Dec. 25, 1962 R. H. DOUGLAS 3,070,764

MICROWAVE APPARATUS

Original Filed July 21, 1958

FIG. 1

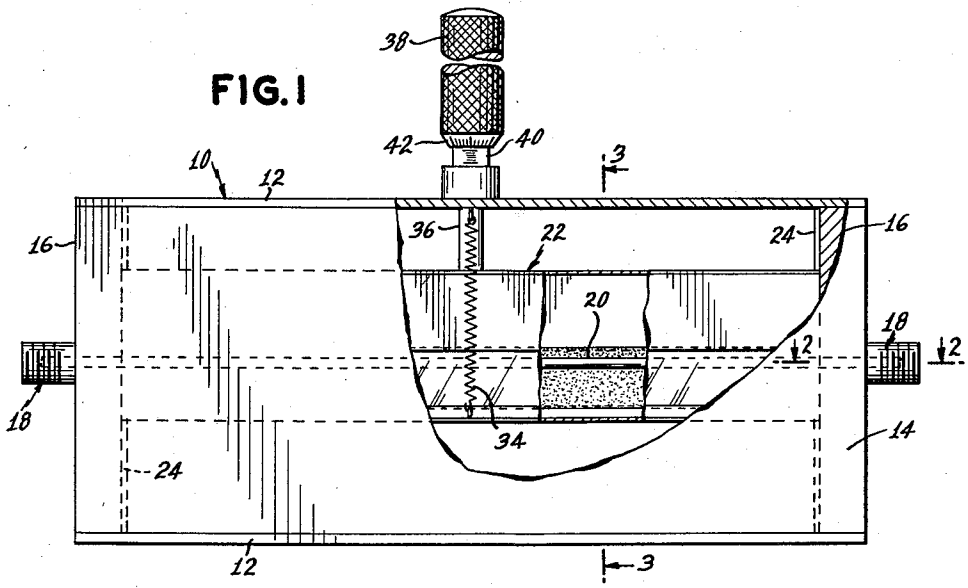


FIG. 2

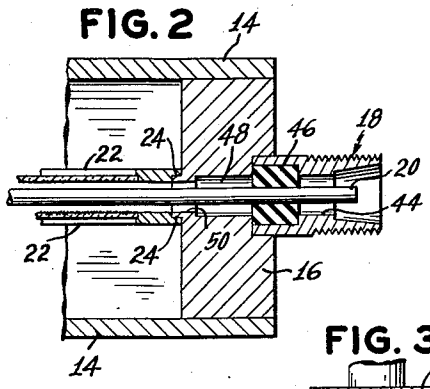


FIG. 4

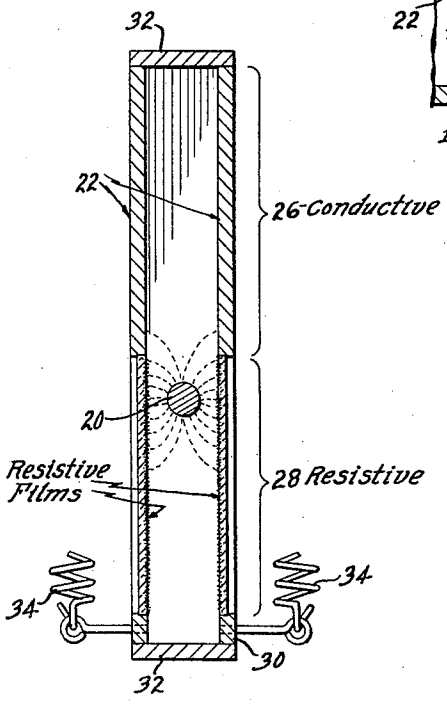
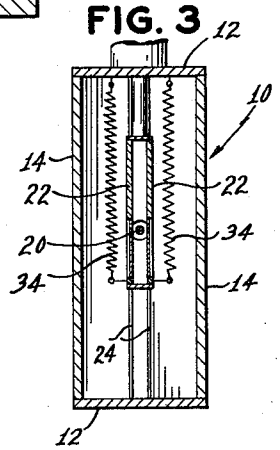


FIG. 3



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3,070,764
Patented Dec. 25, 1962

3,070,764
MICROWAVE APPARATUS

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Continuation of application Ser. No. 749,924, July 21, 1958. This application June 13, 1961, Ser. No. 114,595
26 Claims. (Cl. 333—81)

The present invention relates to microwave apparatus and more particularly to attenuators. This application is a continuation of my copending application Serial No. 749,924, now forfeited.

