Nov. 4, 1958

M. ARDITI

2,859,417

MICROWAVE FILTERS

Filed Dec. 6, 1952

4 Sheets-Sheet 1

Fig. 1

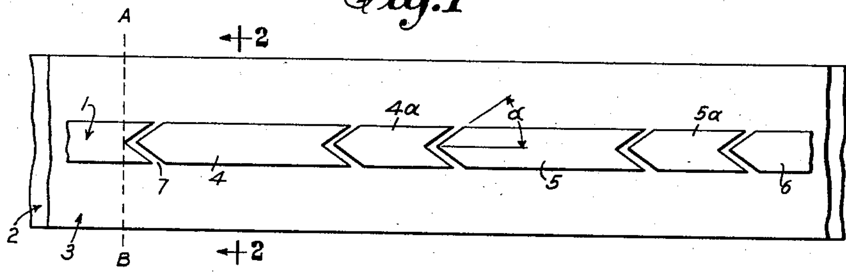

Fig. 2

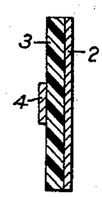

Fig. 3

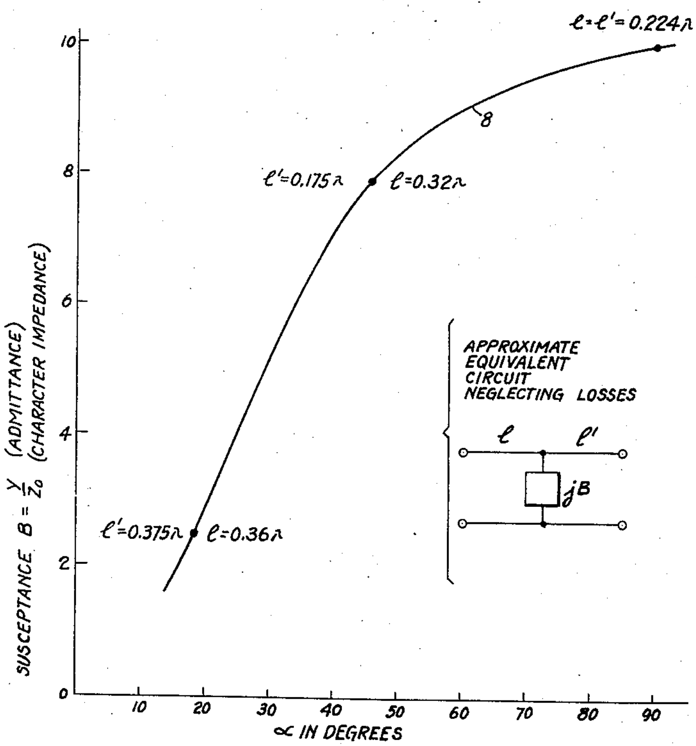

Fig. 4

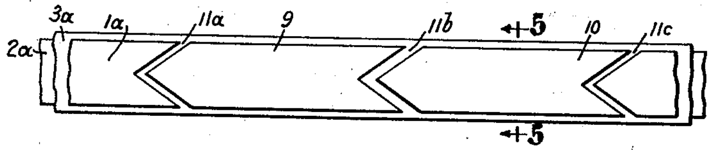

Fig. 5

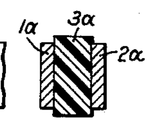

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Fig. 6

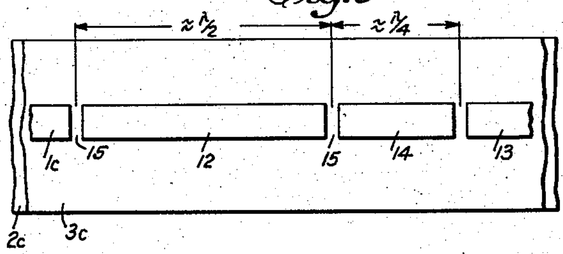
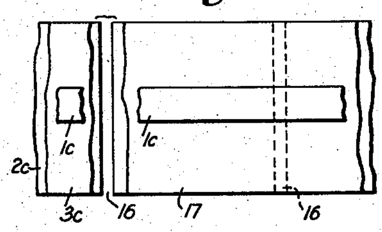


