Nov. 26, 1968 D. V. CAMPBELL 3,413,575

LOW-LOSS, CONTROLLABLE PARAMETER, TRANSMISSION LINE

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FIG. 1

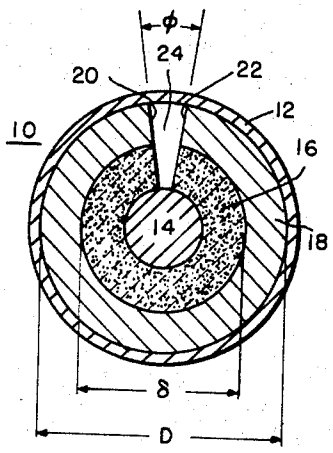


FIG. 2

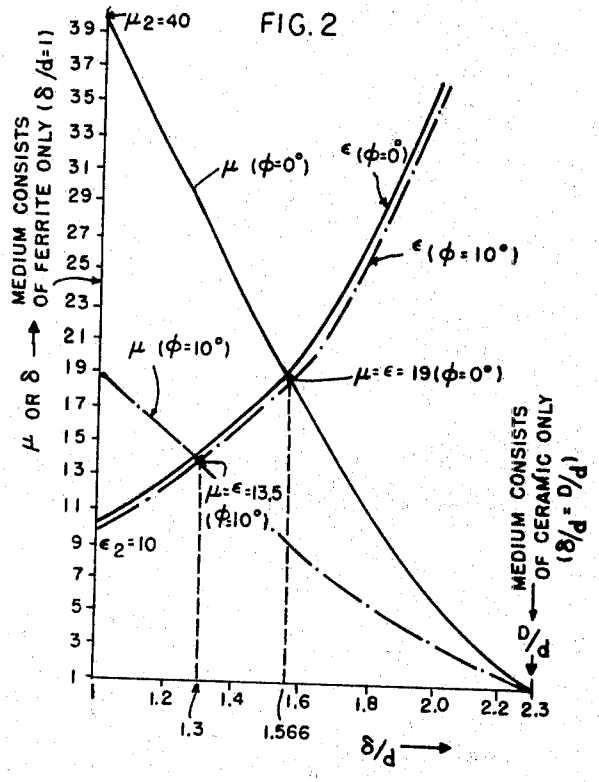
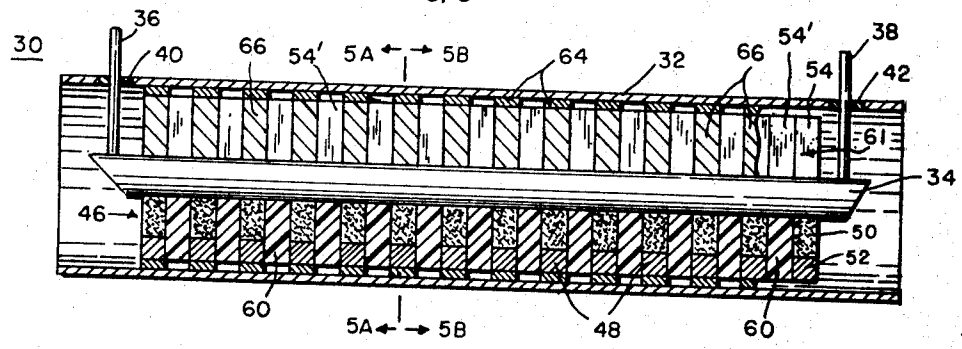


