole technique every transmission zero, is controlled independently. This is a very important asset from the engineering point of view in order to minimize the sensitivity of the network for mass production.

[0024] The synthesis technique is based on a systematic process to extract the (attenuation) poles. In order to deal with asymmetric electrical responses, where the transmission zeros on the imaginary axis of the complex plane are asymmetrically disposed, it is necessary to extract them individually.

[0025] Filters exhibiting their maximum number of finite transmission zeros at real frequencies (N zeros corresponding to N degree) make possible to design transfer functions with very high selectivity. Since an N-degree filter with N transmission zeros has finite insertion losses at infinite frequency (the transfer function is a rational expression with polynomials in the numerator and denominator of the same N degree), a change in the impedance level must be introduced in the network to assure this behaviour. This impedance level change has its circuitual representation as an ideal transformer of relation 1:K, as shown in FIG.1.

[0026] The synthesis process is composed by two different steps. The initial part of the synthesis procedure is carried out in terms of the transfer function of the filter and includes several extraction cycles (as many as finite real transmission zeros) in order to extract the finite poles, each cycle comprising the steps of determining the phase lengths of the unity inverters, the residue of every pole (shunt series resonator), the capacitors and the invariant shunt reactances to cope with the asynchronously tuned network.

[0027] Once the element values of the extracted pole prototype network have been obtained the synthesis procedure improves further to transform the prototype network into the equivalent rectangular waveguide structure arrangement according to the invention. The transformation converts the phase lengths of the transmission lines into an admittance inverter plus a new

phase length, as shown in FIG.3.

[0028] Figure 6 illustrates a simulation of the electromagnetic response of the waveguide structure wherein curve A represents insertion loss and curve B represents return loss. In this figure the effect of a cavity with double behaviour in introducing controlled transmission zero out of the band can be seen in the deep minimal insertion loss shown in curve A.

Filters obtained according to the invention can be connected in arrangements so as to provide a multiplexing or demultiplexing network. Examples of such connections are by connecting a plurality of filters by rectangular waveguides sections and tee's (connection devices in the form of T, known in the art) the height of each is equal to that of the rectangular waveguide of the filters, i.e. in H-plane configuration. An alternative connection is obtained by means of transmission line sections and tee's, and in particular said transmission line sections can be coaxial.

Claims

1. An electric transmission structure for implementing a transfer function of N degree that can incorporate finite real-frequency transmission zeros, the structure comprising a main rectangular waveguide without change in height, i.e. in H-plane configuration, said structure comprising a plurality of resonant cavities (C2, C3) placed adjacent to each other and connected with inductive irises (K1, K2, K3); **characterized in that** the structure comprises at least one cavity (C1, C4) with a double electrical behaviour, thereby said at least one cavity being adapted for operating as a resonant cavity in transmission at central frequency of the passband and for simultaneously introducing a controlled transmission zero out of the passband.
2. An electric transmission structure according to claim 1, wherein said at least one cavity with double behaviour has dimensions being different from those of said resonant cavities.
3. An electric transmission structure according to claim 2, wherein said at least one cavity with double behaviour is extended to a side of the filter structure.
4. An electric transmission structure according to claim 2, wherein said at least one cavity with double behaviour has a width being smaller than a width of a resonant cavity.
5. A electric transmission structure according to claim 1; wherein the total number of cavities, including the resonant cavities and cavities with double behaviour, is equal to the degree of the transfer function.

6. A band pass filter structure according to any one of the claims 1 to 5.
7. A band pass filter structure according to claim 6; wherein said filter structure comprises only cavities with a double electrical behaviour, implementing N transmission zeros of an N degree transfer function. 5
8. A band pass filter structure according to claim 6; wherein some of the resonant cavities are cross coupled by using a folded or a bend configuration. 10
9. A band pass filter structure according to claim 6; wherein an input and/or an output of the structure is by means of a coaxial connector. 15
10. A plurality of filters according to claim 6 connected by rectangular waveguides sections and tee's the height of which being equal to that of the rectangular waveguide of the filters (H-plane configuration), thereby providing a multiplexing or demultiplexing network. 20
11. A plurality of filters according to claim 6 connected by transmission line sections and tee's, thereby providing a multiplexing or demultiplexing network. 25
12. A plurality of filters according to claim 11 wherein said transmission line section is coaxial. 30

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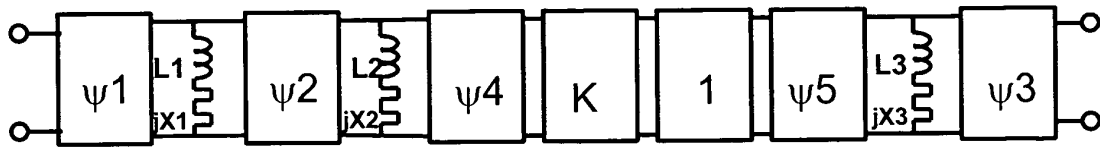


