Jan. 6, 1959 M. ARDITI 2,867,782

MICROWAVE LINES AND HIGH Q FILTERS

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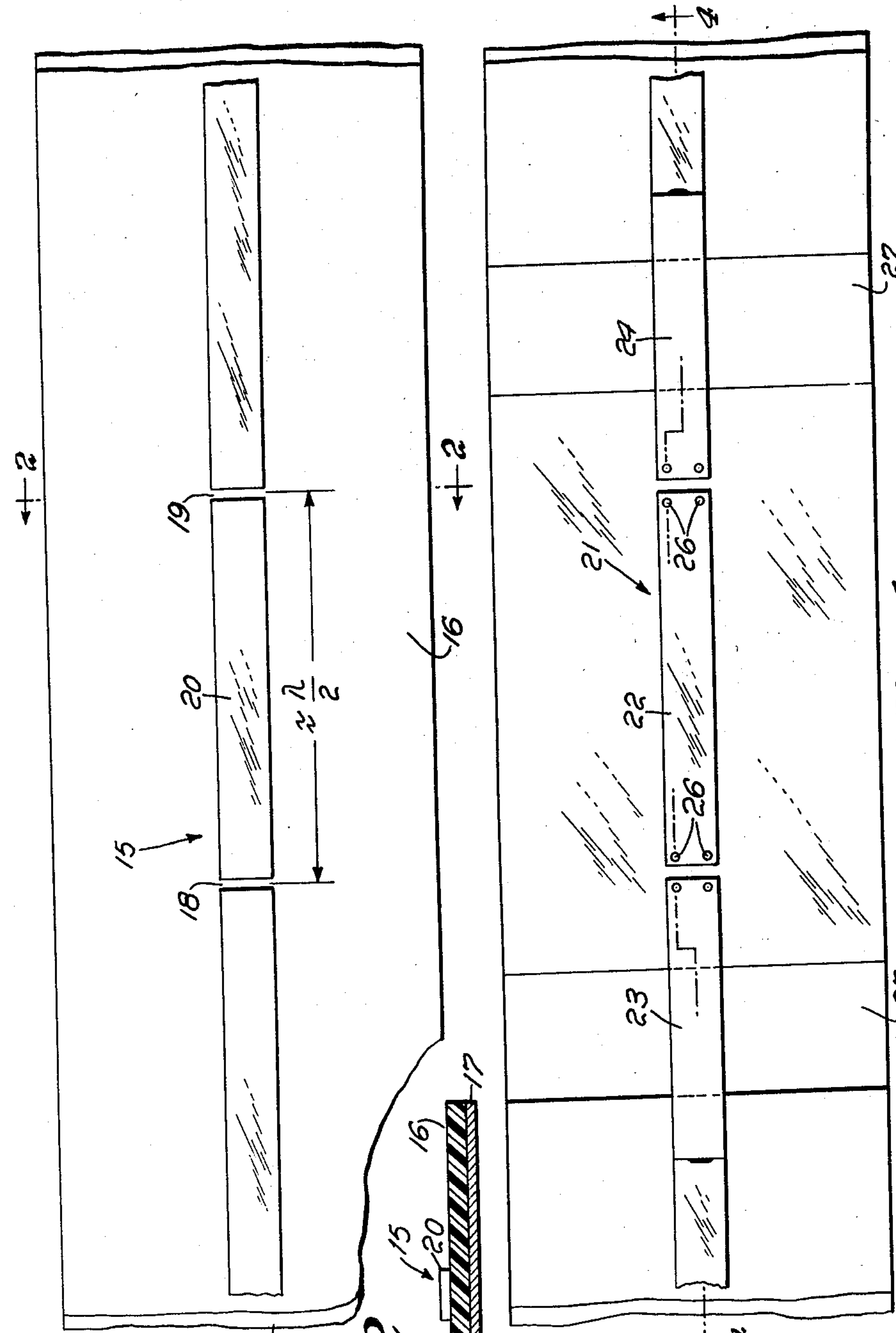