FIG. 3



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FIG. 4

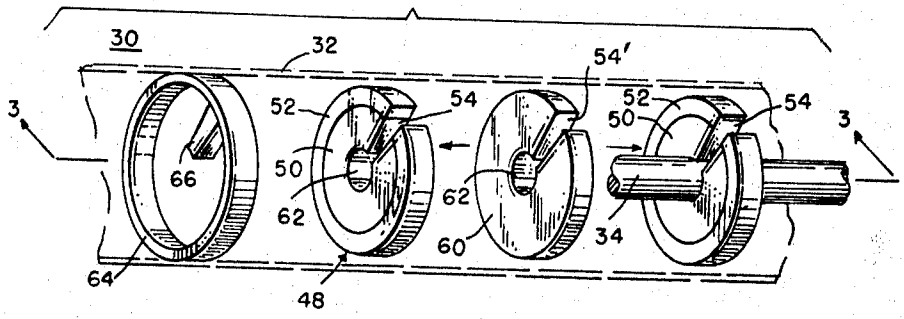


FIG. 5A

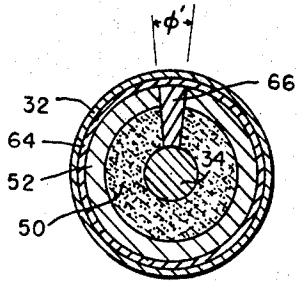


FIG. 5B

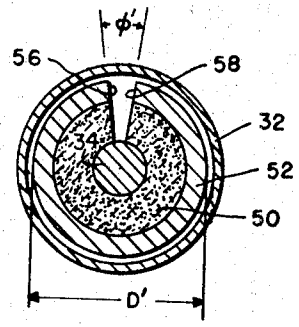


FIG. 6

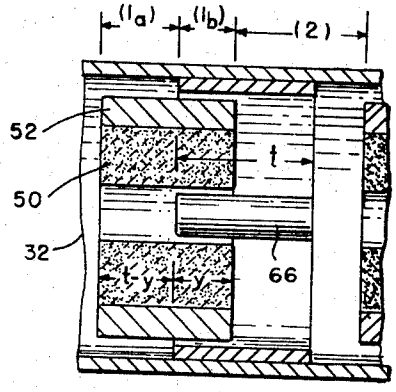
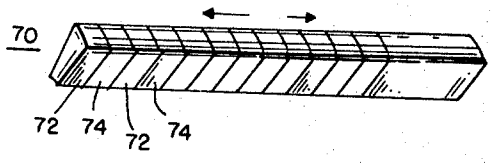


FIG. 7



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LOW-LOSS, CONTROLLABLE PARAMETER, TRANSMISSION LINE

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Filed Nov. 10, 1964, Ser. No. 410,324
8 Claims. (Cl. 333—31)

ABSTRACT OF THE DISCLOSURE

A constant impedance low-loss delay line which includes a coaxial transmission line section comprising an inner conductor and an outer conductor, and a radially stratified propagation medium intermediate the conductors which is adapted to be slideably positioned over the inner conductor. The propagation medium includes a plurality of ferrite-ceramic elements spaced apart by means of plastic spacers. Each of the ferrite-ceramic elements comprises a ceramic body and a ferrite body concentrically disposed with respect to the coaxial line conductors and disposed along a common radial plane. The ferrite-ceramic elements and plastic spacers therebetween include a radial slot and are aligned to form an integrated longitudinal slot along the inner conductor.

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 electromagnetic wave transmission lines and more particularly to an improved low-loss, controllable parameter, transmission line for use as an RF delay line.

As is well known, it is often desirable to control the characteristic impedance and electrical length of RF transmission lines. For example, a radio-frequency transmission line with adjustable electrical length is desirable for introducing a predetermined delay in the feedlines feeding an antenna array. Also, a radio-frequency transmission line with an adjustable characteristic impedance may find application in broadband impedance matching of antennas and in adjusting the voltage and current amplitude in the antenna feed system.

One low-loss continuously variable delay line is described in a co-pending Brueckmann application Ser. No. 315,093 which issued as Patent No. 3,219,950 on Nov. 23, 1965. It capitalizes on the fact that the characteristic impedance of a transmission line whose conductors are surrounded by air is not changed if the air is replaced by a ferrite whose effective relative permeability μ_{eff} equals the effective relative dielectric constant or permittivity ϵ_{eff}. However, the propagation velocity in the line is lowered in proportion to

$$\frac{1}{\sqrt{\mu_{eff} \cdot \epsilon_{eff}}}$$

compared to that in air. On the other hand, it is well known that the propagation velocity of a radio-frequency transmission line whose propagation medium has an effective relative permeability μ'_{eff} and a permittivity ϵ'_{eff} is not changed if a portion, or all, of this propagation medium is replaced by another propagation medium of different effective relative permeability μ''_{eff} and a different effective relative dielectric constant ϵ''_{eff} provided the product $(\mu'_{eff} \times \epsilon'_{eff})$ equals the product $(\mu''_{eff} \times \epsilon''_{eff})$. However, in this case, the characteristic impedance 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 the effective relative dielectric constant for a given conductor configuration and size. One such transmission line is described in a co-pending Brueckmann application Ser. No. 402,669, filed Oct. 8, 1964 and which issued as Patent No. 3,324,426 on June 6, 1967.

