

[54] **MICROSTRIP FILTER**

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[52] **U.S. Cl.**..... 333/73 S, 333/70 S, 333/84 M
 [51] **Int. Cl.**..... H03h 7/10, H01p 3/08
 [58] **Field of Search**..... 333/70 S, 73 S, 84 M

[56] **References Cited**

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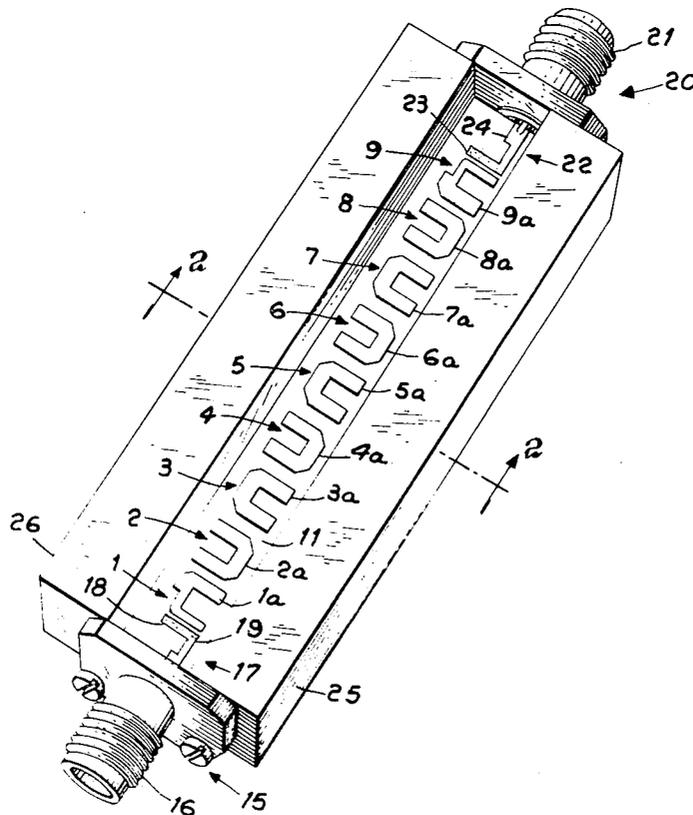
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loss and high rejection at X-band. The filter includes N microstrip open circuited, half-wavelength hairpin resonators disposed in a series coupled relationship with respect to each other, where N is an integer equal to or greater than one. A metallic housing encloses the hairpin resonators for shielding thereof to increase the unloaded Q of the resonators. An improved signal input and output coupling arrangement is also provided for the filter. The signal coupling arrangements include a microstrip conductor having a first width less than the width of the microstrip conductor forming part of each of the hairpin resonators between the input and output hairpin resonators. In the coupling arrangement, the adjacent limb and a portion of the cross-arm connected to the adjacent limb of the conductor of the input and output hairpin resonators also have said first width and the spacing of the limbs of the conductors of the input and output hairpin resonators are greater than the spacing of the limbs of the conductors of the hairpin resonators between the input and output hairpin resonators.