Fig. 7



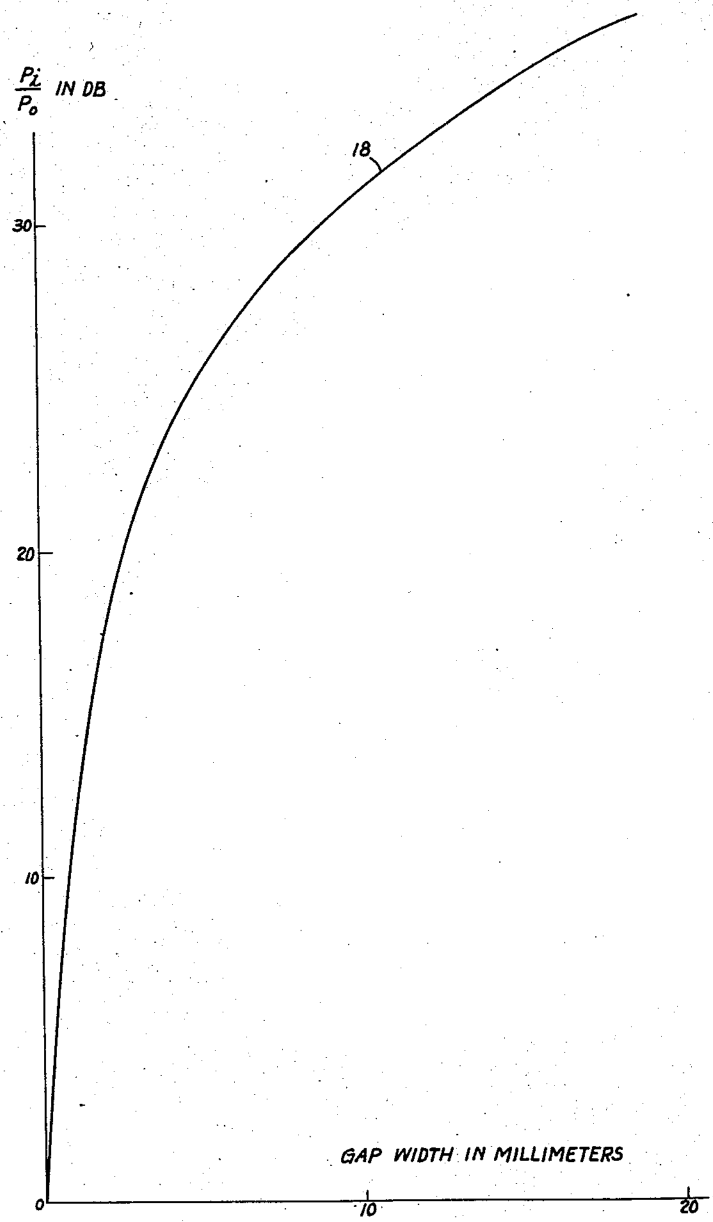


Fig. 8

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Fig. 9

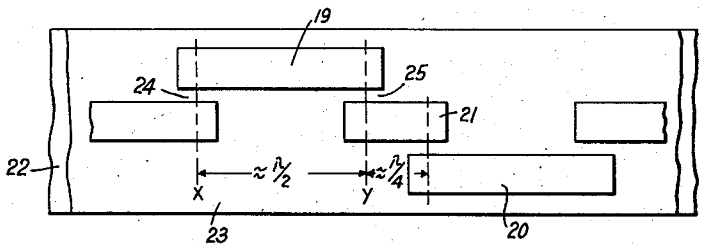

Fig. 11

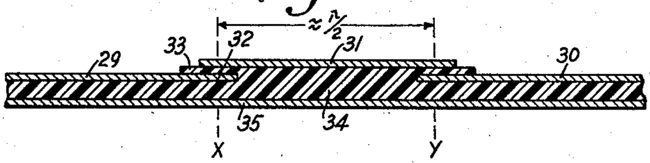

Fig. 12

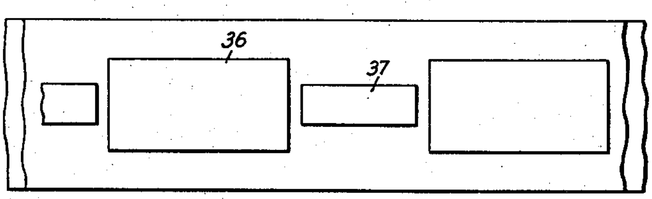

Fig. 13

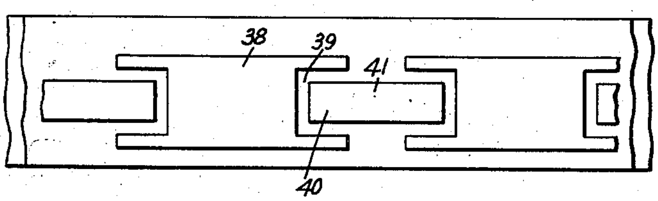

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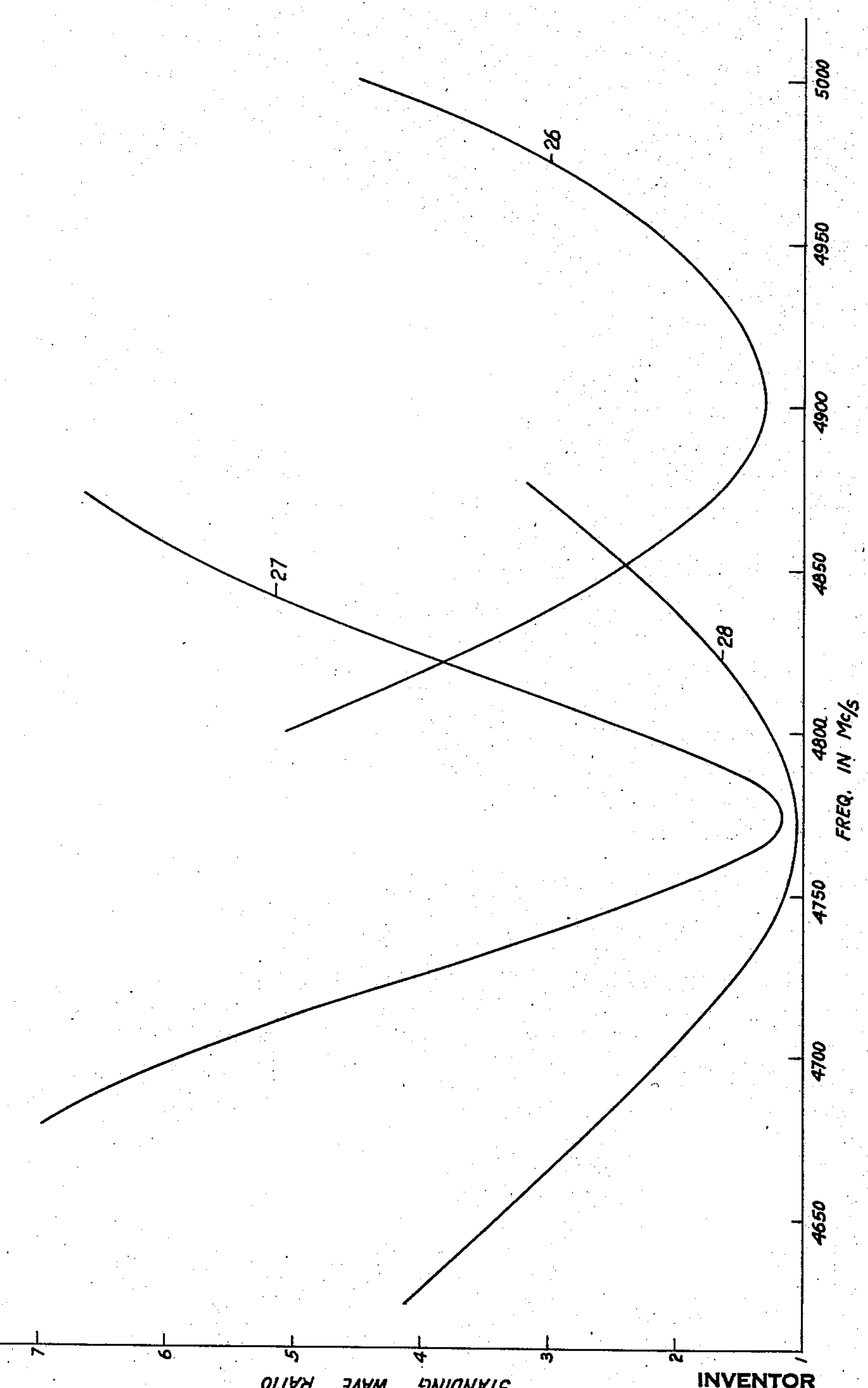
Fig.10



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MICROWAVE FILTERS

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

Application December 6, 1952, Serial No. 324,545

5 Claims. (Cl. 333—73)

This invention relates to microwave transmission systems and more particularly to microwave filters specially applicable to microwave printed transmission lines and circuitry.