Fig. 1

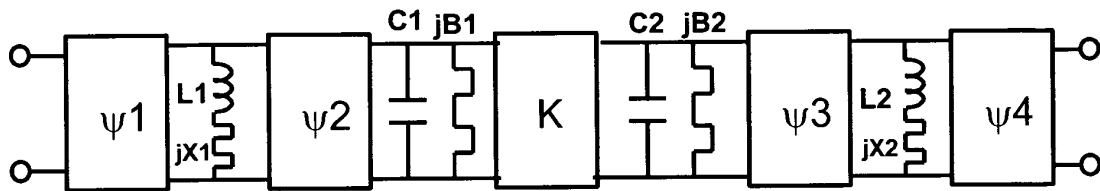


Fig. 2

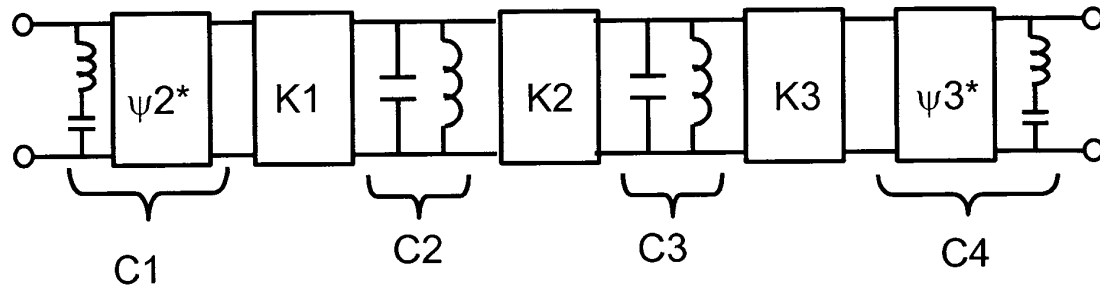


Fig. 3

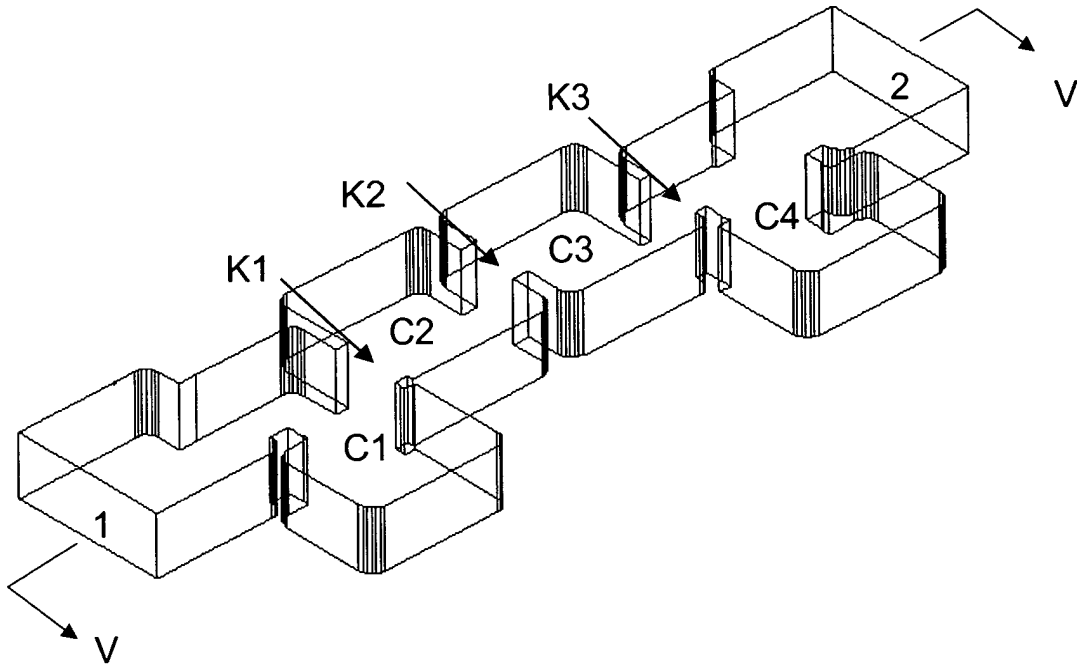


Fig. 4

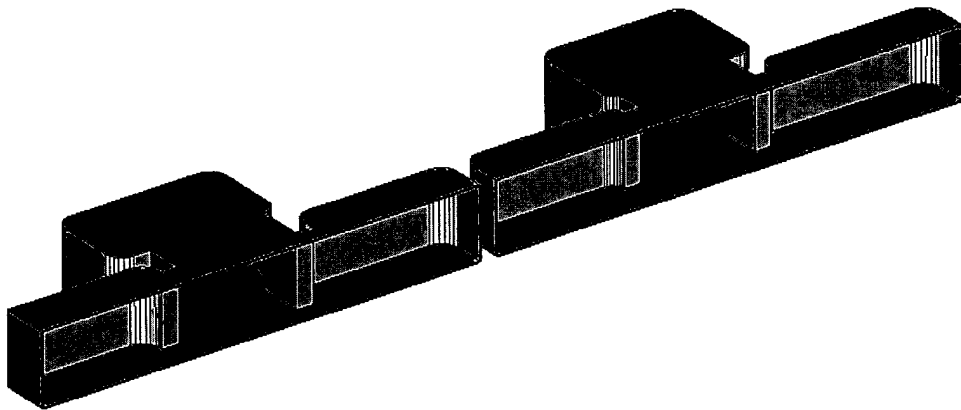


Fig. 5

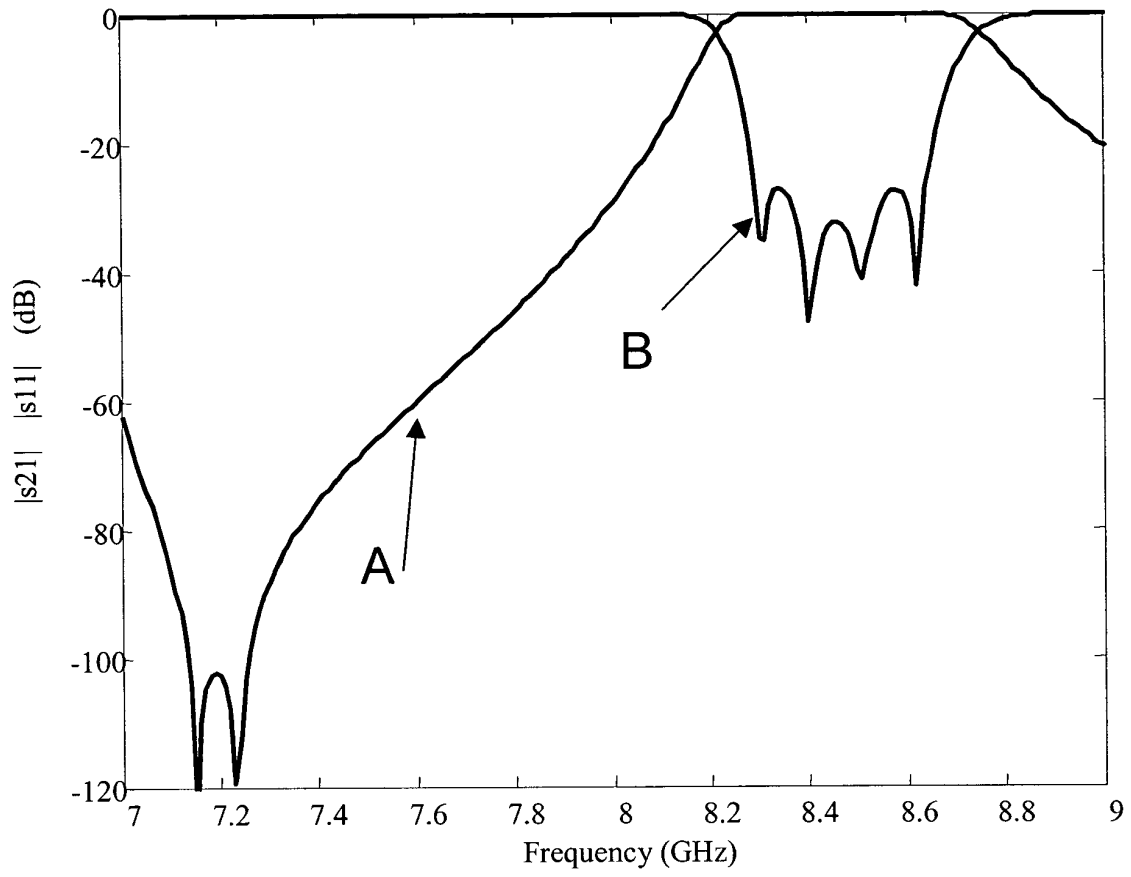


Fig. 6



European Patent
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EUROPEAN SEARCH REPORT

Application Number
EP 03 29 3113

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The present search report has been drawn up for all claims			
Place of search MUNICH		Date of completion of the search 22 March 2004	Examiner Jäschke, H
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