Fig. 1 Fig. 2 Fig. 3

Fig. 4

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Fig. 5

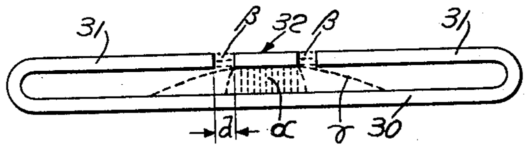


Fig. 6

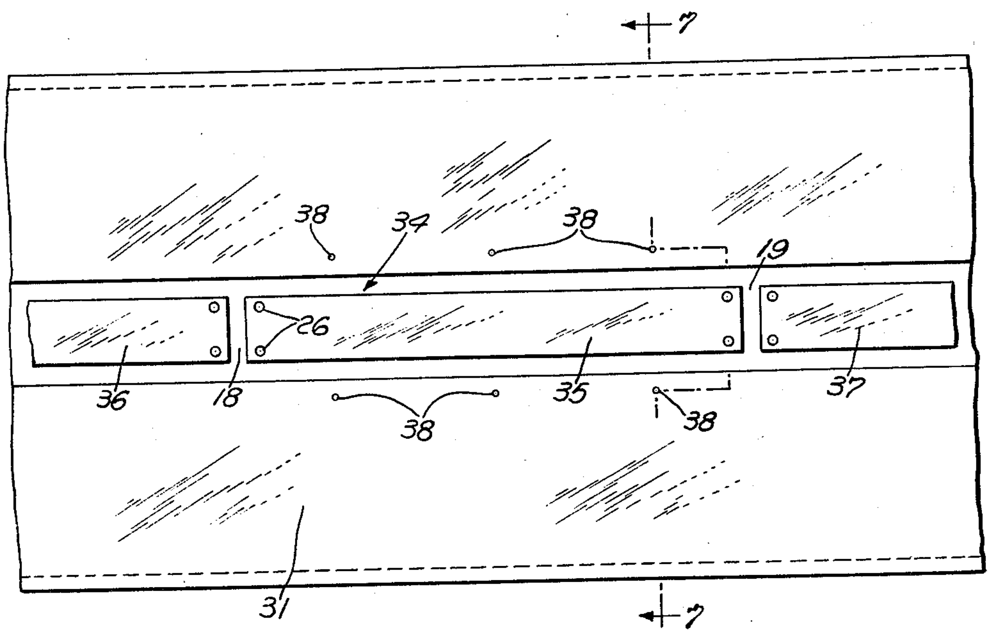
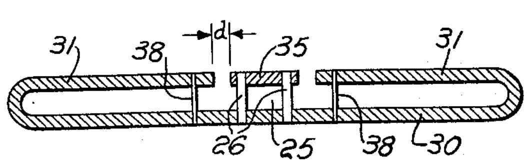


Fig. 7



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MICROWAVE LINES AND HIGH Q FILTERS

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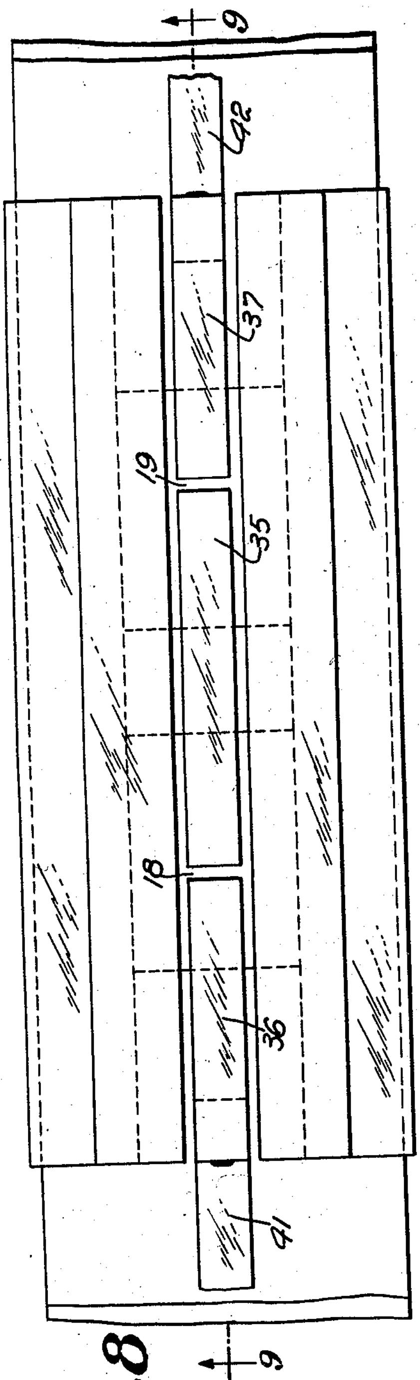

