Dec. 30, 1952 R. W. CORNES 2,623,946

TRANSMISSION LINE TRANSITION

Filed March 29, 1947

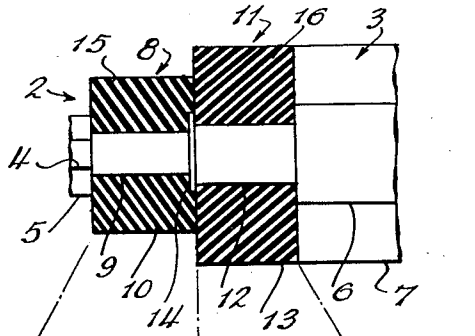


Fig. 1.

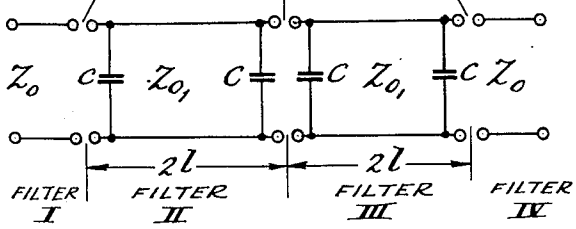


Fig. 2.

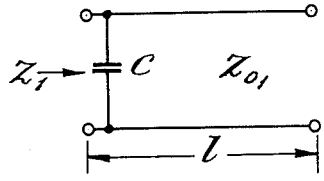


Fig. 2A.

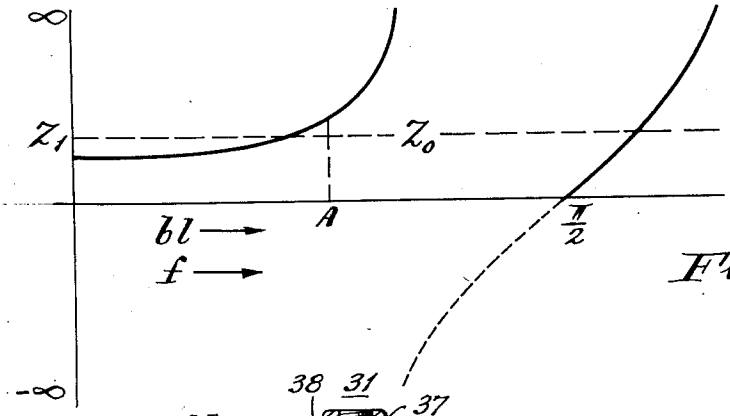


Fig. 3.

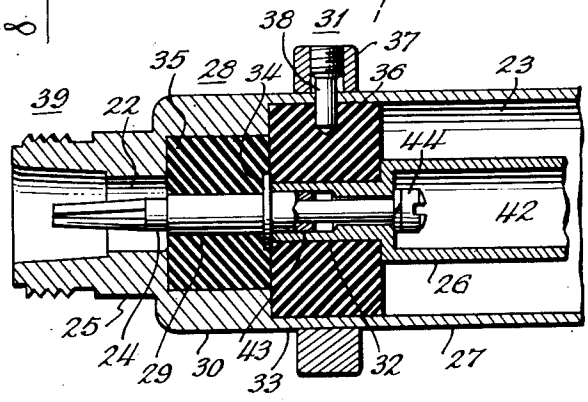


Fig. 4.

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Patented Dec. 30, 1952 2,623,946

UNITED STATES PATENT OFFICE

2,623,946

TRANSMISSION LINE TRANSITION

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Application March 29, 1947, Serial No. 738,193

9 Claims. (Cl. 178—44)

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The present invention relates to the art including transitions or couplings between two transmission lines of differing sizes. It is particularly applicable as a transition between two coaxial lines of differing sizes.

It is an object of the present invention to provide an improved transition between two transmission lines of differing sizes.

It is another object of the present invention to provide between two transmission lines of differing sizes, a substantially-reflectionless transition of comparatively small longitudinal dimension.

It is yet another object of the present invention to provide a broad-band transition between two coaxial lines of differing sizes.

In the preferred embodiment of the invention described hereinafter, the transition couples two different-sized transmission lines of the coaxial type, and comprises a pair of coaxial line transition sections in tandem between the different-sized lines to be connected. A thin flange serving effectively as a capacitance is located at the junction of the inner conductors of these two transition sections, and its effective capacitance is correlated to the characteristic impedances of the lines to be connected, to the characteristic impedances of the transition sections, and to the lengths of the transition sections, in the manner described hereinafter, to provide the advantages and to attain the objects of the present invention.

