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(54) IMPROVEMENTS IN OR RELATING TO MICRO-WAVE FILTERS

(71) We, SIEMENS AKTIENGESELLSCHAFT, a German Company of Berlin and Munich, German Federal Republic, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

The invention relates to micro-wave filters, i.e. to filters for very short electromagnetic waves, consisting of a plurality of mutually coupled resonators in adjacent rows and operated in the dual mode to provide a filter characteristic equivalent to a series of resonant circuits with additional bridge coupling between at least two said resonant circuits which do not lie adjacent in said sequence, there being an input line for a first resonator in the direction of transmission, and an output line connection for the last resonator, considered in said direction, the requisite additional bridge couplings being provided between resonators which do not directly follow one another in the transmission direction.

It is known in micro-wave technology to construct a filter from a plurality of micro-wave resonators which are coupled to one another, using capacitively and/or inductive coupling. The resonators themselves can be coaxial line resonators or waveguide resonators, for example.

In contrast to filters constructed with lumped circuit elements, the geometrically predetermined configuration of the resonators makes it impossible to readily construct an equivalent for every circuit which can be constructed using lumped circuit elements. Particular difficulty occurs if it is necessary to produce attenuation poles in the attenuation characteristic of the filter, and/or to effect an equalisation of transit time in the pass band of the filter by means of additional bridge couplings of filter circuits. One proposal for avoiding this difficulty is described in the German Patent Specification No. 1,942,867 resonators in neighbouring rows being provided with additional bridge couplings in respective common partition walls between pairs of resonators arranged in different rows.

The possibility of constructing micro-wave filters using cavity resonators which are simultaneously operated in more than one mode is also known, see for example the article entitled "Microwave Filters Employing a Single Cavity Excited in More than One Mode", published in "Journal of Applied Physics", Vol. 22 No. 8, August, 1951, by Wei-Guan Lin; or an article entitled "A Four Cavity Elliptic Waveguide Filter", published in "IEEE Transactions on Micro-wave Theory and Techniques", Vol.-MTT 18, No. 12, December, 1970 by A.E. Williams. In these cases preferably two identical but orthogonal modes are employed in H_{101} resonators or H_{111} resonators, and are mutually coupled by a coupling screw arranged at 45° to the direction of the respective E-vectors (dual mode). In this way, two resonant circuits of a filter can be constructed in one single cavity resonator in a technically effective fashion. On account of the saving in respect of weight and volume of up to 50° which can be achieved with such dual-mode operation, it presents important advantages for application in satellite technology, particularly as the filters employed therein are required to satisfy stringent requirements, which is normally manifest by a relatively large number of resonant circuits or their equivalent.

Since these filters require attenuation poles and/or equalisation of the transit time in the pass band, it is obviously desirable to exploit suitable equivalents of lumped circuit filters using the dual-mode technique. In this context one known proposal is described in an article entitled "Nonminimum-Phase Optimum-Amplitude Bandpass Waveguide

Filters", published in "IEEE Transactions on Micro-wave Theory and Techniques", Vol. MTT-22, No. 4, April 1974 by A.E, Atia and A.E. Williams but this proposal is restricted to filter circuits which are symmetrical both in respect of structure and in respect of element values, and which furthermore possess overlapping, additional bridge couplings whose number and geometric position within the filter arrangement cannot be preselected, and the equivalent number of resonant circuits must amount to a multiple of four, as a result of which there are many cases in which this proposal cannot be put into practice. One important prerequisite of the construction of filters with additional bridge couplings and using the dual-mode technique is that the resonator arrangement permits a correct sign realisation for all the couplings.

One possible arrangement for improving the realisability of filter circuits which are asymmetrical in particular in respect of element values and are operable in the dual-mode is described in our co-pending United Kingdom Patent Application No. 8859/76 (Specification No. 1,549,318), in which the resonators are arranged in neighbouring rows, with a different number of resonators in at least two rows.

The coupling of filter circuits in resonators which differ spatially is conditional upon the relevant two filter circuits being identically orientated spatially, so that, for example, the E-vectors thereof are mutually parallel. Since this condition restricts the number of theoretically conceivable couplings, and thus limits the spectrum of possible realisations, unless extra additional bridge couplings are provided, and in any case, presents considerable production disadvantages.

One object of the invention is to provide a construction which substantially overcomes these difficulties in a simple fashion and extends the spectrum of possible realisations.