In the above noted systems, it was found that high effective relative permeabilities μ_{eff} and permittivity or dielectric constants ϵ_{eff} could be obtained by utilizing axially aligned alternate slices of ferrite and ceramic of high dielectric constant in place of the ferrite alone. Such structures proved difficult to design and fabricate inasmuch as it was required that the slices be only a friction of the operating wavelength in thickness. Moreover, the use of such structures was limited inasmuch as they usually required that the impedance be varied step-wise longitudinally in order to raise the values of the effective relative permeabilities μ_{eff} and dielectric constants ϵ_{eff}.

It is an object of the present invention to provide a transmission line wherein the above noted limitations are overcome.

It is another object of the invention to provide a transmission line which is simpler to construct, has low loss, and which requires no sliding contacts.

In brief, there is provided a constant impedance, low-low-loss delay line which includes a coaxial transmission line section comprising an inner conductor and an outer conductor, and a radially stratified propagation medium intermediate the conductors which is adapted to be slideably positioned over the inner conductor. The propagation medium includes a plurality of ferrite-ceramic elements spaced apart by means of plastic spacers. Each of the ferrite-ceramic elements comprises a ceramic body and a ferrite body concentrically disposed with respect to the coaxial line conductors and disposed along a common radial plane. The ferrite-ceramic elements and plastic spacers therebetween include a radial slot and are aligned to form one integrated longitudinal slot along the inner conductor. Included further are a plurality of spaced plastic rings, one for each ferrite-ceramic element, intermediate the propagation medium and the outer coaxial line conductor and affixed thereto. Depending from each of the ceramic rings is a wedge-shaped ferrite slug dimensioned so as to complement the slots of the ferrite-ceramic elements when the propagation medium is axially positioned such that the ferrite-ceramic elements are in register with the ceramic rings, and to fully complement the spacer slots when the propagation medium is axially positioned such that the ferrite ceramic elements are out of register with the ceramic rings. The delay of an RF signal applied to the coaxial transmission line may be varied between a minimum delay produced when the ferrite slugs are completely removed from the ferrite-ceramic elements, and a maximum delay when the ferrite slugs fully complement the slots of the ferrite-ceramic elements.

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:

FIG. 1 is a sectional view of one element of the delay line;

FIG. 2 is a graph useful in obtaining the parameters of the section shown in FIG. 1;

FIG. 3 is a longitudinal cross section of a delay line according to the teachings of the invention;

FIG. 4 is an exploded view of a section of the wave propagation medium comprising the delay line;

FIGS. 5A and 5B illustrate cross sections of the delay line of FIG. 3 taken along the lines 5—5 and represent the two extreme axial positions of the delay line;

FIG. 6 is a schematic diagram illustrating the invention; and

FIG. 7 shows a control bar for use in the delay line.

FIG. 1 represents a cross section of a coaxial transmission line **10** of unit length which includes a ferrite-ceramic RF wave propagation medium comprising the basic element or component of the present invention. A discussion of the underlying principles involved in the structure embodied in FIG. 1 will greatly enhance the understanding of the present invention. In FIG. 1, the outer conductor of coaxial line **10** is shown at **12**, and the inner conductor is shown at **14**. Concentrically arranged with respect to the inner and outer conductors of coaxial line **10** and coextensive therewith are a ceramic medium or body **16** and a ferrite medium or body **18**, with both the ceramic medium **16** and ferrite medium **18** being concentric and terminating at radial surfaces **20** and **22**, as shown, to provide an axial slot **24**. The concentrically arranged media **16** and **18** occupy substantially all the space between outer conductors **12** and inner conductor **14**, except for the slot **24**, and the radial surfaces bounding slot **24** include the angle ϕ therebetween which is hereinafter referred to as the slot width. The concentrically arranged media **16** and **18** comprises an RF propagation medium and is hereinafter referred to as the ferrite-ceramic element. Although the ferrite body **18** is shown as being intermediate ceramic body **16** and outer conductor **12**, the positions thereof may be reversed with the ferrite body **18** placed adjacent inner conductor **14**. Assuming the dimensions shown in FIG. 1, that is, no cylindrical air gaps are present, the effective relative permeability can be shown to be