The invention also relates to the novel features or principles of the instrumentalities described herein, whether or not such are used for the stated objects or in the stated fields or combinations.

Fig. 1 is a schematic line drawing of a generalized transition of the type used in the present invention and usfeul in explaining the operation of the present invention.

Fig. 2 is the equivalent circuit diagram of the transition of Fig. 1.

Fig. 3 is a graph useful in explaining the operation of the apparatus of Fig. 1.

Fig. 4 is a longitudinal-cross-sectional view of one physical embodiment of the apparatus of Fig. 1.

Referring to Fig. 1, a transition is shown schematically as connected between a first coaxial

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line end section 3 having an inner conductor 4 and an outer conductor 5, and a second coaxial line end section having an inner conductor 6 and an outer conductor 7 which are larger in diameter than the respective conductors of the first coaxial line end section 2. Joined in tandem to the first coaxial line end section 2 is a first coaxial line transition section 8 having an inner conductor 9 and an outer conductor 10 whose diameters are larger respectively than those of the inner conductor 4 and the outer conductor 5 of the first end section 2. Connected between the first transition line section 8 and the second end section 3, is a second coaxial line transition section 11, having an inner conductor 12 of diameter intermediate the diameter of the inner conductor 9 of the first transition section 8 and the diameter of the inner conductor 6 of the second end section 3. Transition section 11 also has an outer conductor 13 of the same diameter as the outer conductor 7 of the second end section 3 but of larger diameter than the outer conductor 10 of the first transition section 8. At the junction of the inner conductor 9 and the inner conductor 12 of the two transition sections 8 and 11, there is positioned a thin disc-shaped conductive flange 14 which, as will be seen, determines the effective capacitive admittance at that point.

Dielectric beads 15 and 16 fill the inter-conductor spaces in the first and second transition sections 8 and 11, respectively. The dielectric beads 15 and 16, in addition to their effects on the characteristic impedances of the two transition sections 8 and 11, act as supports for the inner conductors 9 and 12 of the two transition sections.

Having thus described the general arrangement of the present invention, the manner in which it provides its advantages will now be discussed. As is well known, field discontinuities in a coaxial line are caused by changes in outer conductor diameter, inner conductor diameter, or diameters of both conductors. Such discontinuities are troublesome since they cause undesirable standing waves and energy reflection, leading to intolerable frequency sensitivity and losses. The effects of such discontinuities may be calculated by considering each discontinuity as a lumped admittance shunted between the

line conductors at the location of the discontinuity. For frequencies sufficiently low so that the transverse dimensions of the line are less than a half wavelength, which is the case for the recommended operating frequencies of the present novel transition, the discontinuity admittance is capacitive. The values of discontinuity capacity have been calculated for various changes in coaxial line dimensions, as set out in the article by Whinnery, Jameson and Robbins entitled, "Coaxial-line discontinuities," in the Proceedings of the I. R. E. of November 1944.

As indicated above, the specific embodiment of the recent invention described herein is adapted for use between coaxial lines 2 and 3 of different sizes but equal characteristic impedances. However, the present invention is not necessarily limited to equal impedances. The following analysis applies to the use of equal impedances as well as to cases where the characteristic impedances differ but slightly, in which event, for the design problem the characteristic impedance of each coaxial line is assumed to be equal to the average of their true characteristic impedances, without affecting substantially the operation of the transition.

Under these conditions, according to the present invention the change of conductor diameters at the junction of the first end section 2 with the first transition section 8 is selected to provide a discontinuity capacitance equal to that at the junction of the second transition section 11 with second end section 3. Also, the radial dimension (or outer diameter) of the flange 14 at the junction of the first transition section 8 with the second transition section 11 is chosen to provide a discontinuity capacity at that junction equal to twice that at the other junctions.

For simplicity of design calculation and of construction, the same dielectric material is used at 15 and 16, so that the same dielectric constant occurs in both transition sections 8 and 11. Also, the lengths and characteristic impedances of the two transition sections are made equal, by selecting their inner and outer conductors of the same diameter ratio.