In the copending applications of D. D. Grieg and H. F. Engelmann, Serial Nos. 227,896, now abandoned, and 234,503, now Patent No. 2,721,312, filed May 23, 1951, and June 30, 1951, respectively, and M. Arditi and P. Parzen, Serial No. 286,764, filed May 8, 1952, now Patent No. 2,774,046, a type of microwave transmission line is disclosed comprising, in one of its simplest forms, two conductors printed or otherwise disposed in substantially parallel relation on opposite sides of a strip or layer of dielectric material a small fraction of a quarter wavelength thick. The two conductors may be the same width or one may be made wider than the other. In the copending applications of M. Arditi, G. A. Deschamps and J. Elefant, Serial No. 286,761, filed May 8, 1952, now Patent No. 2,820,206, and Serial No. 286,763, filed May 8, 1952, now Patent No. 2,819,452, filter arrangements are disclosed utilizing a section of the aforementioned parallel strip type of line. In one, spaced susceptances are provided in the form of conductor obstacles projecting either partway or all the way across the space between the parallel strip conductors. In the other, spaced susceptances are provided by two obstacles or other discontinuity structures in or on one or the other or both of the conductors of the line at spaced points to form a resonant section therebetween.

An object of this invention is to provide still other microwave filter and susceptance arrangements which are small, light in weight, and relatively simple and inexpensive to make, also utilizing conductor elements or sections of the aforementioned parallel conductor type of line.

One of the features of this invention is the manner of providing spaced susceptances of large value by making gaps in certain of the conductors of a parallel strip type of line. The "gap" susceptances may comprise various shapes widths and angles, and may include gaps between spaced overlapping conductors or spaces between adjacent conductors of the same or different cross-sectional configurations. Another important aspect of the invention is that the gap susceptance permits D. C. isolation between the different sections of the line conductor.

The 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 drawings, wherein:

Fig. 1 is a plan view of one form of filter in accordance with the principles of this invention;

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

Fig. 3 is a graph showing the magnitude of the equivalent shunt susceptances with the reference plane taken along line A—B of Fig. 1;

Fig. 4 is a plan view of an alternate form of filter;

Fig. 5 is a cross-sectional view taken along line 5—5 of Fig. 4;

Figs. 6 and 7 are plan views of other embodiments of the invention;

Fig. 8 is a graph showing values of the ratio

$$\frac{\text{Power input}}{\text{Power output}}$$

versus gap's spacing for the embodiment shown in Fig. 6 wherein the line on both sides of the gap are matched;

Fig. 9 is a plan view of still another embodiment of the invention;

Fig. 10 is a graph showing frequency response curves for filter configurations according to Fig. 1, 6 and 9;

Fig. 11 is a longitudinal cross-sectional view of still another embodiment of the invention; and

Figs. 12 and 13 are plan views of still other alternatives of filter configurations according to the present invention.

Referring to Figs. 1 and 2 the microwave transmission line shown is of the printed circuit type comprising a first or "line" conductor **1** and a second or "base" conductor **2** with a layer of dielectric material **3** therebetween. The conductive material may be applied and/or shaped or etched on a layer of dielectric material, such as polystyrene, polyethylene, quartz, Teflon, Fiberglas or other suitable material of high dielectric quality in accordance with known printed circuit techniques. The spacing of the two conductors is preferably selected a small fraction of a quarter wavelength of the microwave propagated therealong, a suitable fraction being in the order of one-tenth to one-fifth of a quarter wavelength.

The filter comprises a length of base conductor **2**, a layer of dielectric **3**, and several resonant sections of line conductor, such as indicated at **4**, **5** and **6**, quarter wave coupled. Susceptances are formed by the gaps **7** at the ends of each section. The electrical spacing of adjacent susceptances is determined largely by the length of the line conductor therebetween, reference in this regard being made to the equivalent circuit shown in Fig. 3. Resonant sections **4**, **5** and **6** each comprises approximately a half wavelength or a multiple thereof, the resonant sections being coupled by other sections of line, such as **4*a*** and **5*a***, approximately one quarter wavelength or a odd multiple thereof, as may be desired. The magnitude of the susceptance depends on the gap width and also on the angle of the gap with respect to the longitudinal axis of the line conductor.

