June 6, 1967 H. BRUECKMANN 3,324,426

VARIABLE IMPEDANCE TRANSMISSION LINE

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FIG. 1

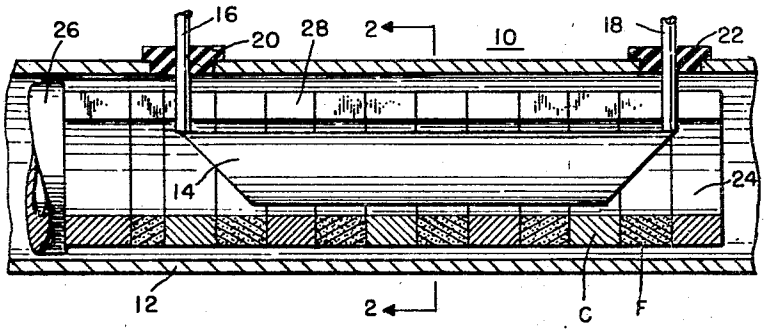


FIG. 2

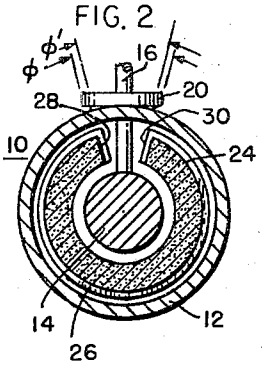


FIG. 5

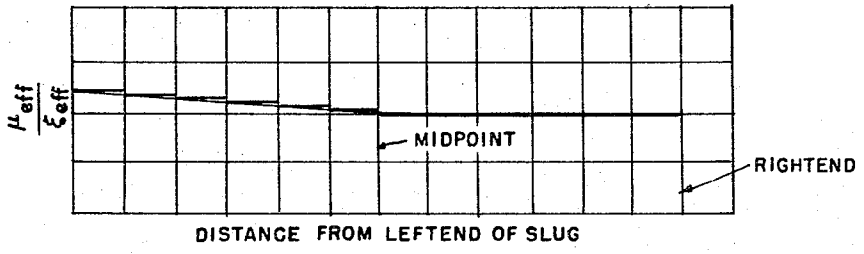


FIG. 3

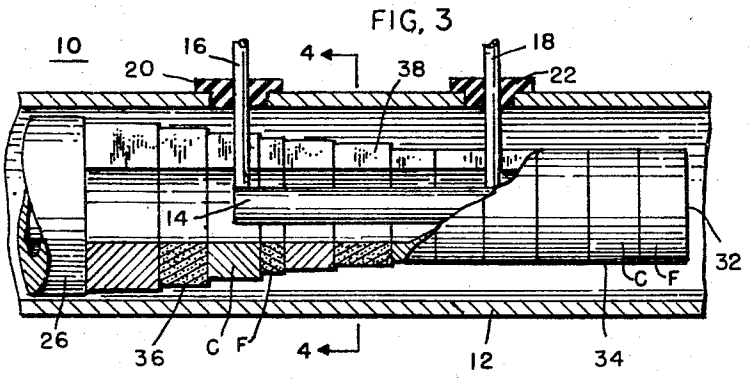
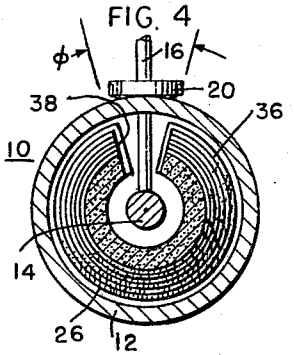