Fig. 8

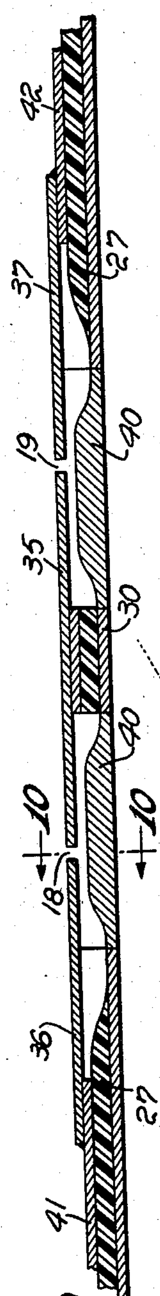

Fig. 9

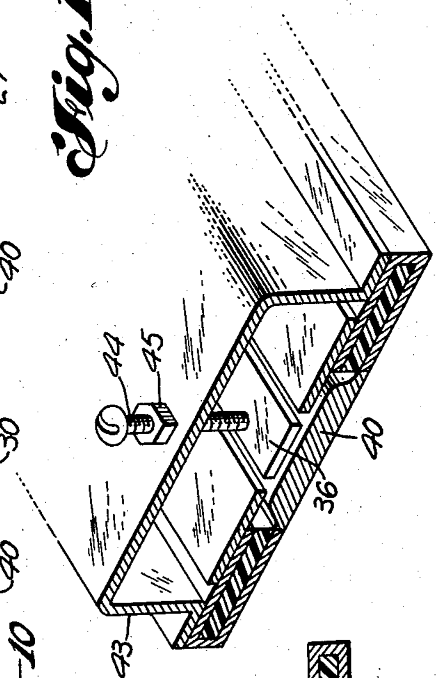

Fig. 11

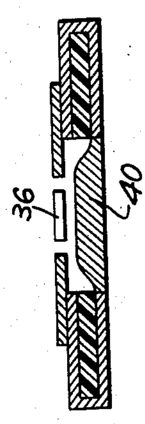

Fig. 10

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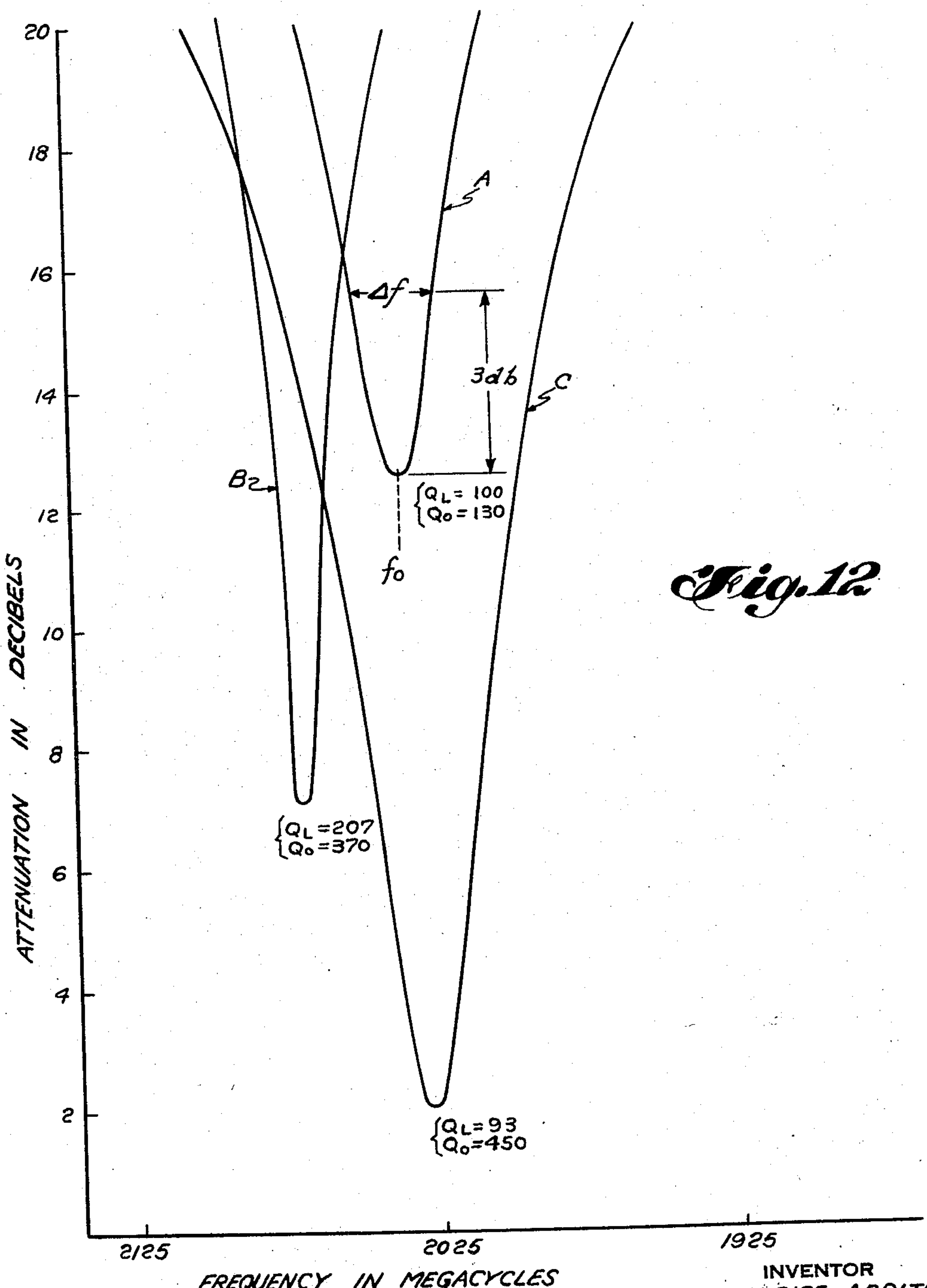