An object of this invention is to devise a novel attenuator of unusually broad-band characteristics without resort to tuned stubs, critical transitions or the like, and more specifically, to provide a novel broad-band attenuator that is adjustable over a wide range of attenuation.

More specific objects of this invention are to provide a new and improved attenuator for coaxial line systems, to provide an attenuator for microwave coaxial lines that is effective to provide a wide range of attenuation in different conditions of adjustment, to provide for adjustable attenuation over a broad frequency range in a coaxial line system, and to provide a novel adjustable attenuator having unusually low minimum insertion loss over a broad frequency range.

The illustrative embodiment described below is the presently preferred embodiment of the invention. A novel microwave apparatus is provided that is adjustable over a wide range to accomplish wide differences in performance while maintaining virtually constant characteristic impedance throughout the adjustment range and over a broad band of frequencies. It involves an adjustable attenuator interposed between two coaxial line elements. The attenuator is in the form of a pair of adjustable flat members mounted to move as a unit in relation to a straight wire midway between those members. The adjustable flat members have opposed conductive areas and opposed resistive areas adjoining the conductive areas, divided along respective lines parallel to the wire. The flat members are arranged to move in their own respective planes, crosswise of the wire between them. The flat members are connected to the outer conductors of the coaxial line elements, and the straight wire forms an extension of the inner conductors of the coaxial line elements. The diameter of the wire and the spacing between the flat members and the wire are proportioned to impart the same characteristic impedance as that of the coaxial line elements at the opposite ends of the attenuator.

The resistivity of the resistive areas may be empirically chosen for best effect. Manifestly, the resistivity should not be so low as to equal that of the conductive areas; nor should the resistive areas be of infinitely high resistivity. The resistive areas in the embodiment described have such resistivity as to effectively define a boundary for the electromagnetic field associated with the wire between the adjustable members.

The conductive elements are preferably made sufficiently wide (in the direction of adjustment) so that when the unit is adjusted for minimum attenuation, the edges of the conductive areas are effectively infinitely far from the wire; and by like token, the resistive elements are desirably of the same substantial width so that they resemble infinite-width elements when the unit is adjusted for maximum attenuation.

Inasmuch as the adjustable members of the illustrative attenuator are flat and parallel and move as a unit in their own respective planes during adjustment, it is apparent that the geometric characteristics upon which its characteristic impedance depend remain unchanged throughout the range of adjustment, from that extreme in

which the wire is between the conductive portions (remote from the resistive portions) and that extreme in which the wire is between the resistive portions (and correspondingly remote from the conductive portions). However, certain novel aspects of the invention are not necessarily identified with maintaining constant characteristic impedance but apply more broadly to providing a desired attenuating characteristic at each part of the range of adjustment, even at the expense of incidental variation in the characteristic impedance. Thus, when the wire is exposed predominantly to the resistive portions of the adjustable members, there is a high level of attenuation and then it may not be mandatory to match the characteristic impedance of the attenuator to that of the supply and load wave-transmission elements. For example, it may be more important to attain a greater maximum level of attenuation than to maintain constant characteristic impedance. In such cases, the spacing of the wire to the resistive members may be changed from point to point along the range of adjustment in accordance with desired criteria. In any event, no special transition is required between the coaxial line elements and the parallel-plane attenuator even for extreme band widths, and no tuning stubs or matching sections are needed for attaining a very low minimum insertion loss.