The invention consists in a micro-wave filter in which two or more rows, each comprising a plurality of mutually coupled resonators operated in the dual-mode to provide two mutually coupled effective resonant circuits in each case, the first and last resonators, considered in the direction of energy transmission, being provided with input and output connection lines respectively, and a plurality of additional bridge coupling being provided, respectively linking selected effective resonant circuits which are not directly consecutive in the transmission direction, said resonators being arranged in a mechanically symmetrical configuration relative to a central point, but the equivalent circuit diagram having an asymmetrical distribution of the coupled resonant circuit values relative to said point, such that the number of additional bridge couplings required is significantly less than would be needed in a purely symmetrical design.

Thus, in a preferred embodiment the equivalent circuit diagram of the embodiment has asymmetrical element values, selected such that the number of additional bridge couplings equals the minimum number of additional bridge couplings, as determined by theory.

The invention is based on the recognition that it is possible to construct a filter in the dual-mode technique with the minimum number of additional bridge couplings by basing a mechanically symmetrical resonator arrangement upon an equivalent circuit diagram which is asymmetrical in respect of its element values.

A particular advantage is achieved in embodiments of the invention in that the limitations regarding the possibility of constructing complicated circuit structures which exist in known filters of this type are considerably reduced.

Further advantages are attained by the significant reduction in the number of additional couplings required for the realisation, and the resultant substantial simplification of production and for tuning of a filter constructed in accordance with the invention.

One advantageous embodiment constructed in accordance with the invention is a transit-time equalised twelve-circuit band-pass filter, with a pair of attenuation poles at finite frequencies both below and above the pass band the resonators being arranged in two adjacent rows of three resonators, with five adidtional bridge couplings.

In a further advantageous embodiment constructed in accordance with the invention has only four additional bridge couplings, as described with reference to the exemplary embodiment.

The invention will now be described with reference to the drawings, in which:-

Figure 1 schematically illustrates the theoretical equivalent circuit diagram of a symmetrical lumped circuit configuration comprising the basis for a twelve section dual-mode band-pass filter;

Figure 2 schematically illustrates the construction of one known resonator arrangement forming a filter unit having characteristics corresponding to the Figure 1 circuit;

Figure 3 schematically illustrates the theoretical equivalent circuit diagram of a circuit with a configuration that is symmetrical, but has an asymmetrical arrangement of resonant circuits and bridge couplings to form a twelve-section dual-mode band-pass filter;

Figure 4 schematically illustrates one exemplary embodiment of a twelve section filter constructed in accordance with the invention;

Figure 5 graphically shows the echo

attenuation characteristic of the filter shown in Figure 4; and

Figure 6 graphically shows the operating attenuation characteristic of the filter shown in Figure 4.

Figure 1 schematically illustrates the theoretical equivalent circuit diagram of a symmetrical configuration of elements that are symmetrically valued, for a twelve section dual-mode band-pass filter of known construction, as described for example in the article, referred to in the introduction entitled "Nonminimum-Phase Optimum-Amplitude Bandpass Waveguide Filters".

The circuit in question is a four terminal network having shunt arms in which are arranged respective parallel resonant circuits S1 to S12, symbolically illustrated as circles, and with mutual couplings effected via coupling reactances 1/2, 2/3, to 11/12, which are represented as simple line connections located in series arms. Additional bridge couplings are provided by the five bridge coupling reactances, 1/12, 2/11, 3/10, 4/9 and 5/8, which symmetrically overlap a centre S of the circuit, and four coupling reactances 1/4, 3/6, 7/10 and 9/12, which are symmetrically disposed relative to the circuit centre S, but do not extend across the circuit centre S. In Figure 1 these bridge coupling reactances have been represented as simple line connections running between the relevant parallel resonant circuits, and are identified by references which indicate the respective two parallel resonant circuits with an interposed oblique stroke. The central line of symmetry passes through the electrical circuit centre S, and, in the case of the known realisation shown in Figure 2 is also mechanically symmetrical relative to the line S. For reasons of symmetry this circuit diagram is subject to the following requirement for the bridge coupling band-widths:

$$\Delta f_{1/4} = \Delta f_{9/12}$$

$$\Delta f_{3/6} = \Delta f_{7/10}$$

A filter structure based upon the circuit illustrated in Figure 1, can be achieved, for example, by means of H_{101} resonators, as schematically for the known structure illustrated in Figure 2. Here the correct-sign coupling of the filter circuits is effected in known manner by a suitable positioning of dual-mode coupling screws (not illustrated) within each resonator, and by coupling slots (not shown) in common partition walls between neighbouring resonators. For this mechanically symmetrical resonator arrangement, which is constructed in two neighbouring rows within each case three resonators, arrows E1 to E12 indicate the position of the respective E-vectors of the corresponding resonant circuits S1 to S12. With this type of realisation of a twelve section band-pass filter, however nine additional bridge couplings are required arranged in common partition walls of the resonators, which necessitates a substantial production expenditure.