Fig. 12

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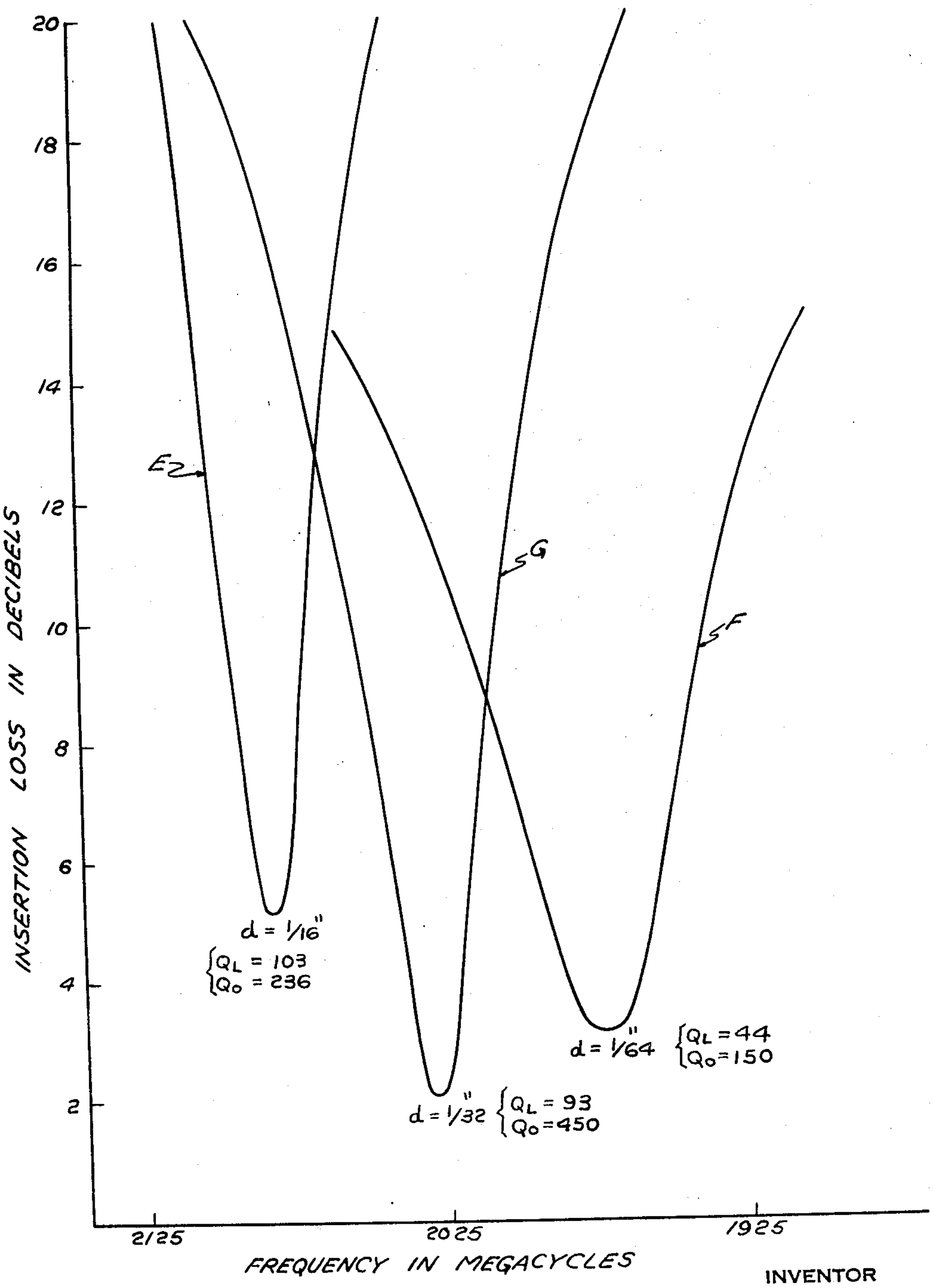

Fig. 13

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United States Patent Office

2,867,782

Patented Jan. 6, 1959

2,867,782

MICROWAVE LINES AND HIGH Q FILTERS

Maurice Arditi, Clifton, N. J., assignor to International Telephone and Telegraph Corporation, Nutley, N. J., a corporation of Maryland

Application May 13, 1955, Serial No. 508,046

10 Claims. (Cl. 333—73)

This invention relates to microstrip lines and particularly high Q microwave filters especially adapted for microstrip transmission lines and circuitry.