The resistive portions of the adjustable composite conductive and resistive element are in the form of a thin supporting layer of insulation bearing a resistive film. The adjustable structure is contained within a protective metal housing in the preferred embodiment. Where a housing is used, its walls are preferably remote from the wire so as not to interfere with the function of the resistive films (when adjusted opposite the wire) as space-bounding surfaces.

The nature of the invention and its various further features of novelty will be apparent from the following description of an illustrative embodiment which is shown in the accompanying drawings forming part of this disclosure. In the drawings:

FIG. 1 is a side elevation of an illustrative embodiment of the invention, with parts broken away for clarity;

FIG. 2 is a fragmentary cross-section of the apparatus in FIG. 1 along the line 2—2 therein;

FIG. 3 is a vertical cross-section of the apparatus in FIG. 1 along the line 3—3 therein; and

FIG. 4 is an enlarged detail of FIG. 3.

In the drawings, the metal housing **10** includes top and bottom walls **12** and side walls **14**. End walls **16** of the housing support coaxial line elements **18** at the opposite ends of the device, being standard fittings for connection of the illustrated apparatus in a coaxial line system.

The inner conductor **20** of the coaxial line elements **18** extend continuously as a straight wire from one end of the unit to the other. A pair of flat members **22** are supported parallel to each other and equally spaced from the wire **20** on opposite sides of the wire. The ends of members **22** are formed complementary to guide rails **24** on end walls **16** of the housing. Each member **22** is divided lengthwise, parallel to wire **20**, into a conductive portion **26** and a resistive portion **28**. The metal that forms conductive portion **26** is extended as a supporting frame **30** about the resistive portion **28**.

Each of the resistive portions of members **22** is in the form of a thin sheet of glass or other suitable insulation bearing a film of resistive material, preferably vapor-deposited metal. The film is on the surface that faces wire **20** and is coplanar with the corresponding surface of conductive portions **26**. Members **22** are mechanically united at their top and bottom edges by metal strips **32**. This

unitary assembly, guided at its ends by rails **24**, is spring-biased upward by a pair of springs **34** outside the walls of the adjustable unit **22—32**. These springs are secured to the top wall **12** of the housing and to pins extending outward from the bottom of unit **22—32**. That unit is adjustably driven downward by shaft **36** that extends through the top wall **12** of the housing from a calibrated micrometer screw **38** and presses against the top **32** of unit **22—32**. The micrometer screw has the usual scale **40** and a vernier scale **42**.

Each of the coaxial elements **18** is of the same characteristic impedance and, in fact, each of these elements is of the same dimensional characteristics. The conductor **20** of the attenuator extends into these coaxial elements as the center conductor thereof and is of the same round cross-section throughout its length. The inside diameter of outer conductor **44** is critically related to the diameter of inner conductor **20** to establish the characteristic impedance of the coaxial line element. A supporting insulator **46** of dielectric material locates the inner conductor within the coaxial line connector, its diameter being related to its dielectric constant to maintain the same characteristic impedance. This impedance is maintained in the end wall **16** of the housing, in that bore **48** is of the same diameter as bore **44**. Bore **48** opens into a vertical groove in end wall **16**. The opposed walls **50** of this groove are separated from each other by that critical distance relative to the wire **20** midway between them so as to have the same characteristic impedance as that of the coaxial line elements **18**. The inside surfaces of members **22**, including both the conductive portions **26** and the resistive portions **28**, are flush with surfaces **50** and remain so in all positions of adjustment along guide rails **24**.

As seen in FIG. 4, the conductor **20** is disposed between a pair of parallel-plane members which are mounted for vertical adjustment relative to that wire. Those members are effectively of infinite width. The characteristic impedance of such a transmission line is expressed by the following equation, to a close approximation:

$$Z_0 = 138 \log 4a/\pi r$$

where Z_0 is the characteristic impedance, a is half of the distance between the inner faces of member **22**, and r is the radius of conductor **20**. The dimensions of this transmission line are chosen to match the characteristic impedance of the coaxial line elements **18** at the ends of the parallel-plane portions of the apparatus. The characteristic impedance of a coaxial line element is:

$$Z_0 = 138 \log \frac{D}{d}$$

where D is the inside diameter of the outer conductor (where there is no dielectric interposed) and where d is the diameter of the inner conductor.