For a twelve section dual-mode filter constructed in accordance with the invention, to provide the same electrical transmission function as the equivalent circuit diagram shown in Figure 1, a basically mechanically symmetrical resonator arrangement of a configuration identical to that of the known structure shown in Figure 2 may be used, if the fundamentally mechanically symmetrical realisation is based upon an asymmetrical electrical equivalent circuit diagram such as that shown in Figure 3.

The theoretical equivalent circuit diagram shown in Figure 3 has a symmetrical configuration, but has asymmetrical element values, and although its characteristics are equivalent to the circuit illustrated in Figure 1, and is formed by parallel resonant circuits S1 to S12, symbolically shown as circles, and series mutual couplings via reactances 1/2, 2/3 to 11/12 arranged in the series arms.

By way of additional bridge couplings, there are introduced in this case an overall bridge coupling reactance 1/12 and the intermediate bridge couplings 4/9 and 5/8, which all overlap the circuit centre (not shown), together with bridge coupling reactances 1/4 and 9/12 which are symmetrical to the circuit centre, but do not overlap. The construction of an element-asymmetrical equivalent circuit diagram of this type by means of a symmetrical resonator arrangement requires four additional couplins less than the known construction corresponding to Figure 1 and 2, and the overall coupling 1/12 is optional. On account of the asymmetry in respect of the element values, in the band-pass filter constructed in accordance with the invention the tuning is achieved if the bridge coupling band widths $\Delta f_{1/4}$ and $\Delta f_{9/12}$ differ from one another.

The exemplary embodiment of the invention shown in Figure 4 illustrates a corresponding filter arrangement which consists of six cavity resonators 1 to 6 and the physical equivalent circuit diagram of which, as described in the following, is governed in principle by the circuit illustrated in Figure 3, except for the omission of the over-all bridge 1/12. As in Figure 2, the resonators 1 to 6 in the exemplary embodiment are distributed between two neighbouring rows in such manner that one row contains the resonators 1 to 3 and the other row contains the resonators 4 to 6, and that the resonators arranged beside one another, and those above one another in the two rows each possess a respective common partition wall.

The exemplary embodiment thus consists of a twelve section dual-mode band-pass filter having only four additional bridge couplings in order to achieve attenuation poles at finite frequencies and a transit time equalisation in the pass band, employing H_{101} resonators. The middle frequency of the band-pass filter indicated is 4,015 MHz, and has a signal band width Δf that amounts to 36 MHz. Apart from the overall additional bridge coupling 1/12, which is dispensed with, the exemplary embodiment corresponds to the theoretical equivalent circuit diagram shown in Figure 3 ($\Delta f_{1/4} \neq \Delta f_{9/12}$), in which all the additional bridge couplings are inductive, and, with the exception of capacitive series coupling reactances 1/2 and 11/12, the remaining coupling reactances 2/3 to 10/11 arranged in the series arms are inductive.

In the exemplary embodiment, the coupling elements which serve to couple the resonators operated in the dual-mode are designed as slot couplings, and are arranged in such manner that the electromagnetic energy fed to the resonator 1 of the filter via input terminal I successively passes through the resonators 1 to 3 of the first row and then through the resonators 4 to 6 of the second row, from which it is coupled out at output 0 of the resonator 6.

In the illustrated exemplary embodiment, in known manner, in each case two neighbouring parallel resonant circuits of the equivalent circuit diagram in Figure 3 are both realised by a single resonator, operated in the dual-mode, with two mutually orthogonal modes. The individual E-vectors are orthogonal within any one resonator, and in the drawing appropriately referenced arrows E1 to E12 identify the associated parallel resonant circuits S1 to S12.