FIG. 4



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FIG. 6

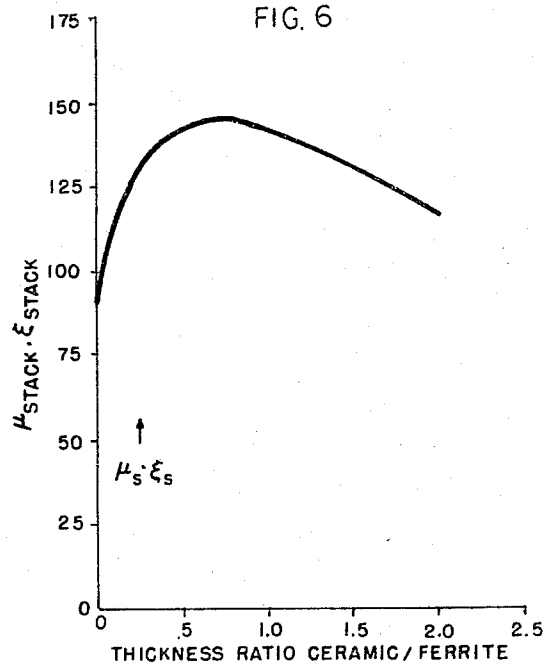
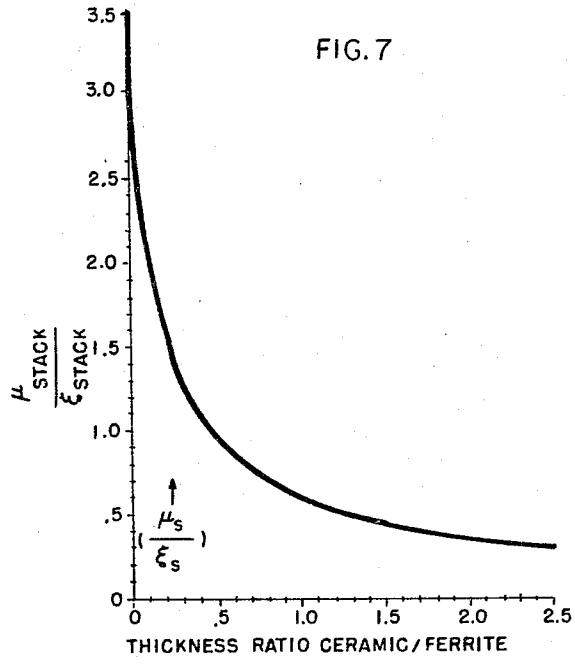


FIG. 7



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VARIABLE IMPEDANCE TRANSMISSION LINE

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6 Claims. (Cl. 333—34)

The invention described herein may be manufactured and used by or for the Government for governmental purposes without the payment of any royalty thereon.

This invention relates to transmission lines and more particularly to transmission lines characterized by a controllable characteristic impedance.

In antenna arrays, it is well known that the current of the elements in the array must be adjusted in phase and amplitude for a particular relationship in order to obtain a particular radiation pattern. In such systems it is desirable that the control for phase and amplitude of the current of the elements in the array be independent of each other. One system of gradually adjusting and controlling the amplitude ratios without changing phase is shown and described in U.S. Patent No. 2,938,209, May 29, 1960. Also in my copending application Ser. No. 315,093, now Patent Number 3,219,950, there is shown a system which, by means of a low loss variable delay line, resolves only the problem of controlling the phase of an element without changing the amplitude or impedance ratio in the device itself. While such singular control systems and other similar systems operate satisfactorily, they have proved to be rather cumbersome, inefficient, and difficult to adjust.

It is an object of the present invention to provide an improved transmission line wherein the aforementioned limitations are overcome.

It is another object of the present invention to provide an improved transmission line which permits gradual control and adjustment of the input-output amplitude relationship of an RF signal propagated thereon.

In brief, there is provided a variable impedance transmission line which includes a pair of electrical conductors and a plurality of successively arranged elements intermediate the conductors which are adapted to be slideably positioned with respect to said conductors. Each of the elements comprise alternate slices or rings of a ferrite material and a dielectric material, preferably a ceramic having a high dielectric constant. The parameters of the ferrite and dielectric materials comprising each of the successively arranged elements are such that each of said elements are characterized by a discrete effective relative permeability, μ_{eff}, and a discrete effective relative dielectric constant, ξ_{eff}, the output product $(\mu_{eff} \cdot \xi_{eff})$ of each of said elements being equal and the ratio of μ_{eff}/ξ_{eff} of each of said elements changing monotonically from one end of the successively arranged elements to the other end thereof.

For a better understanding of the invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawing in which:

FIGS. 1 and 2 are side-sectional and end views, respectively, of a variable impedance transmission line in accordance with the teaching of the invention, with FIG. 2 being a sectional view along the lines 2—2 of FIG. 1;

FIGS. 3 and 4 are side-sectional and end views, respectively, of another embodiment of the invention with FIG. 4 being a sectional view along the lines 4—4 of FIG. 3; and

FIGS. 5, 6 and 7 are explanatory curves.