Microstrip transmission lines and circuitry have heretofore been described in a previous patent (U. S. Patent 2,654,842 of H. F. Engelmann) and in prior publications ("Proceedings of the I. R. E.," December 1952, pages 1644–1650), as well as in several patent applications now pending, some of which are referred to hereinafter. A microstrip transmission line is a device for propagating waves having a frequency of the order of kilomegacycles and consists generally of a ground planar conductor on which there is arranged a layer of solid dielectric, on top of which dielectric there is supported a thin flat strip-like conductor. The distance between the bottom of the strip conductor and the top of the ground is of the order of 0.1 or less of the wavelength of the waves propagated along said line at the mean frequency. The ground plane conductor is three or more times wider than the strip conductor. The main field of a wave propagated along said microstrip line lies between the bottom of the strip conductor and the area of the ground plane conductor which is directly beneath it. There is also a fringe field from the side edges of the strip conductor towards the ground plane conductor. On the top of the strip conductor between the edges thereof, there is relatively virtually no field. Such a line differs sharply from coaxial and waveguide structures. It differs from coaxial lines in that the wave is not confined within the structure by an enclosed outer conductor. It differs from waveguides likewise in that the wave is not confined within the structure by completely surrounding walls and also because in the waveguide there is a distinct cutoff frequency which does not appear in microstrip structures.

Filters utilizing microstrip principles have heretofore been proposed and described in the U. S. applications of Maurice Arditi et al., Serial No. 286,761, filed May 8, 1952, now Patent No. 2,820,206, entitled "Microwave Filters"; Maurice Arditi et al., Serial No. 286,763, filed May 8, 1952, now Patent No. 2,819,452, entitled "Microwave Filters"; and Maurice Arditi, Serial No. 324,545, filed December 6, 1952, entitled "Microwave Filters." These filters are made by providing resonant sections in the microstrip line, these resonant sections in turn being formed by discontinuities in the line provided at suitably spaced points, usually a half wavelength apart at the mean frequency. Such discontinuities may consist of gaps in the line, lateral extensions on one of the conductors, variations in width of one of the conductors, wires extending crosswise of one of the conductors, probes or pins inserted from one of the conductors to the other, as more fully described in the above-mentioned applications. Such prior art microstrip filters generally have a low Q and introduce large insertion losses.

An object of the present invention is the provision of a microstrip type line particularly adapted for use in a

filter which is of high Q and produces very low insertion losses.

It has been found that by removing the dielectric in the microstrip filter a high Q filter is obtained. However, such filters still introduce substantial attenuation. I have discovered that by minimizing the loss due to radiation I am enabled to obtain low loss insertion characteristics in such high Q filters. In accordance with a major aspect of the present invention, I eliminate the solid dielectric of microstrip lines and filter and by folding over the edges of the ground plane so that they are close to the edges of the strip conductor leaving a gap therebetween, I minimize the radiation losses, and can thereby produce a high Q low insertion loss filter. In doing this I distort somewhat the fringe field of the microstrip line. This provides a field which is completely different from the fields existing in waveguides and coaxial lines as well as in other types of microwave transmission lines.

In accordance with a further feature, the distance between the edges of the folded-over ground plane conductor and the strip conductor, that is, the size of the gap is selected to be a critical distance at which minimal insertion loss is introduced when used as a filter. The size of this gap is a small fraction of the wavelength at the mean frequency.

In accordance with still another feature of the present invention, I provide for vernier control of the adjustment of the mid-frequency of the filter by making use of the extremely small portion of the field that escapes from between the folded-over ground plane conductor and the strip conductor.

Other and further objects of the present invention will become apparent, and the foregoing will be better understood with reference to the following description of embodiments thereof, reference being had to the drawings, in which:

Fig. 1 is a schematic plan view of a prior microstrip filter used in describing the present invention;

Fig. 2 is a cross-sectional view taken along the line 2—2 of Fig. 1;

Fig. 3 is a schematic plan view of another prior microstrip filter used in describing the present invention;

Fig. 4 is a longitudinal sectional view taken along the line 4—4 of Fig. 3;

Fig. 5 is a schematic cross-sectional view of a microstrip filter according to the present invention used in describing the theory thereof;

Fig. 6 is a plan view of an embodiment of a microstrip filter according to the present invention;

Fig. 7 is a cross-sectional view taken along the line 7—7 of Fig. 6;

Fig. 8 is a plan view of a modified embodiment of a microstrip filter according to the present invention;

Fig. 9 is a longitudinal sectional view taken along the line 9—9 of Fig. 8;

Fig. 10 is a cross-sectional view taken along the line 10—10 of Fig. 9;

Fig. 11 is a perspective view of the device shown in Figs. 8–10 with a covering hood and vernier center frequency control;

Fig. 12 is a set of curves illustrating the relative characteristics of filters of the prior art and the present invention; and,

Fig. 13 is a set of curves showing the different characteristics obtained with different dimensions of the gap between the side edges of the strip conductor and the adjacent edges of the folded-over ground plane conductor.