[57] **ABSTRACT**

There is disclosed herein a microstrip filter having low

10 Claims, 6 Drawing Figures



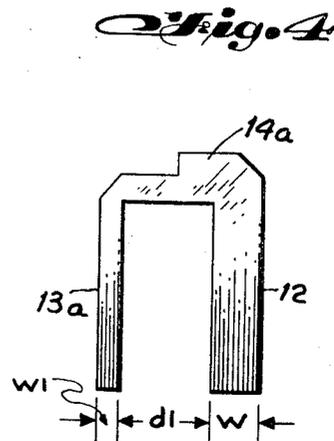
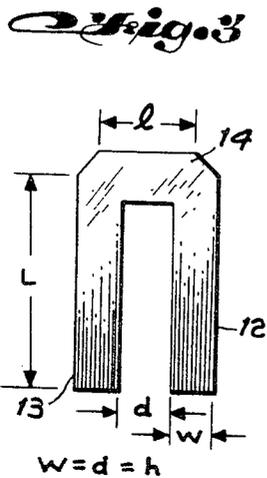
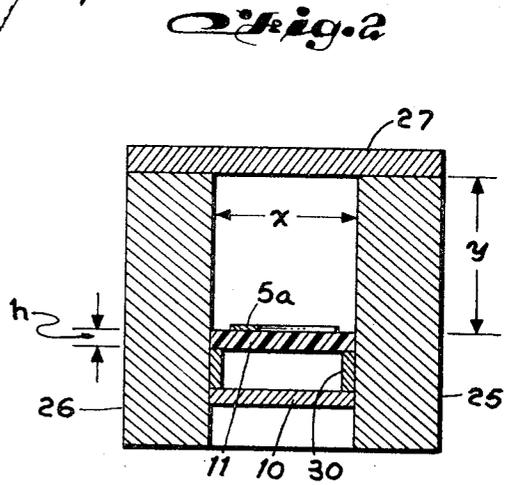
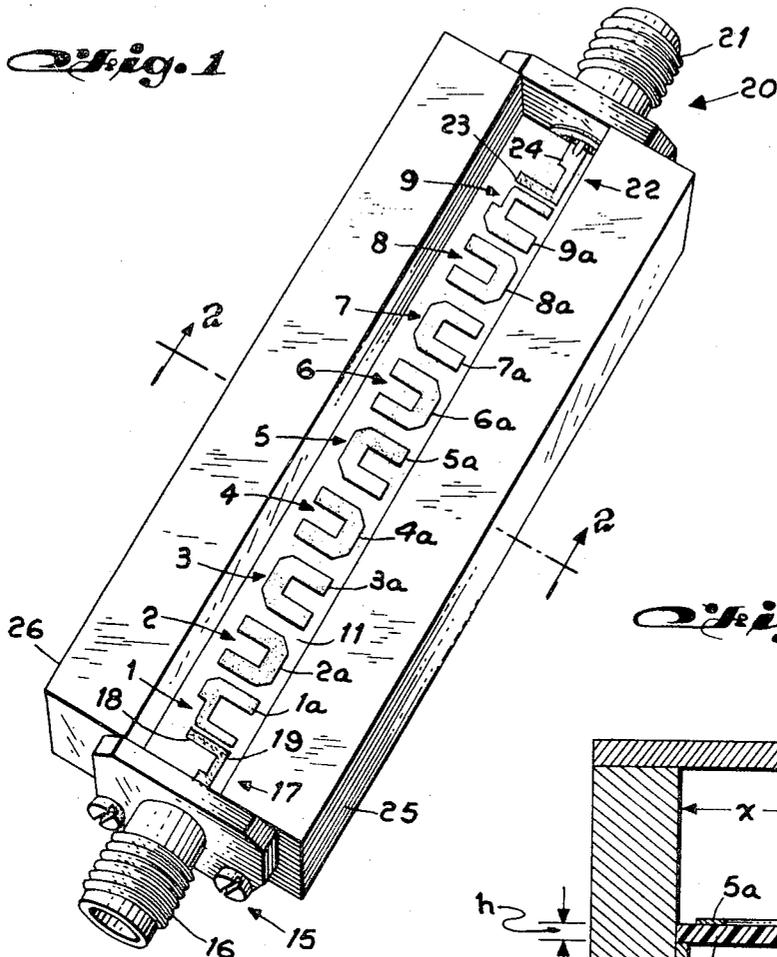