FIG. 4 contains a dotted-line representation of the electric component of the microwave field associated with the wire **20**. This field is seen to be unevenly distributed along the parallel-plane members, concentrated at those regions closest to the wire **20**. The field intensity is reduced greatly at points spaced above and below the wire in the drawing, and in the illustrated embodiment it fades to a negligible value at points above and below the wire that are approximately 2¼ times the separation between the inside faces of the parallel-plane members **22**. Portions **26** and **28** are each of effectively infinite width, in the direction of adjustment, so that structural elements **32** at the top and bottom of the adjustable unit are of no effect on the characteristic impedance of the attenuator in any normal adjustment.

In a practical example, the separation between the inside surfaces of parallel-plane members **22** is 0.230 inch, portions **26** and **28** are each 1.5 inches wide, and wire **20** is 0.125 inch in diameter. The length of members **22** along the wire **20** can be any desired value, depending upon the extent of attenuation desired. The maximum attenuation is a function of frequency, being greatest for the highest operating frequency. With a 10 inch length of resistive element **28**, an attenuation of 40 db at 4000 megacycles is readily attainable with resistive films of 30 ohms per square.

Higher values of resistivity in a system having this characteristic impedance reduce the attenuation realized, a resistivity of 50 ohms per square producing markedly less attenuation. The resistive material thus acts analogous to a shunt load on the microwave source.

By making the coaxial line elements of the same characteristic impedance as that of the parallel-plane transmission line **22—20—22**, a very low value of VSWR is realized, effective over a broad band, without resort to special matching sections, and excellent match of impedance is maintained throughout the range of adjustment of the attenuator. In the above example, coaxial line elements **18** having the same inner-conductor diameter of 0.125 inch provides the same characteristic impedance with an inside diameter **44** of the outer coaxial conductor of 0.285 inch (where there is no dielectric spacer). This example of the illustrative embodiment has a remarkably low figure of minimum insertion loss, averaging less than 0.3 to 0.4 db in the minimum-attenuation adjustment, throughout a very broad frequency range from approximately 12,000 megacycles down to the lower limit for which the coaxial line operates in the transverse electric mode.

It was noted that the conductive portion **26** and the resistive portion **28** of each parallel-plane member **22** is made effectively of infinite width in the direction parallel to the adjustment path; but the range of adjustment of the parallel-plane unit relative to wire **20** need not be much more than one inch in the example for which dimensions are given above. Over this range of adjustment, the variation of attenuation is highly linear, being another important feature of the invention. This feature is an advantage not only for the user, but also in the manufacture of such devices; for calibrating, it is not necessary to explore the entire range of adjustment for each frequency on a point-by-point basis, but only to check the attenuation at isolated points over the range of adjustment. With the calibration of the attenuation thus determined, a still further feature is the reliability and stability of the calibrated attenuator.

One of the values employed in the practical example of the illustrative embodiment above is the 30 ohm-per-square resistivity of resistive portions **28** in a system having a characteristic impedence of 50 ohms. It is evident that the resistive portions cannot have such low resistivity as to make them good conductors; and the resistivity should not be so high as to amount to lossless elements of dielectric material. In the above example, the 30-ohm-per-square resistivity was found to be optimum for maximum attenuation. Naturally there are different optimum values of resistivity for other values of characteristic impedance. It should also be understood that there is a range of resistivities that will produce effective attenuation for any given characteristic impedance. Further, for some purposes it may be desirable to grade the resistivity so as to be higher in some zones than others. The dimensions given in the above example are illustrative, and are not intended to be in any way limiting.

It has been noted above that the housing **10** which encloses the adjustable structure is of metal and functions as a mechanical protector and an electrical shield about the electrically active components **20** and **22**. That shield should be remote from the parallel-plane elements **22**. In practice, the distance between the inside surfaces of side walls **14** should be several times the distance between the inside surfaces of members **22**. It is not essential that the housing **10** be employed; but if it is used, it should not too closely approach resistive films **28**.