Referring now to the filter illustrated in Figs. 1 and 2, this filter is similar to one shown in my above-mentioned copending application, Serial No. 324,545. This filter is similar to a microstrip line in that it consists of a strip conductor **15** supported on a solid dielectric **16** over a ground plane conductor **17**. The strip conductor **15** is provided with two gaps **18** and **19** which produce a resonant section **20** therebetween having an electrical length of a half wavelength at the mean frequency of the waves to be propagated along said line. The resonant section is essentially a series resonant circuit interposed along the microstrip line and may be connected in series with other such filters as has been described, for example, in my said application, Serial No. 324,545.

The dimensions of such microstrip filters may be repeated here. The strip conductor has a thickness of the order of thousandths of an inch. The thickness of the dielectric **16** is of the order of 0.1 wavelength or less at said mean frequency, and the ground plane conductor **17** has a width at least three times that of the strip conductor **15**. The size of the gaps **18** and **19** affect the Q of the filter. A filter of this type tends to be of relatively low Q and has rather broad bandpass characteristics. It tends also to have high insertion loss. Such filters have a definite use, but are not preferred where it is desired to obtain narrower band characteristics and lower insertion losses. It is believed that the losses are due in part to the presence of a lossy dielectric material. It has accordingly been proposed as in the above-mentioned application, Serial No. 286,761, to eliminate the dielectric. A filter of this type is illustrated in Figs. 3 and 4.

Referring now to Figs. 3 and 4, the filter there illustrated has a ground plane conductor **17** over which there is provided a strip conductor **21** having a resonant section **22** separated by gaps **18** and **19** from the other portions **23** and **24**. Instead of a solid dielectric **16**, there is provided an air dielectric **25** between resonant section **22** and the ground plane conductor **17**. The resonant section **22** is supported above the ground plane by metallic pins **26** at the ends thereof, the metallic pins acting as coupling loops for the resonant sections. Similar metallic pins **26** support the inner ends of strip conductor portions **23** and **24**. To provide for a smooth transition and matching of the resonant section with the microstrip lines to which the filter may be connected, the dielectric material **27** of such lines is tapered underneath the portions **23** and **24** leaving air gaps **28** between said portions and the ground plane conductor **17**, while the portions **23** are bent as indicated at **29** to bring the ends of portions **23** and **24** adjacent resonant section **22** to a common height above the ground plane which is less than in the regular microstrip line with solid dielectric in order to compensate for the differences in propagation speed and, therefore, of impedance characteristics.

A filter such as shown in Figs. 3 and 4 has narrower bandpass characteristics and less insertion loss than the filter shown in Figs. 1 and 2. Such a filter still has fairly high insertion loss. It has been found that the insertion loss of the filter of Figs. 3 and 4 is due largely to the fact that there are substantial radiation losses therefrom. In accordance with the present invention, and as illustrated in Fig. 5, it has been discovered that a high Q filter may be obtained by the elimination of the solid dielectric in the filter and by folding over the ground plane conductor **30** as illustrated in Fig. 5 so that edges of the folded-over portions **31** are adjacent the side edges of the strip conductor **32** of the filter. The ground conductor thus has an approximately **C**-shaped cross-sectional configuration. This arrangement, it has been found, minimizes the radiation loss, eliminates the solid dielectric loss, and provides a high Q filter section. The size of the gap **33** between the side edges of the strip conductor and the opposed edges **31** of the folded-over portions is important as will be pointed out hereinafter when referring to Fig. 13. The size of this gap **33** should preferably be of the order of ⅕ the distance between the strip conductor and the flat portion of the ground plane conductor directly therebeneath.

The filter arrangement shown in Fig. 5 must not be confused with a waveguide structure having slots therein since the field conditions are completely different. The main field α lies between the strip conductor **32** and the ground plane conductor **30** directly underneath the strip conductor. There is a fairly substantial fringe field β in the gaps **33** with the field lines extending from the side edges of the strip conductor towards the opposed edges of the folded-over portions **31**. Some extremely weak field γ spreads under the folded-over portion **31**, but it must be emphasized that it is extremely weak. It will, therefore, be seen that this is quite unlike the field produced in a waveguide because the distance between the strip conductor and the portion of the ground plane conductor therebeneath is a small fraction of the wavelength at the mean frequency and is of the order of 0.1 or less of such a wavelength. In consequence thereof, there is no cutoff frequency as is found in waveguides. By increasing this distance and by suitably selecting the length of the gaps between the side edges of the strip conductor and the adjacent edges of the folded-over ground plane, the field in these gaps will become the main field and a different mode of propagation of the wave in said gaps will be obtained.