Fig. 5

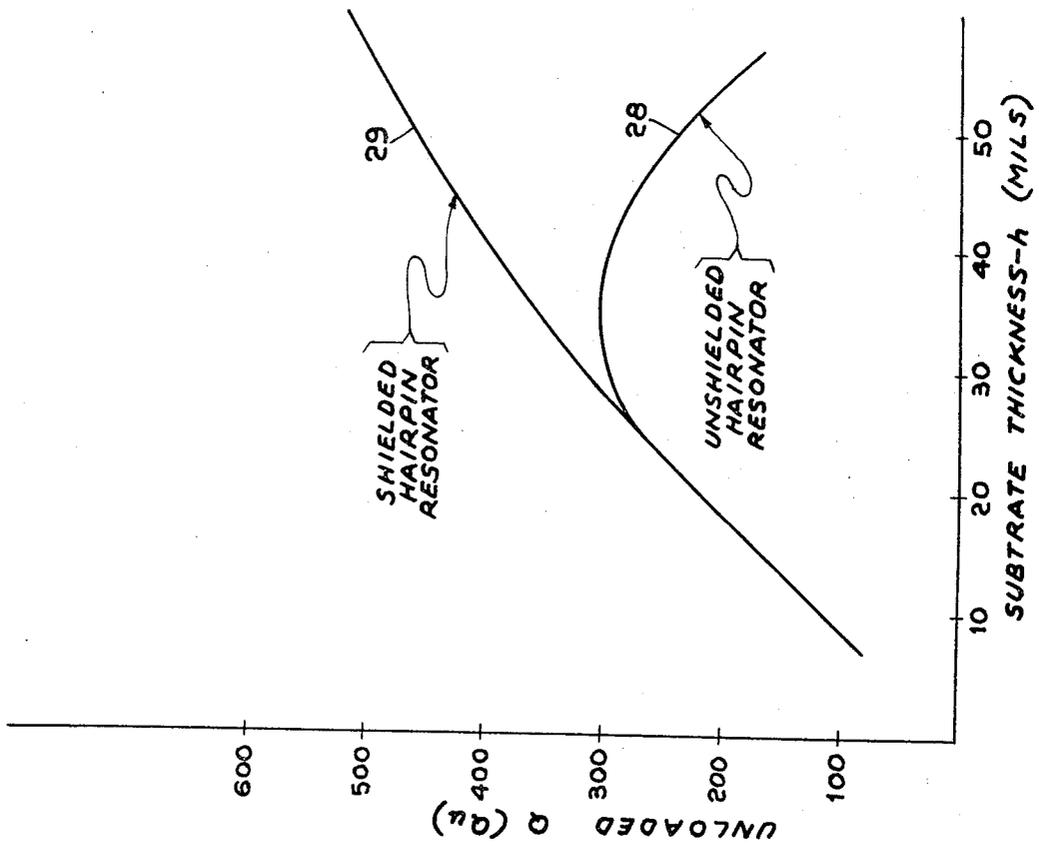
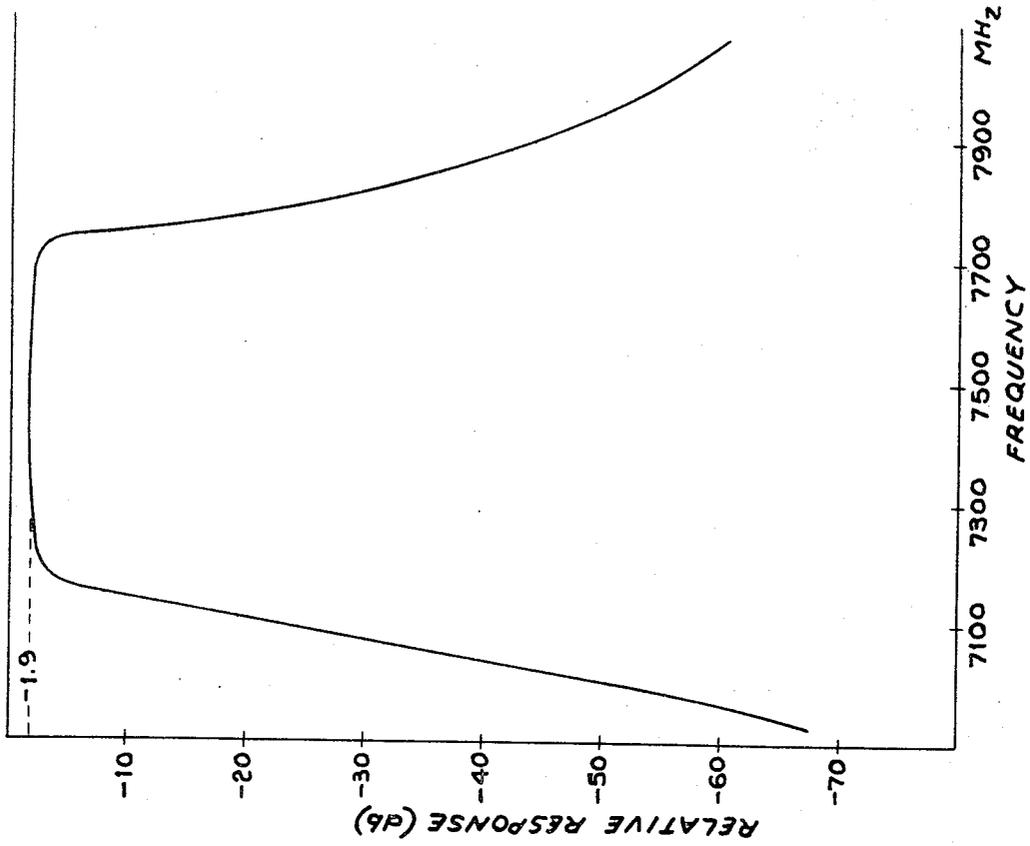