It is well known that the propagation velocity of a coaxial type transmission line having a medium between

conductors characterized by an effective relative permeability μ and a permittivity ξ is not changed if this medium is replaced by another medium of different relative permeability, μ', and the effective relative dielectric or permittivity, ξ', provided the product $(\mu \times \xi)$ equals the product $(\mu' \times \xi')$. The characteristic impedance, however, is lowered or raised by such a replacement since it is proportional to the square root of the ratio of the effective relative permeability and permittivity for a given coaxial configuration. For the coaxial line having an effective relative permeability μ and a permittivity ξ, the characteristic impedance is given by

$$K = \sqrt{\frac{\mu}{\xi}} \cdot \left(\frac{1}{2\pi}\sqrt{\frac{\mu_0}{\xi_0}}\right) \cdot \ln\left(\frac{D}{d}\right) \quad (1)$$

where μ_0 and ξ_0 are the permeability and permittivity of free space, respectively, and D and d represent the outer and inner conductor diameters, respectively. Similarly, for the coaxial line having an effective relative permeability μ' and a permittivity ξ', the characteristic impedance may be given by

$$K' = \sqrt{\frac{\mu'}{\xi'}} \cdot \left(\frac{1}{2\pi}\sqrt{\frac{\mu_0}{\xi_0}}\right) \cdot \ln\left(\frac{D}{d}\right) \quad (2)$$

Referring now to FIGS. 1 and 2 of the drawing, there is shown at **10** a coaxial transmission line section having an outer conductor **12** and an inner conductor **14**. The inner conductor **14** is supported and held fixed at its ends by a pair of longitudinally spaced, parallel arranged, radial conductors **16** and **18** which extend through and are affixed to insulator plugs **20** and **22** respectively provided therefor. As shown, insulator plugs **20** and **22** are affixed to outer conductor **12** to form an integral part thereof. Successively arranged axially disposed tubular elements **24** and **26**, each comprised of alternately disposed rings or slices of a ferrite material, F, and a ceramic material, C, having a high dielectric constant, are concentrically positioned with respect to the outer and inner conductors **12** and **14** of coaxial transmission section **10**. The length of each of the tubular elements **24** and **26** are made as long as or slightly longer than the inner conductor **14**. As shown, the tubular elements **24** and **26** are spaced from the conductors **12** and **14** so that a radial air space exists between the tubular elements **24** and **26** and inner conductor **14**, and also between the tubular elements **24** and **26** and outer conductor **12**. Tubular elements **24** and **26** are provided with aligned longitudinal slots **28** and **30** having a width slightly larger than the width of radial conductors **16** and **18** so that the tubular elements **24** and **26** may be longitudinally actuated along the axis of the transmission line for the entire lengths thereof. Although not limited thereto the surfaces bounding longitudinal slots **28** and **30** are shown in FIG. **1** as being radial and include respective angles ϕ for tubular element **24**, and φ' for tubular element **26**, therebetween. With the longitudinal slots **28** and **30** aligned with the radial conductors **16** and **18**, the tubular elements **24** and **26** may be slideably positioned along the longitudinal axis of the coaxial line section **10** for the entire respective lengths thereof. Of course, any suitable means well known in the art may be used to slideably position tubular elements **24** and **26** longitudinally intermediate the outer and inner conductors of coaxial line **10** as described above. The effective relative permeability μ_{eff} and the permittivity ξ_{eff} of tubular elements **24** and **26** are functions of the ratio of the thicknesses of the ceramic and ferrite rings or slices. The effective permeability and permittivity of the tubular elements **24** and **26** are simply the weighted average of the respective values of the two materials, the weighing factor being the thickness ratio of ferrite and ceramic. In mathematical language, the values

of μ_{eff} and ξ_{eff} of tubular elements **24** and **26** may be expressed as

$$\mu_{eff}\ (\text{stacked}) = \frac{1}{P+1}\left[(\mu_{eff})\ \text{Ferrite} + P\right] \quad (3)$$

and

$$\xi_{eff}\ (\text{stacked}) = \frac{1}{P+1}\left[(\xi_{eff})\ \text{Ferrite} + P(\xi_{eff})\ \text{ceramic}\right] \quad (4)$$