The foregoing represents an exemplary embodiment of various features of the invention. It will be understood

however, that certain of its features may be employed without others and its basic concepts are naturally susceptible to a wide range of variation and application. Therefore, the invention should be broadly construed in accordance with its full spirit and scope.

What is claimed is:

1. An attenuator, including a straight wire and a pair of flat conductive members parallel to each other and to said straight wire, said members being equally spaced from the wire on opposite sides thereof and said members being mounted for movement in their own planes transverse to said wire, and confronting space-bounding resistive walls extending from longitudinal edges of said conductive members and movable therewith so that as the conductive members are displaced away from said wire the resistive walls are displaced transversely of the wire and into confronting relation to said wire, and vice versa.

2. An attenuator, including a straight wire and an attenuator unit opposite said wire, said unit being divided into space-bounding resistive and conductive portions, the division between the resistive and conductive portions extending along the wire, and an adjustable mounting for said unit providing for the movement thereof along a line transverse to the division between said resistive and conductive portions to expose said resistive and conductive portions to the wire in any proportions.

3. An attenuator, including an elongated and relatively narrow conductor and at least one considerably wider space-bounding member extending along but spaced from said conductor, said member and said conductor establishing an elongated transmission path therebetween, said member having a resistive area and a conductive area extending side by side, the division between said areas extending along said transmission path, and means mounting said member for adjustment relative to said conductor transversely of the transmission path to expose the resistive and conductive areas of said one member to said elongated conductor in any desired proportions.

4. An adjustable microwave attenuator, including an elongated wire, a companion member spaced from said wire and forming therewith a length of transmission line, said member being divided into resistive and conductive parts extending side by side, the division between said parts extending along said wire, and means for adjustably supporting said member for adjustment transverse to the division between the resistive and conductive parts so as to adjust the relative distances between the wire and the respective resistance and conductive parts of said member.

5. An attenuator, including elongated first and second members which jointly establish a length of microwave transmission path, one of said members having space-bounding resistive and conductive portions extending side by side, the division between said resistive and conductive portions extending along the transmission path, and means mounting said members for adjustment in relation to each other transverse of the transmission path to expose the resistive and conductive portions of said one member to the other member in any desired proportion.

6. An attenuator, including two coaxial line elements each having a center conductor and an outer conductor and both said coaxial line elements having the same characteristic impedance, said outer conductors being spaced apart endwise, a straight wire interconnecting said center conductors, and a pair of flat members parallel to each other and to said straight wire and equally spaced from the wire at opposite sides thereof, said members being mounted for movement as a unit in their respective planes transverse to said wire, said flat members each being divided along a line parallel to said wire into a resistive portion and a conductive portion, the resistive portions of the pair of flat members being on confronting relation and being wide enough to approximate infinite-width members in relation to said wire when centered opposite said wire and the conductive portions of the flat members being in confronting relation and being wide enough to approximate infinite-width members in relation to said wire when centered opposite said wire and said flat members being spaced from the wire so as to have the same characteristic impedance as that of said coaxial line elements.

7. An attenuator, including two coaxial line elements of the same characteristic impedance including center and outer conductors, a straight wire interconnecting said center conductors, and an adjustable unit including at least one flat member parallel to said straight wire and interconnecting said outer conductors, said flat member being mounted for movement in its own plane and transverse to said wire, said flat member being divided into resistive and conductive portions, the width of each such portion being large in relation to the separation between said wire and said member, said adjustable unit being spaced from the wire so as to have the same characteristic impedance as said coaxial line elements.

8. An attenuator, including two coaxial line elements of equal size each having round center and outer conductors, said outer conductors being spaced apart endwise, and a straight wire of round cross-section interconnecting said center conductors, said straight wire being of the same diameter as said center conductors, and a pair of flat members parallel to each other and to said straight wire and equally spaced from the wire at opposite sides thereof, said members being mounted for movement in their own planes transverse to said wire, said flat members being divided along respective lines parallel to said wire into confronting resistive and confronting conductive portions, each pair of confronting portions being wide enough to approximate infinite-width members when centered opposite the wire, and said flat members being so spaced from the wire as to have the same characteristic impedance as said coaxial line elements, and an enclosing shield about said wire and said flat members, said shield being remote from said wire.