Fig. 6



MICROSTRIP FILTER

BACKGROUND OF THE INVENTION

This invention relates to microstrip filters and more particularly to microstrip filters operable at X-band.

Microstrip filters for X-band operation are generally lossy, and also provide very limited rejection out-of-band. The problem is attributed to radiation into the free space above the microstrip substrate. The following articles have suggested techniques to overcome this problem. (1) R. J. Roberts and B. Easter, "Microstrip Resonators Having Reduced Radiation Loss," *Electronic Letters*, Vol. 7, No. 8, pp. 191-192, Apr. 1971; (2) A. F. Hinte, G. Kopcsay and J. J. Taub, "Alumina Sandwich Line Filters for High Performance Integrated Circuit Applications," 1971 G-MTT Symposium Digest, pp. 26-27; and (3) A. R. Chinchillo and R. W. Perry, "Microstrip Filter Loss Reduction Techniques," *NEREM 1970 Record*, pp. 72-73.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a microstrip filter for operation at X-band having low loss and high rejection employing a technique different than techniques described in the above-identified prior art articles.

A further object of the present invention is to provide a microstrip filter for X-band operation employing microstrip open circuited, half-wavelength hairpin resonators enclosed in a non-critical enclosure for shielding of the resonators.

Another object of the present invention is to provide a microstrip filter for X-band operation employing microstrip open circuited, half-wavelength hairpin resonators enclosed in a non-critical enclosure for shielding of the resonators having an improved arrangement to couple signals to and to couple signals from the microstrip filter.

A feature of the present invention is the provision of a microstrip filter comprising: N microstrip open circuited, half-wavelength hairpin resonators including a ground plane, a substrate disposed adjacent to, coextensive with and parallel to the ground plane and N hairpin shaped conductors disposed in series coupled relationship with each other on one surface of the substrate opposite the ground plane, where N is an integer equal to or greater than one, each of the N conductors including a pair of parallel spaced limbs interconnected by a cross-arm, adjacent ones of the N conductors having an opposite orientation with respect to each other and adjacent ones of the limbs of adjacent ones of the N conductors being in spaced parallel relationship with respect to each other to provide the series coupled relationship; a microstrip input coupler including a first conductor disposed on the one surface of the substrate in spaced, series coupled relationship with an adjacent one of the limbs of a first of the N conductors; a microstrip output coupler including a second conductor disposed on the one surface of the substrate in spaced series coupled relationship with an adjacent one of the limbs of a last of the N conductor; and metallic members coextensive with the ground plane and the substrate enclosing the one surface of the substrate and the first, second and N conductors to shield the hairpin resonators to increase the unloaded Q of the resonators with respect to the unloaded Q obtainable with unshielded hairpin resonators.