For the adjustment of coupling between the orthogonal modes operated therein, each of the resonators is provided with a respective coupling screw K12, K34, K56, K78, K910 and K1112, each of which is arranged between the corresponding E-vectors at an angle of 45° thereto. These screws in each case produce the coupling between two neighbouring parallel resonant circuits of the equivalent circuit, which resonant circuits are constructed in that one resonator.

Furthermore, in the illustrated exemplary embodiment the coupling elements in the common partition walls of the individual resonators are designed as slot couplings, which could possibly be replaced, or partially replaced, by hole couplings, the coupling of the resonator 1 to the resonator 2 being effected through pairs of coupling slots CS1/4 and CS2/3, whilst additional bridge coupling 1/4 is effected through a pair of coupling slots CS1/4, and the series coupling reactance 2/3 of the equivalent circuit diagram located in the series arm being effected through a pair of coupling slots CS2/3. In this case the coupling always takes place between those two modes whose associated E-vectors are aligned in neighbouring resonators, and in parallel with one another, via coupling slots which are arranged mutually perpendicular to these E-vectors in the common partition wall of these resonators. These considerations regarding the arrangement of the coupling slots also apply to the following resonators 2 to 6, identified by the associated E-vectors, E3 to E12, respectively. The common partition wall between the resonators 2 and 3 contains coupling slots CS4/5, the common partition wall between the resonators 3 and 4 contains coupling slots CS6/7 and CS5/8, the common partition wall between the resonators 4 and 5 contains coupling slots CS8/9, whilst the common partition wall between the resonators 5 and 6 contains coupling slots CS9/12 and CS10/11. In the common partition wall between the resonators 2 and 5 there is also arranged a bridge coupling slot CS4/9, which runs perpendicularly to the E-vectors E4 and E9.

The construction of the twelve section dual-mode filter can thus have five bridge couplings less than in a known construction corresponding to Figure 1 and 2, and thus offers considerable advantages both electrically and in particular from the point of view of production technology.

Figure 5 graphically shows the echo attenuation course of an exemplary embodiment as shown in Figure 4. As can be seen from this drawing, within a frequency range having a width of $\Delta f = 44.3$ MHz, the measured echo attenuation curve lies above a value of 23 dB, which corresponds to a reflection factor of $\leq 7\%$.

The two clearly defined pairs of poles both below and above the pass band can be seen from the curve, illustrated in Figure 6, which shows the operating attenuation in the blocking band.

WHAT WE CLAIM IS:-

1. A microwave filter in which two or more rows, each comprising a plurality of mutually coupled resonators operated in the dual-mode to provide two mutually coupled effective resonant circuits in each case, the first and last resonators, considered in the direction energy transmission, being provided with input and output connection lines respectively, and a plurality of additional bridge coupling being provided, respectively linking selected effective resonant circuits which are not directly consecutive in the transmission direction, said resonators being arranged in a mechanically symmetrical configuration relative to a central point, but the equivalent circuit diagram having an asymmetrical distribution of the coupled resonant circuit values relative to said point, such that the number of additional bridge couplings

required is significantly less than would be needed in a purely symmetrical design.

2. A filter as claimed in Claim 1, in which the filter characteristic is that of a transit-time equalised band-pass filter having a pair of attenuation poles at finite frequencies both below and abot the pass band, said resonators being arranged in two juxtaposed rows which each contain three resonators, with five additional bridge couplings.

3. A filter as claimed in Claim 1, in which the filter characteristic is that of a transit-time equalised band-pass filter having a pair of attenuation poles at finite frequencies both below and above the pass band, said resonators being arranged in two juxtaposed rows which each contain three resonators, with four additional bridge couplings.

4. A microwave filter substantially as described with reference to Figure 4.

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1590860 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