$$\mu_{eff}=1+\left[\frac{\mu_2}{1+\frac{\phi}{2\pi}(\mu_2-1)-1}\right]\cdot\left[1-\frac{\ln\frac{\delta}{d}}{\ln\frac{D}{d}}\right] \quad (1)$$

where μ_2 is the relative permeability of the ferrite medium and the relative permeability of the ceramic medium $\mu_1\approx 1$. The effective relative dielectric constant, or permittivity, of the line shown in FIG. 1 can be shown to be

$$\epsilon_{eff}=\epsilon_2\left(1-\frac{\phi}{2\pi}\cdot\left[1-\left(1-\frac{\epsilon_2}{\epsilon_1}\right)\cdot\frac{\ln\frac{\delta}{d}}{\ln\frac{D}{d}}\right]^{-1}+\frac{\phi}{2\pi}\right. \quad (2)$$

where ϵ_1 is the permittivity of the ceramic medium **16** and ϵ_2 is the permittivity of the ferrite medium **18**. In FIG. 2, the μ_{eff} and ϵ_{eff} of Equations 1 and 2 are plotted versus the normalized diameter δ/d which ranges from unity to $D/d=2.3$. This value of D/d was selected arbitrarily by way of illustration and it yields a characteristic impedance of 50 ohms ($K_0=60\ln D/d$) when the propagation medium consists of air only. The relative permeability $\mu_2=40$, the permittivity $\epsilon_1=85$, and the permittivity $\epsilon_2=10$. If the position of the ferrite and ceramic bodies are interchanged, as mentioned above, with the ferrite body **18** placed adjacent inner conductor **14**, then $\mu_2\approx 1$ and

$$\mu_{eff}=1+\left[\frac{\mu_1}{1+\frac{\phi}{2\pi}(\mu_1-1)}-1\right]\frac{\ln\frac{\delta}{d}}{\ln\frac{D}{d}} \quad (3)$$

where μ_1 is the permeability of the ferrite body **18**. The ϵ_{eff} for this position will remain as in Equation 2, but with ϵ_1 the permittivity of the ferrite body **18** and ϵ_2 the permittivity of the ceramic body **16**.

As is well known, the characteristic impedance, K, and propagation velocity, V, of transmission lines can be controlled by using a propagation medium whose effective relative permeability, μ_{eff}, and permittivity, ϵ_{eff}, may

be adjusted since these properties are related to K and V by

$$K=K_0\sqrt{\frac{\mu_{eff}}{\epsilon_{eff}}} \quad (4)$$

where K_0 is the characteristic impedance with air as the propagation medium and

$$\frac{V}{c}=\frac{1}{\sqrt{\mu_{eff}\cdot\epsilon_{eff}}} \quad (5)$$

where c is the velocity of light in a vacuum. Hence it can be seen that K and V are governed ultimately by Equations 4 and 5. It is evident from the examination of FIG. 2, or from Equation 1, that μ_{eff} strongly depends upon the slot width, or angle ϕ, while ϵ_{eff} is affected by the angle ϕ to a much smaller degree. In a first approximation, ϵ_{eff} may be regarded as independent of ϕ. On the other hand, μ_{eff} is not greatly influenced by cylindrical air gaps, while ϵ_{eff} is severely reduced by even small radial clearances. Thus, for the radially-stratified ferrite-ceramic media shown in FIG. 1, μ_{eff} can be adjusted over a wide range by merely modifying the slot with ϕ and, on the other hand, ϵ_{eff} may be adjusted by introducing or changing the cylindrical air gaps. It has also been shown that μ_{eff} suffers little change with changes in air gaps, as long as they are kept reasonably small, and ϵ_{eff} is little affected by small changes in slot width or angle ϕ. It is interesting to note that $\mu_{eff}=\epsilon_{eff}\approx 13.5$ where $\delta/D=1.3$ and $\phi=10°$. Using the well known fact that the propagation in the line is lowered in proportion to