Still another feature of the present invention is the provision of a microstrip filter comprising: N microstrip open circuited, half-wavelength hairpin resonators including a ground plane, a substrate disposed adjacent to, coextensive with and parallel to the ground plane and N hairpin shaped conductors disposed in series coupled relationship with each other on one surface of the substrate opposite the ground plane, where N is equal to an integer greater than two, each of the N conductors including a pair of parallel spaced limbs interconnected by a cross-arm, adjacent ones of the N conductors having an opposite orientation with respect to each other and adjacent ones of the limbs of adjacent ones of the N conductors being in spaced parallel relationship with respect to each other to provide the series coupled relationship; a microstrip input coupler including a first conductor disposed on the one surface of the substrate in spaced, series coupled relationship with an adjacent one of the limbs of a first of the N conductors; and a microstrip output coupler including a second conductor disposed on the one surface of the substrate in spaced, series coupled relationship with an adjacent one of the limbs of a last of said N conductors; each of the limbs and the cross-arm of each of the N conductors between the first and last of the N conductors having a width equal to a first given amount; the spacing between each of the limbs of each of the N conductors between the first and last of the N conductors is equal to the first given amount; the first conductor including a first portion parallel to the adjacent one of the limbs of the first of the N conductors and a second portion perpendicular to the first portion, the first portion and a section of the second portion directly connected to the first portion each having a width equal to a second given amount less than the first given amount; the second conductor including a third portion parallel to the adjacent one of the limbs of the last of the N conductors and a fourth portion perpendicular to the third portion, the third portion and a section of the fourth portion directly connected to the third portion each having a width equal to the second given amount; and the adjacent one of the limbs of each of the first and last of the N conductors and a section of the cross-arms directly connected to the adjacent one of the limbs of each of the first and last of the N conductors having a width equal to the second given amount, the other of the limbs of each of the first and last of the N conductors and the remainder of the cross-arms connected to the other of the limbs of each of the first and last of the N conductors having a width equal to the first given amount and the spacing between the adjacent one and the other of the limbs of each of the first and last of the N conductors is greater than the first given amount.

BRIEF DESCRIPTION OF THE DRAWING

Above-mentioned and other features and objects of this invention will become more apparent by reference to the following description taken in conjunction with the accompanying drawing, in which:

FIG. 1 is a perspective view with the cover removed of a microstrip filter in accordance with the principles of the present invention;

FIG. 2 is an enlarged cross-sectional view taken along line 2-2 of FIG. 1;

FIG. 3 is a top plan view of one of the hairpin shaped conductors of the hairpin resonator disposed between

the input and output hairpin resonators illustrating the dimensions thereof;

FIG. 4 is a top plan view of a hairpin shaped conductor of the hairpin resonator that may be used in the input or output resonator of the filter of FIG. 1 illustrating the dimensions thereof;

FIG. 5 is a curve of the unloaded Q as a function of the substrate thickness at 7,500 MHz (megahertz) on a 99.5 percent alumina substrate for both shielded and unshielded hairpin resonators; and

FIG. 6 illustrates the frequency response of the nine pole filter employing the shielded microstrip hairpin resonators of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIGS. 1, 2, 3 and 4, there is disclosed therein a microstrip filter operable at X-band in accordance with the principles of the present invention. The microstrip filter includes N microstrip open circuited, half-wavelength hairpin resonators 1-9 including a ground plane 10, a dielectric substrate 11 composed of 99.5 percent alumina and N hairpin shaped conductors 1a-9a disposed in series coupled relationship with each other on one surface of substrate 11 opposite ground plane 10 where N is equal to nine in the embodiment illustrated. It should be noted, however, that the microstrip filter in accordance with the principles of the present invention is not limited to a microstrip filter having nine poles or resonator, but may include any number of poles or resonators greater than two.

As illustrated in FIG. 3 each of the N conductors 2a-8a of hairpin resonators 2-8 include a pair of parallel spaced limbs 12 and 13. Resonators 2-8 are those resonators disposed between input resonator 1 and output resonator 9. The spaced limbs 12 and 13 are interconnected by a cross-arm 14. It should be noted that adjacent ones of the conductors 1a-9a have opposite orientation with respect to each other and adjacent ones of the limbs of adjacent ones of the conductors 1a-9a are in spaced parallel relationship with respect to each other to provide the series coupled relationship for the entire microstrip filter.

A microstrip input coupler 15 includes a coaxial connector 16 and a conductor 17 disposed on the same surface of the substance as conductors 1a-9a. Conductor 17 includes a first portion 18 parallel to an adjacent limb of conductor 1a and a second portion 19 extending perpendicular to portion 18 and connected to the inner conductor of the coaxial conductor 16.