Fig. 1

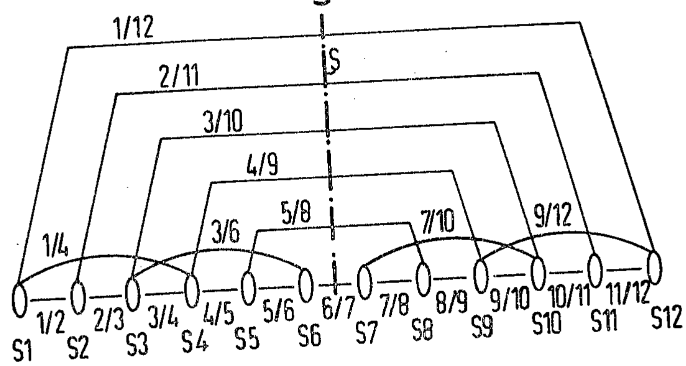


Fig.2

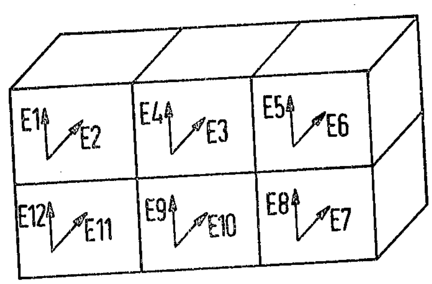
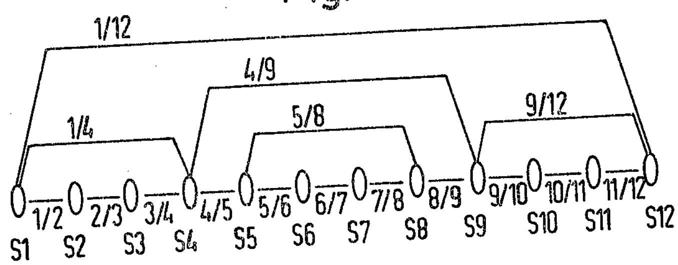


Fig. 3



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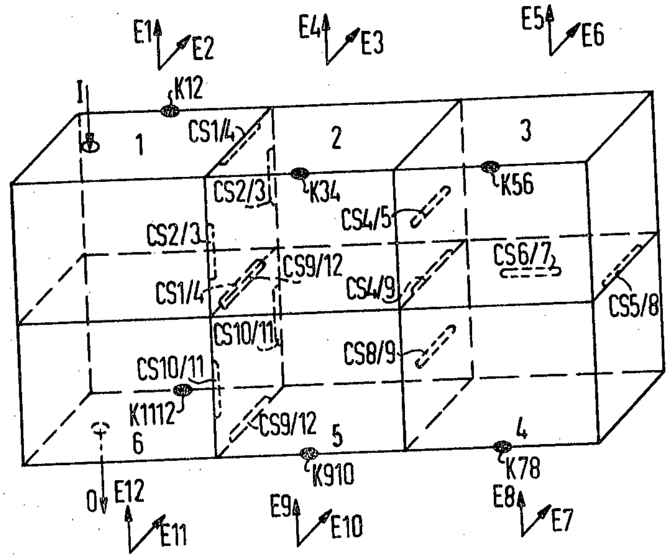
Sheet 2

Fig.4



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Sheet 3

Fig.5

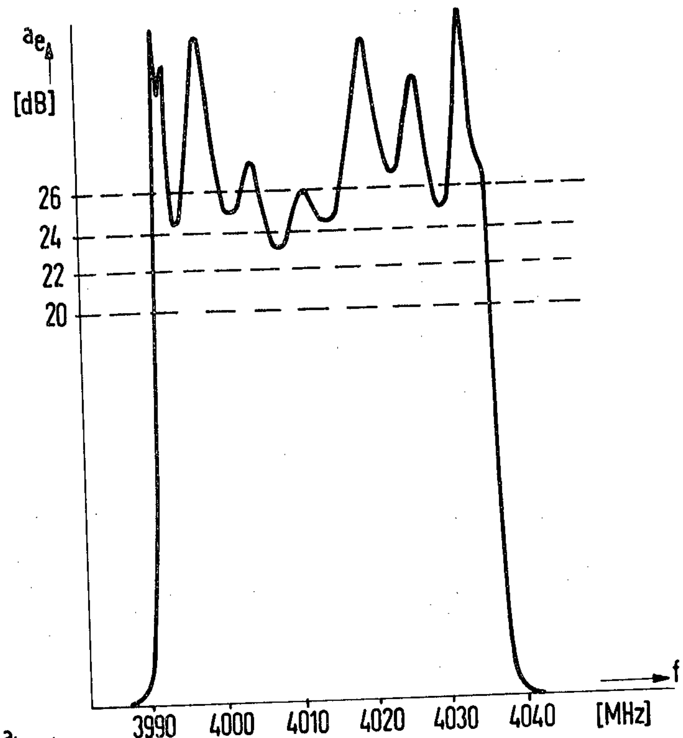

Fig.6