Fig. 2 shows a schematic circuit diagram equivalent to the structure shown in Fig. 1. End section 2 can be represented by a filter I constituted by a transmission line of characteristic impedance Z_0, and end section 3 is represented by a similar filter IV.

The first transition section 8 and the second transition section 11 may then be represented by filters II and III in cascade, each filter comprising a transmission line section of length $2l$ and of characteristic impedance Z_{01} the transmission line section being shunted by the same capacity C at each end thereof. The capacity C has a value equal to the discontinuity capacity at the junction between each end section with its adjoining transition section. The two capacities C at the junction between the two filters II and III provide a resultant capacity of double value, thereby being equal to the discontinuity capacity offered by flange 14 of Fig. 1 under the conditions imposed. Thus, two similar symmetrical filters II and III in cascade represent the transition. Each symmetrical filter is somewhat similar to a π section at lower frequencies, but has a line section of length $2l$ therein. The entire apparatus of Fig. 1 is thus represented by filters I, II, III and IV in cascade.

Each of the filters II and III may be considered as formed of two half-filters, generally referred to as half-sections, each of which consists of a length l of transmission line L shunted at one end by a capacity C, as shown in Fig. 2A. The image impedance Z_I of each half section looking into the half section from the capacity end (as defined, for example, at page 81 of "Transmission Networks and Wave Filters" by T. E. Shea, Van Nostrand Company, 1929) may for practical purposes be considered to be:

$$Z_I=\frac{Z_{01}}{\sqrt{1+2WCZ_{01}\cot 2bl-W^2C^2Z_{01}^2}} \qquad (1)$$

where

$$b=\frac{2\pi}{\lambda}$$

where λ=wavelength, in the line
$w=2\pi f$ where f=frequency
Z_{01}=characteristic impedance of the line L.

A graph of Z_I versus bl is shown in Fig. 3, in which bl is plotted along the X-axis and Z_I is plotted along the Y-axis. Inasmuch as bl is proportional to frequency f (when l is constant) the graph can also be considered a plot of Z_I versus f for fixed l.

The graph shows that Z_I changes very little with variation in frequency from $f=0$ to $f=A$. Thus, if the image impedance Z_I of the half section of Fig. 2A be chosen as equal to Z_0 at some point in that frequency band, the impedance mismatch over the band of frequencies from $f=0$ to $f=A$ is comparatively small. This may be referred to as the low pass region of the image impedance.

The choice of the parameters of the half section filter for matching purposes is facilitated by considering the image impedance Z_I of the half section as f approaches zero. Considering f approaching 0 as a limit, the image impedance Z_I at $f=0$ may, for practical purposes, be considered to be:

$$Z_I\Big|_{f=0}=Z'=\frac{Z_{01}}{\sqrt{1+\frac{Z_{01}Cv}{l}}} \qquad (2)$$

where v is the velocity of wave propagation in the dielectric. The parameters of the half section are then chosen so that

$$Z'=\eta Z_0 \qquad (3)$$

where η is a mismatch factor depending upon the maximum permissible VSWR over the desired band of frequencies and having a maximum value of 1. It will generally have the value of .99 or slightly lower.

For greater bandwidth, the characteristic impedance Z_{01} of the transition sections is made greater than the characteristic impedance Z_0 of the end sections.

Inasmuch as each transition section is a symmetrical filter consisting of two such half-section filters and the entire transition consists of two such symmetrical filters, it can be seen that the overall design of the transition is obtainable from the parameters of the single half-section.

From Equation 1 it can be seen that the rate of change of Z_I with frequency is a function of the rate of change of cot bl with frequency. If l is large, the rate of change of cot bl with frequency is more rapid than with l small. Therefore, the frequency band over which the variation of Z_I with frequency is comparatively small decreases with increasing axial length of the transition section. However, the axial length of the dielectric bead in each transition section

must be sufficient to give proper mechanical support for the inner conductor. The axial length of the transition section should therefore be a compromise between small length for broader frequency band and large length for increased mechanical strength.