$$\frac{1}{\sqrt{\mu_{eff}\cdot\epsilon_{eff}}}$$

compared to air, it can be seen that for the choice of slot width of 10°, the propagation velocity of the line shown in FIG. 1 will be 1/13 of the propagation velocity of light in vacuum.

With the above principles in mind, reference is made now to FIGS. 3–5 wherein there is shown at **30** a constant impedance, low-loss line stretcher or delay line suitable for operation at relatively high RF frequencies. The transmission line illustrated in FIGS. 3–5 operates on the well known principle that the characteristic impedance K_0 of a transmission line whose dielectric is air is unaffected if the air is replaced entirely or in part by a propagation medium whose effective relative permeability and dielectric constant are equal while the velocity of propagation is reduced in inverse proportion to the square root of their product (Equation 5). The line stretcher **30** includes a coaxial transmission line having an outer conductor **32** and an inner conductor **34** concentrically supported at its ends within outer conductor **32** by means of longitudinally spaced parallel-arranged radial conductors **36** and **38**. Radial conductors **36** and **38** extend through and are affixed to insulator plugs **40** and **42** respectively provided therefor. As shown, insulator plugs **40** and **42** are affixed to counter conductor **32** to form an integral part thereof. If desired, input conductor **36** and output conductor **38** can also be concentrically positioned with inner conductor **34** at the ends thereof.

Slideably mounted on inner conductor **34** and substantially coextensive therewith is an RF propagation medium **46** which is shown in detail in FIG. 4. Referring now to FIGS. 3 and 4, the propagation medium **46** comprises a plurality of axially spaced, radially-stratified ferrite-ceramic elements **48** which are constructed in accordance with the principles described above in connection with FIG. 1. As shown, each of the elements **48** comprises a ceramic body or medium **50** and a ferrite body of medium

52 concentrically arranged about inner conductor 34, and an axial slot 54 bounded by radial surfaces 56 and 58 as shown in FIG. 5B. The ferrite body 52 may be made of any of the well known commercial ferrite materials adapted for use at radio-frequencies such as those known as Q_1 or Q_2 or Q_3. Also, the ceramic body 50 may comprise any suitable material such as titanium dioxide (TiO_2) which has a high dielectric constant and low loss, and with a permeability $\mu \approx 1$. Ferrite body 52 is affixed to ceramic body 50 and the axial thickness, t, of each of the elements 48 is made about 1/12 of the wavelength in the ferrite-ceramic elements 48 at the highest operating frequency. The axial slots 54 of the spaced ferrite-ceramic elements 48 are of same slot width, or angle ϕ', and are axially aligned along the inner conductor 34. The ferrite-ceramic elements 48 are axially spaced from each other by the axial dimension t, and the spacing between elements 48 is maintained by means of plastic spacers 60 cemented to the elements 48. Such plastic spacers may be made of a material such as Teflon, or foam polystyrene, having values of permeability and dielectric constant very close to that of air, that is $\mu = \epsilon \approx 1$. As shown, each of the plastic spacers 60 is provided with an axial slot 54' having the same dimensions as axial slot 54 of the elements 48, and all the slots are aligned to form a continuous longitudinal slot 61 along the inner conductor 34. The continuous longitudinal slot 61 is aligned with the radial conductors 36 and 38 which are made narrower in width than the longitudinal slot 61. The high frequency RF input signals to be delayed may be applied to the coaxial section through radially or axially disposed conductor 36 and the delayed output signal may be derived from radially or axially disposed conductor 38. The radial dimensions of the ferrite-ceramic elements 48 is readily determined once the slot width dimension ϕ' is chosen as explained above in connection with FIGS. 1 and 2. The central bore 62 of propagation medium 46 comprising the identically constructed ferrite-ceramic elements 48 and identically constructed spacers 60 is made to fit as tightly as possible around inner conductor 34 and yet permit the propagating medium 46 to be slideably positioned axially along the inner conductor 34 for the distance t. Of course, any suitable mechanism well known in the art may be utilized to limit the longitudinal movement of propagation medium 46 to the distance t.