It will be clear to those skilled in the art that alternate gaps may be arranged at different angles and/or different widths and in different directions. The V-shaped gaps **7** provide for larger R.-F. coupling as compared to a truly transverse gap, such as indicated in Figs. 6 and 7. The width of the gaps is important and should be maintained small depending on the configuration of the adjacent end portions of the conductor sections. The angle α (Fig. 1) has also an important bearing on the value of the susceptance. In Fig. 3 the equivalent circuit elements are given as a function of the angle α with respect to the longitudinal axis of the line conductor, Fig. 1. The values illustrated by curve **8** of Fig. 3 were obtained with a gap width of one millimeter, a line conductor **1** of six millimeters width, a conductor **2** of twenty-six millimeter width and a dielectric spacing between conductor **1** and **2** of 1.5

millimeters, wherein the dielectric employed was Fiberglas.

In Figs. 4 and 5, the line conductor *1a* is shown to be broken up into sections as indicated at **9** and **10**, wherein the ends of successive sections are directly coupled by V-shaped gaps **11***a*, **11***b* and **11***c*. The gaps **11***a* and **11***c* are small in width and present relatively small values of susceptance while gap **11***b* is much larger in width and presents a relatively large susceptance. In this embodiment, the conductors **1***a* and **2***a* are shown to be of equal width and, as an example, this width may be five millimeters while the dielectric may be six millimeters in width. Whether or not the conductors are made of the same width, the gaps may be provided in either of the two conductors or alternate therebetween, it being more practical, however, to make the gaps in the narrower of the two where they are of unequal widths.

Figs. 6 and 7 show two embodiments of the invention, one in which the narrow line conductor is made in sections and in the other, where the wider base conductor is made into sections. In Fig. 6, for example, the line conductor **1***c* is shown to comprise resonant sections **12** and **13**, quarter wave coupled by a quarter wave section **14**. The gap susceptances **15** are disposed transverse to the longitudinal axis of the line conductor. The base or ground conductor **2***c* is shown to be wider than the line conductor **1***c* and to underlie throughout the resonant sections formed of the line conductor. A thin layer of dielectric material **3***c* maintains the conductors in spaced relation.

In Fig. 7 the line conductor **1***c* is made continuous while the ground conductor **2***c* is provided with gaps **16** at spaced points thus forming a resonant section **17** therebetween, this resonant section being approximately one-half wavelength between susceptances although a multiple thereof will suffice where desired, the same as in connection with the other embodiments herein disclosed. It should also be recognized that the gaps **15** and **16** may be varied in width in accordance with the susceptance values and the type of coupling desired.

The curve **18** shown in Fig. 8 illustrates the transmission property through a gap **15** of line conductor of the type shown in Fig. 6. The test data for this curve was taken from a susceptance gap of the configuration shown in Fig. 6, wherein the line conductor was six millimeters wide, the base conductor **2***c* was twenty-six millimeters wide and the spacing therebetween was 1.5 millimeters. The values for the curve were obtained by varying the width of the gap between 1 and 20 millimeters.

In the embodiment shown in Fig. 9, resonant sections **19** and **20** are shown of line conductor material approximately one half wavelength electrically between reference planes X and Y of the associated gaps, coupled by approximately quarter wavelength sections, as indicated at **21**, the sections being disposed in lapped spaced relationship in a plane parallel to the ground conductor **22**. The line sections are supported on the ground conductor by a thin layer of dielectric material **23**. The gaps **24** and **25** may be varied both in width and length in accordance with the susceptance value desired. In this connection, it should be recognized that the length of the sections **19**, **20** and **21** may be varied considerably depending upon the width and length of the gaps **24** and **25**. Sections **19**, **21** therefore are not truly half wavelength nor is coupling section **20***a* quarter wavelength.