Fig. 4 shows the actual construction of one form of the invention embodying the principles discussed hereinabove. The transition unit is connected between a second coaxial line end section 23 and a smaller first coaxial line end section 22 which is terminated in a standard female fitting 39. The transition unit comprises a first coaxial line transition section 28 having an inner conductor 29 and an outer conductor 30 whose diameters are larger respectively than those of the inner conductor 24 and the outer conductor 25 of the smaller coaxial line end section 22. Connected between the first coaxial line transition section 28 and the second coaxial line end section 23 is a second coaxial line transition section 31 having an inner conductor 32 of diameter intermediate the diameter of the inner conductor 29 of the first transition section 28 and the diameter of the inner conductor 26 of the second coaxial line end section 23. The second transition section 31 also has an outer conductor 33 of the same diameter as the outer conductor 27 of the second end section 23. At the junction of the inner conductor 29 and the inner conductor 32 of the two transition sections 28 and 31, there is positioned a thin disc-shaped conductive flange 34. Filling the interconductor spaces in the first and second transition sections 28 and 31 are respective dielectric beads 35 and 36. Surrounding and joined to outer conductor 33 of the second transition section 31 is flange 37. Equally disposed around flange 37 are three dielectric pins 38, each of which is threadedly engaged with the flange 37 and extends into a cylindrical hole in the dielectric bead 36. The dielectric pins 38 are composed of the same material as the dielectric bead 36 and keep the dielectric bead 36 fixed with respect to the outer conductor 33 of the second transition section 31. Inasmuch as dielectric bead 36 is fixed with respect to the outer conductor 33, the disc-shaped conductive flange 34, in addition to its electrical function of providing capacity, aids in holding in place the inner conductor 29 of the first transition section 28 and the inner conductor 32 of the second transition section 31,

In the construction shown in Fig. 4, the outer conductors of the smaller second end section 22, the first transition section 28, the second transition section 31 and the second end section are one integral subassembly. Two subassemblies 42 and 40 make up the inner conductors of the four sections. The first inner conductor subassembly 42 is an integral unit formed of the inner conductor 26 and the inner conductor 32 of the second end section 23 and the second transition section 31 respectively, both inner conductors 26 and 32 being of hollow construction. The second subassembly 40 is an integral unit formed of the inner conductor 29 and the inner conductor 24 of the first transition section 28 and the smaller end section 22. The second subassembly also includes the conductive flange 34 and a tubular internally-threaded portion 43 which is adapted to be inserted into the hollow inner conductor 32 of the second transition section 31.

In the assembling of the transition 31, the dielectric bead 35 is inserted in position in the outer conductor subassembly. The second inner conductor subassembly 40 is then inserted through the hole in the dielectric bead 35, the conductive flange 34 resting against the dielectric bead 35. The dielectric bead 36 is next inserted into position in the outer conductor subassembly. The first inner conductor subassembly is then inserted into position, the tubular projection 43 of the second inner conductor subassembly 40 projecting into the hollow inner conductor 32 of the first inner conductor subassembly 42, and the inner conductor 32 resting against the conductive flange 34. The two inner conductor subassemblies are held together by a screw 44 engaging tubular projection 43. The dielectric pins 38 are then inserted into the dielectric bead 36. To prevent the inner conductor subassemblies 40 and 42 from rotating within the outer conductor subassemblies, the outer surfaces of the inner conductors 29 and 32 are knurled.

In one form actually constructed to yield the above mentioned advantages, the transition was designed to connect a ⅞'' coaxial line end section to a coaxial line end section having a type —N— fitting termination. In the ⅞'' coaxial line section, the outer diameter of the inner conductor was .375 inch and the inner diameter of the outer conductor was .812 inch. In the coaxial line end section terminated in a type —N— fitting, the outer diameter of its inner conductor was .120 inch and the inner diameter of its outer conductor was .271 inch. The various elements of the transition between the two end sections had the following dimensions:

A. First coaxial line transition section:
   1. Outer diameter of inner conductor—.131 inch
   2. Inner diameter of outer conductor—.586 inch
   3. Axial length—.405 inch
B. Second coaxial line transition section:
   1. Outer diameter of inner conductor—.181 inch
   2. Inner diameter of outer conductor—.812 inch
   3. Axial length—.405 inch
C. Conductive flange:
   1. Outer diameter—.265 inch
   2. Axial length—.015 inch

The material forming both dielectric beads was a cross-linked condensation polymer of aniline and formaldehyde, sold under the trade name of Dielectene No. 100 by the Continental-Diamond Fibre Company, Newark, Delaware. Its dielectric constant is 3.4.