9. An attenuator, including two 50-ohm coaxial line elements each having center and outer conductors, said outer conductors being spaced apart endwise, a straight wire interconnecting said center conductors, and an adjustable unit between said coaxial elements including a pair of flat members parallel to each other and to said straight wire and equally spaced from the wire at opposite sides thereof, said coaxial line elements opening into a grooved guide for said flat members and the walls of the groove being flush with the inside surfaces of said flat members, said flat members being divided along a line parallel to said wire into confronting resistive and confronting conductive portions of effectively infinite width, said flat members being so spaced from the wire as to have a characteristic impedance of 50 ohms, and the resistivity of the resistive portions being approximately 30 ohms per square.

10. An attenuator, including two coaxial line elements each having a center conductor and an outer conductor and both said elements having the same characteristic impedance, said outer conductors being spaced apart endwise, a straight wire interconnecting said center conductors, and a unit parallel to said straight wire and adjustable relative thereto in a manner constraining the inner surfaces of the unit to remain at constant spacing from the wire, said unit being divided along a line cross-wise of the path of adjustment into resistive and conductive portions, said wire and said adjustable unit being so spaced from each other as to have the same characteristic impedance as said coaxial line elements.

11. An attenuator, including two coaxial line elements spaced apart endwise and having inner and outer conductors of respectively equal diameters, a straight wire interconnecting the center conductors, and a pair of relatively wide flat space-bounding members parallel to each other and to the straight wire and on opposite sides of the wire, said flat members being spaced from each other and from the wire so as to have the same characteristic impedance

as said coaxial elements, at least one of said members having a flat resistive area whose resistivity is large enough to effect substantial attenuation but low enough to form a boundary for the electromagnetic field.

12. An attenuator, including two matched coaxial line elements spaced apart endwise and having inner and outer conductors, a straight wire interconnecting the center conductors, and a pair of flat members parallel to each other and to the straight wire and spaced apart on opposite sides thereof so as to match the coaxial line elements, said flat members including resistive and conductive areas, and means for adjusting the attenuation produced by said areas while maintaining constant the spaces between said members and said wire.

13. An attenuator, including a straight wire and a pair of flat space-bounding members parallel to each other and to said straight wire and equally spaced from the wire on opposite sides thereof, said members being mounted for movement in their own planes transverse to said wire, said flat members being divided parallel to the wire into confronting resistive portions and confronting conductive portions, the resistivity of said resistive portions being low enough to essentially confine the electromagnetic field, each portion being wide enough to approximate infinite-width members when centered opposite to said wire, and an enclosing shield remote from said wire.

14. An attenuator, including a straight wire and a pair of flat space-bounding members parallel to each other and to said straight wire and on opposite sides of the wire spaced from each other and spaced equally from said wire so as to have a characteristic impedance of 50 ohms, said flat members having resistive portions of 30 ohms-per-square resistivity.

15. An attenuator, including a straight wire and a pair of flat members parallel to each other and to said straight wire, said members being equally spaced from the wire on opposite sides thereof and proportioned to have a characteristic impedance of 50 ohms, said members being mounted for movement in their own planes transverse to said wire, said flat members being divided parallel to the wire into confronting resistive and confronting conductive portions of effectively infinite width, the resistivity of the resistive portions being approximately 30 ohms per square.

16. An attenuator including a straight wire and an attenuator unit opposite said wire and having a constant spacing from the wire along its length, said unit being divided into resistive and conductive portions, the division between the resistive and conductive portions extending along the wire, and an adjustable mounting for said unit providing for the movement thereof along a line transverse to the division between said resistive and conductive portions while maintaining constant spacing between said wire and said unit.