The frequency response characteristics of the previous microstrip filters and those according to the present invention are represented in Fig. 12 in which attenuation in decibels (insertion loss) is plotted against frequency in megacycles. Referring now to Fig. 12, curve A represents these characteristics for a filter having a lossy dielectric (Fiberglas G–6), such as described in connection with Fig. 1; curve B refers to a filter in which the solid dielectric has been removed, leaving only an air dielectric such as is described in connection with Fig. 3; and curve C refers to a filter according to the present invention such as in Fig. 5. It will be seen that curve A is wider than curve B and that its attenuation is greater than that of curve B. Curve C has a substantially lower insertion loss than curve B. The insertion losses in the filter or resonant section can be expressed by the value of the unloaded Q_0 of the section by the following equation:

$$\text{Losses in decibels (insertion losses)} = -20 \log_{10}\left(1-\frac{Q_L}{Q_0}\right)$$

where Q_L is the loaded Q of the filter section and is evaluated according to the equation

$$Q_L=\frac{\Delta f}{f_0}$$

where Δf is the bandwidth at 3 db above the lowest attenuation point (as indicated in curve A), and f_0 is the center frequency. It will be recognized that for a given value of Q_L the greater the value of Q_0, the smaller the insertion loss. As indicated in Fig. 12, for the filter section producing the characteristics indicated in curve A, $Q_L=100$, $Q_0=130$; for curve B, $Q_L=207$ and $Q_0=370$; and for curve C, $Q_L=93$ and $Q_0=450$. It will thus be seen that the lowest Q_0 occurs with the filter having a solid dielectric, that the Q_0 is greater with the air dielectric and much greater with the folded-over ground conductor **31**. Because of the structure according to the present invention and the field configurations heretofore pointed out, substantially the entire field is confined within the structure. There is, however, a minute field escaping outside this structure, and use is made of this minute field as will be described hereinafter in relation to Fig. 11 to produce a vernier control of the center frequency.

The distance across the gap **33**, referred to hereinafter as "*d*," is critical in attaining minimal losses. Fig. 13 shows the effect of this distance *d*. Curve E shows the characteristics of a filter, such as is illustrated in Fig. 5, where *d* is equal to 1/16″; curve F shows its characteristics where *d* is equal to 1/64″, and curve G shows its characteristics when *d* is equal to 1/32″. It will first be noted with respect to these curves, in which frequency in megacycles is plotted against the insertion loss in decibels, that curve E has a higher insertion loss with relatively narrow bandwidth; curve F has lesser loss with a somewhat wider bandwidth, while curve G (with $d=\frac{1}{32}''$) has the lowest insertion loss and a relatively narrower bandwidth than curve F. The relative values of Q_L and Q_0 is indicated in said figure and are listed here for convenience: where $d=\frac{1}{16}''$, $Q_L=103$ and $Q_0=236$; where $d=\frac{1}{64}''$, $Q_L=44$ and $Q_0=150$; and where $d=\frac{1}{32}''$, $Q_L=93$ and $Q_0=450$.

It can also be seen in Fig. 13 that the proximity of the folded-over portions **31** displaces the resonant frequency towards the lower frequencies as the distance *d* decreases. This effect is probably due to an increase in the capacity of the resonant section.

Embodiments of the present invention are described in detail hereinafter with respect to Figs. 6–11. Referring now to the embodiments of Figs. 6 and 7, there is shown a strip conductor **34** having a resonant section **35** supported on pins **26** over the ground plane conductor **30**, leaving an air dielectric or space **25**. The resonant section **35** is separated by gaps **18** and **19** from strip conductor portions **36** and **37** connected to either other filters or forming part of a microstrip line coupled to said filter. To provide for a smooth transition and impedance matching, a portion of the solid dielectric under portions **36** and **37** may be cut away in the form of a taper as indicated in Fig. 4 and said portions **36** and **37** may be bent as likewise shown in Fig. 4 so that the inner ends thereof adjacent resonant section **35** are closer to the ground plane conductor **30** for reasons explained in connection with Fig. 5. The side portions **31** of the ground plane conductor are folded over as is shown in Fig. 5 so that the side edges of the resonant section **35** face the opposed edges of the folded-over portions **31** across narrow gaps *d*. While in the example illustrated in curve G of Fig. 13, the preferred size of *d* was $\frac{1}{32}''$, it will be recognized that this critical value depends upon many parameters of the filter and can only be empirically determined. Nevertheless, there is in each case a preferred size for *d* which can give the minimal insertion losses. In any case, *d* will remain a very small fraction of a wavelength at the mean frequency and be of the order of ⅕ the distance of the strip conductor **35** and the ground plane conductor immediately therebeneath. Because of the proximity of the side edges of the folded-over portions **31** there may exist some tendency for the wave to propagate itself between these edges and the side edges of the strip conductor **34**, thus giving a mode of operation other than the dominant mode. In some cases this is undesirable. To prevent this, there is provided a series of pins **38** which short circuit such other modes.