The impedance mismatch caused by the transition having the above-mentioned dimensions was well within satisfactory limits over a frequency range of 0–4000 mc. The VSWR of the standing waves caused by the transition was below 1.1 over that frequency range. The transition as so constructed is particularly recommended for operation in the frequency range of 600–3500 mc. It can be seen, therefore, that each transition section is much shorter than ¼ λ at the center frequency of the band and the entire transition is appreciably shorter than a reasonably efficient tapered transition for that band of frequencies.

Inasmuch as a desired discontinuity capacity may be obtained by changes in inner conductor diameter alone, in outer conductor diameter alone, or in both inner and outer conductor diameters, the scope of the invention is not restricted to the particular changes shown but encompasses all types of constructions that may

be used to effect a desired discontinuity capacity. Also, inasmuch as the image impedance of a half section is a function of many parameters of the half section, the scope of the present invention encompasses all combinations of values of the different parameters of the half section that give a desired image impedance.

Although each transition section is described above as a symmetrical filter, it can be seen that impedance matching can also be effected in accordance with the teachings herein by transition sections that are asymmetrical filter sections. Also, although the transition sections are described above as being physically similar sections, it can be seen that proper matching can also be effected by dissimilar sections.

In addition, although described above as a transition between coaxial lines of different sizes but of substantially the same characteristic impedance, the invention is not limited to such transitions but, by proper design, is applicable as a transition between coaxial lines of differing characteristic impedances.

Also, the scope of the invention is not limited to transitions between coaxial lines, but, by direct analogy includes transitions between other transmission lines of the hollow-internally-conducting type, such as waveguides, wherein a desired discontinuity admittance may be effected by a proper change in line size or by elements positioned within the line.

Thus, it can be seen that I have provided a novel transition between transmission lines that has wide application; that is compact; and that produces only a very low VSWR over an extremely broad frequency band.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A transition between two coaxial lines of differing sizes comprising a first transition section of coaxial line of size differing from one of said coaxial lines and joined to said one of said coaxial lines whereby a first discontinuity capacity exists at the juncture of said first transition section and the said one of the coaxial lines; a second transition section of coaxial line joined to said first transition section and of size differing from the size of the second of said coaxial lines, said second transition section of coaxial line being joined to said second of said coaxial lines whereby a second discontinuity capacity exists at the juncture of said second section and the second of said coaxial lines, the juncture of said first and second sections providing a discontinuity whose discontinuity capacity is substantially equal to the sum of said first and second discontinuity capacities.

2. Apparatus as in claim 1 in which said second discontinuity capacity is equal to said first discontinuity capacity.

3. Apparatus as in claim 1 in which the axial lengths of said first section and said second section are equal.

4. Ultra high frequency apparatus comprising a first coaxial line section including an inner conductor and an outer conductor spaced therefrom; a second coaxial line section having an inner conductor joined to the said inner conductor and an outer conductor joined to said outer conductor, at least one of said conductors of said second section of coaxial line differing in size from its corresponding conductor of said first coaxial line section; a third coaxial line section including an inner conductor and an outer conductor spaced therefrom, said latter inner conductor being joined to said second section inner conductor and said latter outer conductor being joined to said second section outer conductor, at least one of said conductors of said third coaxial line section differing in size from its respective conductor of said second coaxial line section; a capacity element at the juncture of the inner conductor of said second coaxial line section and the inner conductor of said third coaxial line section; and a fourth coaxial line section having an inner conductor and an outer conductor, said latter inner conductor and said latter outer conductor being joined respectively to the inner conductor and outer conductor of said third section of coaxial line, one of said conductors of said fourth section differing in diametral dimension from its corresponding conductor of said third coaxial line section.

5. Apparatus as in claim 4 further including solid dielectric material filling the space between the inner conductor and the outer conductor of said second coaxial line section, and also including solid dielectric material filling the space between the inner conductor and the outer conductor of said third coaxial line section, whereby said solid dielectric materials aid in supporting said inner conductors.