17. An attenuator, including first and second transmission-line members arranged to be excited in the TEM mode, one of said members having resistive and conductive portions, the division between said portions extending along the transmission path, and means for adjusting said members in relation to each other transverse of the transmission path so as to expose the resistive portion and the conductive portion of said one member in any proportion to the field while preserving the geometry of said attenuator unchanged.

18. An attenuator, including a transmission-line section arranged to be excited in the TEM mode, said transmission line section including a wall normal to the electric field component, said wall including conductive and resistive portions extending side by side along a line of division that extends along the transmission path, and means for adjusting said wall relative to the remainder of the transmission line section transversely of the transmission path for changing the proportions of the conductive portion and the resistive portion exposed to the space within the transmission line section while preserving the geometry thereof unchanged in all degrees of adjustment.

19. An attenuator, including a transmission-line section arranged to be excited in the TEM mode, including a member normal to the electric field and having resistive and conductive portions divided along a line that extends along the transmission path, and means for adjustably interchanging the proportions of said portions exposed to the field transversely of the transmission path while maintaining the geometry of the transmission path unchanged.

20. An adjustable microwave attenuator, including a straight wire, at least one flat member parallel to said wire, said member being divided into resistive and conductive parts extending side by side, the division between said portions extending along said wire, and means for adjustably supporting said flat member for adjustment transverse to the division between the resistive and conductive parts but in its own plane, for adjusting the distance between the wire and the respective resistive and conductive parts of said flat member.

21. An attenuator, including elongated first and second members which jointly bound a length of microwave transmission path, one of said members having resistive and conductive portions extending side by side, the division between said resistive and conductive portions extending along the transmission path, and means mounting said members for adjustment in relation to each other transverse of the transmission path to expose the resistive and conductive portions of said one member to the other member in any desired proportion while preserving constant geometry of the microwave transmission-path boundaries.

22. An attenuator including a transmission element defining a length of microwave transmission path and including a wall having a resistive portion and a conductive portion extending side by side and divided from each other, the division between said portions extending along the transmission path, and means adjusting said wall transversely of the transmission path but in its own plane for adjusting the effective exposure of the respective portions of said wall to said path while preserving constant the geometric dimensions determining the characteristic impedance of said element, in combination with means at each end of said transmission element for extending the microwave transmission path, said last-named means having geometric dimensions providing equal characteristic impedance to that of said transmission element.

23. An attenuator including means defining a microwave transmission path, said means including a member having resistive and conductive portions extending side by side along the transmission path and means for adjustably supporting said member for movement of the resistive and conductive portions in their own plane transverse of the transmission path, interchanging the effective exposure of said portions to said path, and additional path-defining means extending said first-mentioned means, both said means having the same characteristic impedance.

24. An attenuator, including an elongated and relatively narrow conductor and at least one considerably sider space-bounding member extending along but spaced from said conductor, said member and said conductor establishing an elongated transmission path therebetween, said member having a resistive area and a conductive area extending side by side, the division between said areas extending along said transmission path, and means mounting said member for adjustment through a range relative to said conductor transversely of the transmission path to expose the resistive and conductive areas of said one member to said conductor in any desired proportions, said member and said elongated conductor having constant spacing therebetween throughout said range of adjustment at each point along the transmission path.

25. An attenuator, including a transmission element defining a length of microwave transmission path and including a wall having a space-bounding resistive portion and a conductive portion extending side by side and

divided from each other, the division between said portions extending along the transmission path, and means adjusting said wall transversely of the transmission path in a direction to adjust the effective exposure of the respective resistive and conductive portions of said wall to said path, in combination with means at each end of said transmission element for extending the microwave transmission path providing equal characteristic impedance to that of said transmission element at least when said conductive portion is predominantly exposed to the transmission path.

26. An attenuator, including means defining a microwave transmission path, said means including a member having resistive and conductive portions extending side by side along the transmission path and means for adjustably supporting said member for movement of the resistive and conductive portions transverse of the transmission path for adjustably interchanging the effective exposure of said portions to said path, and additional path-defining means joined to said first-mentioned means to extend the microwave transmission path, both said means having the same characteristic impedance at least when said conductive portion is predominantly exposed to said conductive portion.

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