A microstrip output coupler 20 includes a coaxial connector 21 and a conductor 22 disposed on the same surface of substrate 11 as conductors 1a-9a and includes a first portion 23 parallel to and spaced from the adjacent limb of conductor 9a and a second portion 24 disposed perpendicular to portion 23 connected to portion 23 and to the inner conductor of coaxial conductor 21.

Conductors 2a-8a have the dimensions illustrated in FIG. 3, namely, a conductor width W, a cross-arm length λ , a height L and a spacing between limbs 12 and 13 equal to d wherein the value of W equals the value of d and equals the value of h, the thickness of substrate 11.

FIG. 4 illustrates the configuration of the input and output resonators 1a and 9a, respectively, wherein limb 13a adjacent portion 18 has a width W1, which is less

than width W. The width W1 of limb 13a is equal to the width of portion 18 with this width being carried through a section of the cross-arm 14a. The reduced width of limb 13a and cross-arm 14a increases the impedance of the input conductor 1a. The other limb 12 of conductor 1a adjacent conductor 2a has the same width W as the other conductors 2a-8a. Portion 18 and a section of portion 19 of input conductor 17 has the width W1. The remainder of portion 19 has its width increased to match the impedance of the input source coupled to coaxial line coupler 16. The same configuration is employed in conjunction with output conductor 9a and conductor 22 as described hereinabove with respect to the input conductor 1a and conductor 17. It should be noted that to compensate for the resultant shift in frequency due to the change of impedance of the input and output conductor 1a and 9a of resonators 1 and 9 that the dimension d (the spacing between the limbs) is increased to an amount equal to d1 as illustrated in FIG. 4.

Metallic members 25 and 26 together with metallic cover 27 are coextensive with ground plane 10 and substrate 11 and have a non-critical horizontal dimension x and a non-critical vertical dimension y to enclose the surface of substrate 11 containing conductors 1a-9a of resonators 1-9 and the conductor portions of input conductor 17 and output conductor 22 to shield the hairpin resonators in a manner to increase the unloaded Q of the filter with respect to the unloaded Q obtainable with unshielded hairpin resonators.

FIG. 5 illustrates a pair of curves relating to the unloaded Q (Q_u) as a function of the thickness of substrate 10 at 7,500 MHz on a 99.5 percent alumina substrate 10. Curve 28 illustrates Q_u for various thickness h of substrate 10 for an unshielded hairpin resonator while curve 29 illustrates the Q_u for various substrate thickness h for shielded hairpin resonators in accordance with the principles of the present invention.

FIG. 6 illustrates the frequency response of the nine pole filter employing shielded microstrip hairpin resonators of FIG. 1.

Referring to FIG. 2, it is illustrated therein that substrate 11 is separated from ground plane 10 by an amount determined by the height of metal carrier 30 which is employed to test and adjust the various resonators of the filter contained on substrate 11 outside of the final assembly, the final assembly being illustrated in FIGS. 1 and 2. The inclusion of the metal carrier or testing jig 30 in the final assembly maintains the environment of the filter in the final assembly substantially identical with that present in the testing jig. The employment of the testing jig in the final assembly and the advantage thereof are fully described in the copending application of C. Greenwald and M. Digrindakis, Ser. No. 191,284, filed Oct. 21, 1971, now abandoned the disclosure of said copending application being incorporated in the present application by reference.

The use of hairpin resonators of the open circuited, half-wavelength resonator type reduces the resonance losses significantly at the expense of a slight increase of resistive loss. The curves of FIG. 5 summarize the results of a study of the Q_u of hairpin resonators formed on 99.5 percent alumina substrates. It is concluded that a 35 mil substrate is optimum if unshielded resonators are to be used: $Q_u = 310$ maximum. For thick substrates, the cross-arm length λ is an appreciable part of the total resonator, and it radiates to the extent that Q_u

becomes lower than upon some thinner substrates. If Q_u must be higher than 310, shielded microstrip on substrates thicker than 25 mil must be used.