6. Ultra high frequency apparatus comprising a first coaxial line section including a first innre conductor and a first outer conductor, and having a predetermined characteristic impedance; a second coaxial line section including a second inner conductor whose diameter is larger than the diameter of said first inner conductor joined to said first inner conductor, said second coaxial line section also including a second outer conductor whose diameter is larger than the diameter of said first outer conductor and joined to said first outer conductor, said second coaxial line section further including solid dielectric material filling the space between said second inner conductor and said second outer conductor, whereby a first discontinuity capacity exists at the juncture of said first coaxial line section and said second coaxial line section; a third coaxial line section having a third inner conductor and a third outer conductor joined respectively to said second inner conductor and said second outer conductor, said third inner conductor and said third outer conductor having diameters larger than the respective diameters of said second inner conductor and said second outer conductor, said third coaxial line section also including solid dielectric material filling the space between the said third inner conductor and said third outer conductor; a flange at the junction of said second second and third inner conductors and providing a second discontinuity capacity whose value is substantially twice that of said first discontinuity capacity; and a fourth coaxial line section whose characteristic impedance is substantially equal to the characteristic impedance of said first coaxial line section and including a fourth outer conductor joined to said third outer conductor section, the diameter of said fourth outer conductor being equal to the diameter of the said third outer conductor, said fourth coaxial line section also including a fourth

inner conductor joined to said third inner conductor, the diameter of said fourth inner conductor being larger than the diameter of said third inner conductor and having at their junction a third discontinuity capacity substantially equal to said first discontinuity capacity.

7. Coaxial line apparatus comprising an inner conductor having a predetermined diameter for a first axial extent of said coaxial line, an enlarged diameter over a second axial extent of said coaxial line contiguous to said first axial extent, a still greater enlarged diameter over a third axial extent and contiguous to said second axial extent and equal in length to it, and greatest diameter for a fourth axial extent contiguous to said third axial extent; an outer conductor having a predetermined diameter for said first extent, an enlarged diameter for said second axial extent, and a still further enlarged diameter for said third and said fourth axial extents; solid dielectric material filling the space between said inner conductor and said outer conductor in said second and said third axial extents; and a flange element on said inner conductor at the junction of said second and third axial extents; the ratio of the diameters of said inner conductor and said outer conductor over the said fourth axial extent being substantially equal to the ratio of the diameters of said inner conductor and said outer conductor over said first axial extent, whereby the characteristic impedance of said fourth axial extent of said coaxial line is substantially equal to the characteristic impedance of said first axial extent of line, the diameter of the inner conductor in said third axial extent of said coaxial being so related to the diameter of the inner conductor in said fourth axial extent line as to produce a first discontinuity capacity substantially equal to the second discontinuity capacity due to the discontinuity existing between said second and said first axial extents of said coaxial line, the radial dimension of said flange being such as to produce a third discontinuity capacity substantially equal to twice said first or second discontinuity capacity.

8. Apparatus as in claim 7 in which the image impedance Z_I, of said second line extent looking into said second axial extent of said coaxial line from said first axial extent, is substantially equal to the average of the characteristic impedances of said first and fourth axial extents of said coaxial line at a point in the low pass frequency region of said image impedance, where

$$Z_I=\frac{Z_{01}}{\sqrt{1+2WC\,Z_{01}\cot 2bl-W^2C^2Z_{01}^2}}$$

where

$b=2\pi$ divided by wavelength λ at said point

$W=2\pi$ times frequency f at said point

Z_{01}=the characteristic impedance of said second axial extent of said coaxial line

C=discontinuity capacity due to the discontinuities between said first and second axial extents of said coaxial line

l=one-half the axial length of said second axial extent of coaxial line.

9. Ultra high frequency apparatus comprising first, second, third and fourth transmission line sections in tandem connection for energy transfer between said first and fourth sections through said second and third sections, each of said first, second, third and fourth sections having an axial inner conductor and an outer conductor, the inner and outer conductors of said first transmission line section being of appreciably smaller transverse dimensions than the inner and outer conductors of said fourth transmission line section, each of said second and third transmission line sections being differently dimensioned transversely in at least one conductor than the adjacent transmission line sections whereby a transverse dimensional step exists at each junction between successive transmission line sections, resulting in a shunt capacitance concentration thereat, said second and third transmission line sections each comprising a coaxial transmission line section wherein the inter-conductor space is filled with solid dielectric material, radially extending conductive means at the junction between said second and third transmission line sections providing a shunt capacitance concentration thereat appreciably exceeding the capacitance concentrations at each of the other two junctions in said apparatus.

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