where P is the ratio of the thicknesses of the ceramic and ferrite slices. FIGS. 6 and 7 illustrate the relationship of Equations 3 and 4, respectively, for a typical stacked element having a given diameter and a given slot width. The values of μ_{eff} and ξ_{eff} for tubular element **24** are chosen to give a desired characteristic impedance K_1 in accordance with Equation 1. Tubular element **26** is identical in structure to tubular element **24**, with values μ'_{eff} and ξ'_{eff} differing from that of tubular element **24** but with the same product so that $(\mu'_{eff} \times \xi'_{eff}) = (\mu_{eff} \times \xi_{eff})$. The characteristic impedance K_2 of course will be in accordance with Equation 2. By this arrangement, tubular element **26** may be inserted in place of tubular element **24** to provide changes in characteristic impedance of the coaxial line but not in its electrical length. In actual operation, radial conductor **18** may terminate into a load such as one element of an antenna array. As a result, the input impedance of the coaxial line **10** seen by a signal generator at radial conductor **16** changes in accordance with well known laws when tubular element **24** is replaced by tubular element **26**. Of course the input impedance and the change in impedance depends on the ratio of the load impedance and the characteristic impedances K_1 and K_2, respectively, as well as the electrical length of the line. While only two tubular elements are shown in FIG. 1, it is to be understood that the invention is not to be limited thereto. A sufficient number of such successively arranged tubular elements may be utilized to provide sufficiently small increments of associated characteristic impedances so that any variation of the input impedance may be achieved. In this case, the ratio μ_{eff}/ξ_{eff} of each of the elements is such as to change monotonically from one end of the successively arranged elements to the other end thereof. In order for the coaxial line **10** to be considered as one having distributed rather than lumped parameters, the thickness of a pair of ferrite and ceramic rings is made small compared to the wavelength of the highest operating frequency.

FIGS. 3 and 4 illustrate another embodiment of the invention where like numerals refer to like elements. Referring now to FIGS. 3 and 4, there is shown at **10** a coaxial transmission line section having an outer conductor **12** and an inner conductor **14**. The inner conductor **14** is supported and held fixed at its ends by a pair of longitudinally spaced, parallel arranged radial conductors **16** and **18** which extend through and are affixed to insulator plugs **20** and **22**, respectively, provided therefor. As shown, insulator plugs **20** and **22** are affixed to outer conductor **12** to form an integral part thereof. Longitudinally positioned within coaxial line **10** and concentrically disposed with respect to the outer and inner conductors **12** and **14** is a tubular element **32** of about twice the length of inner conductor **14**. Tubular element **32** is comprised of alternately disposed rings or slices of a ferrite material, F, and a ceramic material, C, having a relatively high dielectric constant. As shown, one-half of tubular element **32**, as at **34**, is of uniform cross-section with the ratio μ_{eff}/ξ_{eff} being a constant value. The other half of tubular member **32**, as at **36**, is comprised of alternate rings of a ferrite material, F, and a ceramic material of high dielectric constant, C, such that the ratio μ_{eff}/ξ_{eff} of a pair of rings, that is, a ferrite ring and an adjacent ceramic ring, changes monotonically in a geometric progression from the extreme left end of tubular member **32** to the longitudinal center thereof. These changes may be affected by changes either of diameters, slotwidth, or thickness ratio, or a combination thereof. If the rate of change of the ratio μ_{eff}/ξ_{eff} is made very small from one pair of rings to the next, the outer periphery of section **36** may taper exponentially from the left end thereof to the longitudinal center of tubular element **32**. FIG. 5 graphically illustrates the value of the μ_{eff}/ξ_{eff} ratio from one end to the other. It is well known that an exponential line has the property of transforming at frequencies well above cut-off a matched terminating impedance into a resistive input impedance of different magnitude. As in FIG. 1, the tubular element **32** is provided with a longitudinal slot **38** (ϕ), having a width slightly larger than the width of radial conductors **16** and **18** so that tubular element **32** may be longitudinally actuated along the axis of transmission line **10**. Although not limited thereto, the surfaces bounding longitudinal slot **38** may be radially disposed. The transfer ratio of the line shown in FIG. 3 depends primarily on the rate of change of the characteristic impedance and the length of the transmission line. While such a line has an imaginary component, which depends somewhat on frequency, under certain well known conditions this imaginary component can be made to be small or can be compensated for. Such conditions can be met over a wide frequency range by proper choice of line length and rate of change of characteristic impedance. It is to be understood, of course, that the invention is not to be limited to the exponential configuration shown in FIG. 3. For example, the tapered half of the tubular element **32** may comprise a taper which alternates several times between upward or downward exponential taper and zero rate of taper. Also, the exponential taper may be the reverse of that shown in FIG. 5. The degree of the taper, of course, may be achieved by increasing or decreasing the increment μ_{eff}/ξ_{eff} ratio of successive pairs of rings as described above.