In the modification illustrated in Figs. 8–11, the pins **26** are eliminated and another method of supporting the resonant strip conductor **35** is provided. This is best seen in Fig. 9 in which the resonant conductor **35** is supported at the center thereof by a piece of solid dielectric **39** which, being at a nodal point where the voltage is a minimum, introduces no appreciable losses. For impedance matching of the filter where the air dielectric appears, the ground plane conductor **30** may be thickened as indicated at **40**, this being most simply done by cutting away sections of the ground conductor and replacing them with appropriately thickened portions. The dielectric **27** is tapered to provide suitable transitions, and portions **36** and **37** of the strip conductor may be affixed at their edges to the regular strip conductor **41** and **42**, respectively, of microstrip lines feeding the filter. As has been previously pointed out, a minute portion of the field may escape through gaps **18** and **19**. To prevent this portion from coupling into adjacent apparatus, it is preferred to put a metallic cover or hood **43** over the filter section as indicated in Figs. 8 and 10 which has a height from at least 5 to 10 times as great as the distance between the strip conductor and the planar portion of the ground plane conductor directly beneath the strip conductor. This slight radiated field, now confined within hood **43**, may be used to produce a vernier adjustment of the center frequency of the filter section. This is effected by providing a screw **44** extending through the top of the hood **43** inside thereof with an engaging female thread (not shown) in the hood cover. A lock nut **45** may be used to fix the adjustment.

While I have described specific embodiments of my invention, it will be apparent that changes may be made without departing from the spirit thereof. For example, it is possible to use a round conductor instead of the strip conductor. Furthermore, the conductor above the ground plane may be located directly between the edges of the folded-over portion, or slightly above it or slightly under it, the preferred location being directly between. As pointed out hereinbefore by suitably dimensioning the space underneath the strip conductor and by suitably dimensioning the gaps between the edges of the strip conductor a mode of propagation may be used in which the wave is propagated along said gaps and the principal field will lie therein instead of inside underneath the strip conductor. In the previous example likewise the round wire conductor may be substituted for the strip conductor.

Furthermore, while the examples given have been principally in connection with filters, it is obvious that they apply equally well to transmission lines which are not filters.

Accordingly, while I have described my invention above with reference to specific embodiments, it is to be understood that the invention is to be interpreted according to the state of the prior art and the appended claims.

I claim:

1. A microwave transmission line comprising a pair of elongated conductors extending in the same direction including a first conductor, a second conductor of approximately **C**-shaped cross section, with the side edges being inwardly turned to face each other, and means for supporting said first conductor adjacent the opposed in-turned edges of the gap of said **C** configuration with said edges being spaced a distance from said first conductor equal to a fraction of the wavelength at the means frequency of waves propagated along said line, said first conductor being mounted directly between said in-turned edges.

2. A microwave transmission line according to claim 1, further including a dielectric between said first and second conductors principally of air.

3. A microwave transmission line according to claim 1, wherein the distance between the first conductor and said edges is filled with an air dielectric.

4. A microwave transmission line according to claim 1, wherein said first conductor is ribbon-like and the side edges thereof face the opposed in-turned edges of said second conductor.

5. A microwave filter comprising a pair of elongated conductors extending in the same direction, including a ribbon-like first conductor and a second conductor of approximately **C**-shaped cross section with the side edges being inwardly turned to face each other, means for supporting said first conductor in flat position between the opposed in-turned edge of the gap of said **C** configuration with the side edges of the first conductor spaced a short distance from the adjacent in-turned edges of the second conductor, and a pair of obstacle discontinuities disposed in longitudinally spaced relation along said conductors to form a resonant section therebetween.

6. A microwave filter according to claim 5, further including a dielectric consisting principally of air separating the part of said first conductor in said resonant section from the portion of the second conductor immediately below it.

7. A microwave filter according to claim 5, further including a metallic covering member arranged over and enclosing said first conductor and the inwardly-turned sides of said second conductor, said cover being spaced

from said first conductor and said inwardly-turned sides of said second conductor.

8. A microwave filter according to claim 7, further including means for introducing a variable obstacle discontinuity between said cover and said first and second conductors for producing an adjustment of the center frequency of said filter.

9. A microwave filter according to claim 5, wherein said supporting means comprises a piece of solid dielectric extending between the center of the width of said first conductor and the portion of the second conductor directly opposite said center, said solid dielectric extending longitudinally along the filter for a distance equivalent to a minor fraction of the total length of said part of said first conductor, the remaining space under said part of said first conductor being occupied by said air dielectric.

10. A microwave filter comprising a pair of elongated conductors extending in the same direction and including a ribbon-like first conductor and a second conductor of approximately C-shaped cross section having a substantially flat portion between folded-over side portions, said flat portion being at least three times as wide as said first conductor and spaced therefrom by a distance equal to 0.1 wavelength or less at the mean frequency of the electromagnetic waves propagated through said filter section, a pair of obstacle discontinuities disposed in longitudinally spaced relation along said conductors to form a resonant section therebetween, means supporting the part of said first conductor in said resonant section above said flat portion leaving an air gap therebetween, the edges of said folded-over side portions facing and being spaced from the edges of said first conductor, the distance between the edges of said folded-over side portions and the edges of said first conductor being of the order of $1/5$ the distance between said first conductor and said flat portion of the second conductor.

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