In a reduction to practice the nine pole filter shown in FIG. 1 was built on a 50 mil alumina substrate and shielded by a channel having the dimension $x = 0.250$ inches and the dimension $y = 0.300$ inches. It should be pointed out, however, that the dimensions x and y are not critical to the operation of the filter in accordance with the principles of the present invention. The hairpin resonator was used in the embodiment of FIG. 1 despite its 15 percent lower Q_u than the linear resonator because (1) a more compact structure is obtained, one that can be placed in a waveguide of higher cutoff frequency, to ensure a predictable response to about 20 GHz (gigahertz); (2) the metal shielding structure is less critical because the hairpin resonator already eliminates the greater part of the radiation; and (3) coupling between non-adjacent resonators is greatly reduced, which diminishes the ripple caused by such coupling.

One of the problems that was uncovered in testing the microstrip filter employing the technique of the present invention is the difficulty of coupling into and out of the filter structure. This problem was solved by increasing the impedance of the first and last resonator by decreasing the width of the limb of the conductor thereof to have the same width as a portion of the input and output coupling conductors coupled to the coaxial connectors 16 and 21. The increase in impedance achieved by changing the width of the limb of the input and output resonators 1 and 9 to have an impedance equal to the input and output conductors 17 and 22 resulted in a shift in frequency which was corrected by a change in the spacing between the limbs of conductors 1a and 9a to a value of $d1$, as illustrated in FIG. 4, which is greater than the value d illustrated in FIG. 3 for resonators 2-8.

The curve illustrated in FIG. 6 is the measured frequency response of the filter of FIG. 1. The insertion loss of -1.9db (decibels) corresponds to a Q_u of 460 for a 0.1db Chebyshev design with a fractionable bandwidth of 7.4 percent. The out-of-band rejection was found to be excellent up to 12.4 GHz, the limit of the measuring equipment. Below the passband, the rejection is greater than 75db while above the passband the rejection was 65db.

A major objection to microstrip filters for use at X-band has been low out-of-band rejection. This has been eliminated by the design and technique presented herein. The losses, another objection, can be reduced by a simple microstrip design as incorporated in the filter of the present invention and FIG. 5 indicates that even lower losses are possible. The necessity of enclosing the substrate in a metal channel for shielding purposes is not a limitation since the filter must be shielded from other circuits if current RFI (radio frequency interference) specifications are to be met.

While I have described above the principles of my invention in connection with specific apparatus it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of my invention as set forth in the objects thereof and in the accompanying claims.

I claim:

1. A microstrip filter comprising:

N microstrip open circuited, half-wavelength hairpin resonators including a ground plane, a substrate disposed adjacent to, coextensive with and parallel to said ground plane and N hairpin shaped conductors disposed in series coupled relationship with each other on one surface of said substrate opposite said ground plane, where N is equal to an integer greater than one, each of said N conductors including a pair of parallel spaced limbs interconnected by a cross-arm, adjacent ones of said N conductors having an opposite orientation with respect to each other and adjacent ones of said limbs of adjacent ones of said N conductors being in spaced parallel relationship with respect to each other to provide said series coupled relationship;

a microstrip input coupler including a first conductor disposed on said one surface of said substrate in spaced, parallel relationship with an adjacent one of said limbs of a first of said N conductors to provide a series coupled relationship between said first conductor and said adjacent one of said limbs of said first of said N conductors;

a microstrip output coupler including a second conductor disposed on said one surface of said substrate in spaced, parallel relationship with an adjacent one of said limbs of a last of said N conductors to provide a series coupled relationship between said second conductor and said adjacent one of said limbs of said last of said N conductors;

each of said N conductors and said first and second conductors being in alignment;

metallic members coextensive with said ground plane and said substrate enclosing said one surface of said substrate and said first, second and N conductors to shield said hairpin resonators to increase the unloaded Q of said resonators with respect to the unloaded Q obtainable with unshielded hairpin resonators.