The three frequency response curves of Fig. 10 illustrate the pass band characteristics of the filters herein disclosed. Curve **26** corresponds to a filter of the configuration illustrated in Fig. 1, wherein the angle α of the V-shaped gap is 35 degrees, the other dimensions being in accordance with those given for the curve illustrated in Fig. 3, that is, the line conductor was six millimeters wide, the ground conductor twenty-six millimeters wide and the dielectric thickness was 1.5 millimeters. Curve **27** corresponds to a filter configuration in accordance with the form illustrated in Fig. 6 with the exception that the gap at one end of the resonant section was one-tenth millimeter in width and the gap at the other end of the section was .75 millimeter in width. The dimensions of the conductors and the dielectric layer were otherwise the same as those of the filter from which curve **26** was derived. Curve **28** corresponds to a filter section in accordance with the embodiment illustrated in Fig. 9, the length of the section corresponding to section **19** being fifty-four millimeters long, the width of the gap being 0.2 millimeter and the length of the gap being eighteen millimeters. The line conductor was six millimeters wide and the ground conductor was twenty-six millimeters wide. The dielectric material employed in all three specimens was Fiberglas.

Instead of the lapped spaced relationship, such as indicated for sections **19** and **20** in Fig. 9, being in a plane parallel to the line or ground conductor, the lapped relationship may be in a plane normal to the plane of the conductors. Such a resonant section is shown in Fig. 11. The ends of the line conductors **29** and **30** are spaced apart and a line section **31** is spaced thereabove in overlapping relation as shown. The resonant section between the reference planes X and Y is approximately one half wavelength electrically. The gaps **32** where the section **31** overlies the end portions of the line conductor may be controlled as desired by the thickness of the dielectric layer **33**. The dielectric layer **33** may be integral with the dielectric layer **34** between the line conductor and the ground conductor **35** or it may be separate therefrom, whichever is desired. The dielectric layer **33** may also correspond to the layer **34** in thickness, the susceptance value in that case being adjusted by varying the amount of overlap between the end portions of the conductors **29** and **31**, for example.

Many variations of the gap configuration between adjacent sections of the line conductor are possible and as further illustrated, Fig. 12 shows alternate sections **36** and **37** of different width whereby the end portions of the wider section is disposed in spaced relation to the end portion of the narrower section. In Fig. 13 a similar arrangement is shown except that the end portion of the larger section **38** is recessed at **39** to receive in spaced relation thereto the end portion **40** of the smaller section **41**. This latter form, of course, is similar to the form illustrated in Fig. 1 with respect to the lapped male-female relationship of the adjacent end portions of the line conductors.

The resonant sections of the various embodiments may be tuned by any of the methods disclosed in the aforesaid applications Serial Nos. 286,761, now Patent No. 2,820,206, and 286,763, now Patent No. 2,819,452.

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 microwave bandpass filter comprising a ribbon-like line conductor, a ribbon-like ground conductor, dielectric means disposing said conductors in spaced substantially parallel relation a small fraction of wavelength apart, said line conductor being divided into distinct lengths, adjacent lengths of said line conductor being spaced apart to form susceptance gaps and the conductor length between certain adjacent gaps being of a size such that the parallel conductors thereof constitute a resonant section, the terminating ends of adjacent conductors being disposed in overlapping spaced relation with the gap between adjacent conductor lengths being small with negligible capacitive effect but sufficient to establish an electromagnetic field bulging laterally with respect to said gap, thereby presenting a discontinuity in the propagation path of microwave energy along said conductors.

2. A microwave bandpass filter according to claim 1 wherein the overlapping terminations of adjacent conductor portions are angularly disposed to present a gap disposed at an acute angle to the longitudinal axis of said line conductor.

3. A microwave bandpass filter according to claim 1 wherein the overlapping terminations of the adjacent portions of said line conductor comprise conductor lengths disposed in offset overlapping relation in a common plane parallel to the plane of said ground conductor, said ground conductor being disposed in underlying relation to said conductor portions.

4. A microwave bandpass filter according to claim 1 wherein two of said conductor lengths lie in the same plane parallel to the plane of said ground conductor and a third conductor length lies in another plane parallel to the planes of said two conductors in spaced overlapping relation with the terminations of said two conductors.

5. A microwave bandpass filter according to claim 1 wherein the overlapping relation between two adjacent

conductor lengths comprises a recess in one of said lengths and a projection for the other of said lengths received in spaced relation in said recess.

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