In discussion the operation of the transmission line shown in FIG. 3, assume first that the right end of the line is terminated into a load which matches the line when tubular member **32** is in its extreme left position. In this position the transformation ratio is 1:1. When the tubular member **32** is in its extreme right position, the transformation ratio is highest or lowest, depending on whether the characteristic impedance tapers up or down, respectively, from the termination towards the input end. Any value of the transformation ratio between these extremes can also be obtained within the limits given by the chosen incremental change of μ_{eff}/ξ_{eff} from one pair of rings to the next. This gradually controllable transformation ratio is achieved without changing the phase relation between the input and output signal and without any power loss other than that caused by the loss factor of the materials comprising tubular member **32** and the conductor resistivity. In a practical embodiment, all dimensions can be kept constant except the thickness ceramic/ferrite ratio by utilizing the relatively level portion of the

$$[\mu_{eff}\ (\text{stacked}) \cdot \xi_{eff}\ (\text{stacked})]$$

of FIG. 6 about its maximum. While

$$[\mu_{eff}\ (\text{stacked}) \cdot \xi_{eff}\ (\text{stacked})]$$

is nearly constant, the ratio of

$$\mu_{eff}\ (\text{stacked}) / \xi_{eff}\ (\text{stacked})$$

as shown in FIG. 7, changes rapidly in the region for $P=0.4$ to $P=1.0$.

While there has been described what is at present considered to be the preferred embodiment of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is therefore aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention. For example, line configurations other than the coaxial line configurations such as strip line and bal-

anced open wire line may be used. As another example, two electrically separate lines in one unit, "back-to-back" for example, may employ a single tubular element or a differential transformer.

What is claimed is:

1. A transmission line transformer comprising a pair of electrical conductors, a plurality of successively arranged elements intermediate said conductors, each of said elements comprising alternate slices of a ferrite material and a dielectric material having parameters such that each of said elements are characterized by a discrete effective relative permeability μ_{eff} and a discrete effective relative dielectric constant, ξ_{eff}, the product of the effective relative permeability and the effective relative dielectric constant of each of said elements being equal, and the ratio of μ_{eff}/ξ_{eff} of each of said elements changing monotonically from one end of successively arranged elements to the other end thereof to provide a monotonically varying characteristic impedance, said elements being slidably positioned with respect to said conductors.

2. A transmission line transformer comprising an inner conductor and outer conductor coaxial therewith, a plurality of successively arranged tubular elements adapted to be axially positioned intermediate said conductors, each of said tubular elements comprising alternate rings of a ferrite material and a dielectric material having parameters such that each of said tubular elements are characterized by a discrete effective relative permeability μ_{eff} and a discrete effective relative dielectric constant ξ_{eff}, the product of the effective relative permeability and the effective dielectric constant of each of said tubular elements being equal, and the ratio μ_{eff}/ξ_{eff} of each of said elements changing monotonically from one end of the successively arranged elements to the other end thereof to provide a monotonically varying characteristic impedance.

3. The transmission line in accordance with claim 2 wherein the tubular elements are spaced from both said inner and outer conductors when intermediate said conductors.

4. The transmission line in accordance with claim 2 wherein each of said tubular elements are as long as said center conductor.

5. In combination with a coaxial transmission line adapted to propagate an RF signal, means for simultaneously varying the characteristic impedance of said coaxial transmission line and maintaining a constant propagation velocity, said means comprising a plurality of successively arranged tubular elements adapted to be axially positioned intermediate the inner and outer conductor of said coaxial line, each of said tubular elements comprising alternate rings of a ferrite material and a dielectric material having parameters such that each of said tubular elements are characterized by a discrete effective relative permeability μ_{eff} and a discrete effective relative dielectric constant ξ_{eff}, the product of the effective relative permeability and the effective relative dielectric constant of each of said tubular elements being equal, the ratio of μ_{eff}/ξ_{eff} of each of said elements changing monotonically from one end of the successively arranged tubular elements to the other end thereof, said successive tubular elements being adapted to be axially positioned intermediate said conductors.

6. A transmission line for propagating an RF signal comprising, an inner conductor and an outer conductor coaxial therewith, a tubular member adapted to be axially positioned intermediate said conductors, one longitudinal half of said tubular member being uniform in cross section and comprising alternate rings of a ferrite material and a dielectric material characterized by a constant value of the ratio of the effective relative permeability and the effective relative dielectric constant, the other longitudinal half of said tubular member comprising alternate rings of a ferrite material and a dielectric material having parameters such that the ratio of the effective relative permeability and the effective relative dielectric constant of any one pair of alternate rings is a discrete value and changing monotonically along said other longitudinal half of said tubular member from one end thereof to the other end thereof.

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