2. A filter according to claim 1, wherein

each of said limbs and said cross-arm of each of said N conductors between said first and last of said N conductors have a width equal to a first given amount;

the spacing between each of said limbs of each of said N conductors between said first and last of said N conductors is equal to said first given amount;

said first conductor includes a first portion parallel to said adjacent one of said limbs of said first of said N conductors and a second portion perpendicular to said first portion, said first portion and a section of said second portion directly connected to said first portion each have a width equal to a second given amount less than said first given amount;

said second conductor includes a third portion parallel to said adjacent one of said limbs of said last of said N conductors and a fourth portion perpendicular to said third portion, said third portion and a section of said fourth portion directly connected to said third portion each have a width equal to said second given amount; and

said adjacent one of said limbs of each of said first and last of said N conductors and a section of said cross-arms directly connected to said adjacent one of said limbs of each of said first and last of said N conductors have a width equal to said second given amount, the other of said limbs of each of said first and last of said N conductors and the remainder of

said cross-arms connected to said other of said limbs of each of said first and last of said N conductors have a width equal to said first given amount and the spacing between said adjacent one and said other of said limbs of each of said first and last of said N conductors is greater than said first given amount.

3. A filter according to claim 2, wherein the thickness of said substrate is equal to said first given amount.

4. A filter according to claim 3, wherein said substrate is composed of 99.5 percent alumina.

5. A filter according to claim 1, wherein said substrate and said ground plane is separated by a metal carrier employed to test and adjust said filter prior to providing a final assembly thereof, said testing and adjusting taking place at a point removed from said final assembly.

6. A microstrip filter comprising:
 N microstrip open circuited, half-wavelength hairpin resonators including a ground plane, a substrate disposed adjacent to, co-extensive with and parallel to said ground plane and N hairpin shaped conductors disposed in series coupled relationship with each other on one surface of said substrate opposite said ground plane, where N is equal to an integer greater than one, each of said N conductors including a pair of parallel spaced limbs interconnected by a cross-arm, adjacent ones of said N conductors having an opposite orientation with respect to each other and adjacent ones of said limbs of adjacent ones of said N conductors being in spaced parallel relationship with respect to each other to provide said series coupled relationship;

a microstrip input coupler including a first conductor disposed on said one surface of said substrate in spaced, parallel relationship with an adjacent one of said limbs of a first of said N conductors to provide a series coupled relationship between said first conductor and said adjacent one of said limbs of said first of said N conductors; and

a microstrip output coupler including a second conductor disposed on said one surface of said substrate in spaced, parallel relationship with an adjacent one of said limbs of a last of said N conductors to provide a series coupled relationship between said second conductor and said adjacent one of said limbs of said last of said N conductors;

each of said N conductors and said first and second conductors being in alignment;

each of said limbs and said cross-arm of each of said N conductors between said first and last of said N

conductors having a width equal to a first given amount;

the spacing between each of said limbs of each of said N conductors between said first and last of said N conductors is equal to said first given amount;

said first conductor including a first portion parallel to said adjacent one of said limbs of said first and said N conductors and a second portion perpendicular to said first portion, said first portion and a section of said second portion directly connected to said first portion each having a width equal to a second given amount less than said first given amount;

said second conductor including a third portion parallel to said adjacent one of said limbs of said last of said N conductors and a fourth portion perpendicular to said third portion, said third portion and a section of said fourth portion directly connected to said third portion each having a width equal to said second given amount; and

said adjacent one of said limbs of each of said first and last of said N conductors and a section of said cross-arms directly connected to said adjacent one of said limbs of each of said first and last of said N conductors having a width equal to said second given amount, the other of said limbs of each of said first and last of said N conductors and the remainder of said cross-arms connected to said other of said limbs of each of said first and last of said N conductors having a width equal to said first given amount and the spacing between said adjacent one and said other of said limbs of each of said first and last of said N conductors is greater than said first given amount.

7. A filter according to claim 6, wherein the thickness of said substrate is equal to said first given amount.

8. A filter according to claim 7, wherein said substrate is composed of 99.5 percent alumina.

9. A filter according to claim 8, wherein said substrate and said ground plane is separated by a metal carrier employed to test and adjust said filter prior to providing a final assembly thereof, said testing and adjusting taking place at a point removed from said final assembly.

10. A filter according to claim 6, wherein said substrate and said ground plane is separated by a metal carrier employed to test and adjust said filter prior to providing a final assembly thereof, said testing and adjusting taking place at a point removed from said final assembly.

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