Affixed to the inner periphery of outer conductor 32 are a plurality of axially spaced ceramic rings 64 each having the axial dimension t, and spaced from one another by the same axial dimension, t. As explained above, the axial dimension, t, is preferably chosen to be about 1/12 of the wavelength at the highest operating frequency and is identical to that of the ferrite-ceramic elements 48. As shown, the ceramic rings 64 are substantially coextensive with inner conductor 34 and a respective ceramic ring 64 is provided for each of the ferrite-ceramic elements 48 comprising propagation medium 46. Depending from the inner periphery of each ceramic ring 64 is a wedge-shaped ferrite slug 66 so dimensioned that it is adapted to fully complement the axial slot 54 when a respective ceramic ring 64 is axially aligned with its corresponding ferrite-ceramic element 48. Like the respective axial slots 54 and 54' of the ferrite-ceramic elements 48 and spacers 60 comprising propagation medium 46, the wedge-shaped ferrite slugs 66 are longitudinally aligned so as to be in register with the integrated longitudinal slot 61 of the propagation medium 46 along the inner conductor 34. The ceramic rings 64 are positioned such that when the propagation medium 46 is in one extreme position, respective ferrite-ceramic elements 48 of propagation medium 46 are in register with associated ceramic rings 64 and when propagation medium 46 is in the other extreme position, the plastic spacers 60 of propagation medium 46 are in register with the ceramic rings 64. It can be seen that when the respective ceramic rings 64 are in register with associated ferrite-ceramic elements 48, the respective ferrite slugs 66 fully complement the axial slots 54 of their associated ferrite-ecramic elements 48 and at the same time the respective ceramic rings 64 completely surround their associated ferrite-ceramic element. With such an arrangement, the cylindrical air gaps between the ferrite-ceramic elements 48 and outer conductor 12 of coaxial line 10 are diminished and the slots 54 do not exist. This is shown in FIG. 5A. On the other hand, when the respective ceramic rings 64 are in register with the associated plastic spacers 60 of propagation medium 46, the respective ferrite slugs 66 complement the axial slots 54' of their associated plastic spacers. In this position, a maximum cylindrical air gap exists between each ferrite-ceramic element 48 and outer conductor 12 together with the axial slots 54. This is shown in FIG. 5B. It is to be understood of course, that there is just enough tolerance or clearance between the inner periphery of the ceramic rings 64 and the outer periphery of propagation medium 46 to permit relative axial movement therebetween.

In operation, when the ceramic rings 64 are in register with the ferrite-ceramic elements 48 the diameter δ of ceramic body 50 may be chosen so that $\mu_{eff} = \epsilon_{eff}$ is obtained. These will be high in value. When the ceramic rings 64 and the ferrite-ceramic elements are disengaged by an axial displacement, both a cylindrical air gap and the slot ϕ' now exist. The slot width ϕ' may be chosen so that μ_{eff} is quite low. When ϕ' is thus chosen the outer diameter D' (FIG. 5B) of the ferrite body 52 for $\mu = \epsilon$ is automatically specified. This assures that $K = K_0$ for each cross section of the transmission line. As a numerical example, a line stretcher or delay line has been designed whose $\mu_{eff} = \epsilon_{eff} \approx 19$ when the ferrite-ceramic elements 48 of propagation medium 46 and the ceramic rings 64 are engaged in or register, and when not engaged,

$$\mu_{eff} = \epsilon_{eff} \approx 6.35$$

The slot width $\phi' = 20°$ and $K_0 = 50$ ohms.

FIG. 6 shows schematically how the line stretcher functions. In region 1*a* the medium has low effective relative values $\mu_{1a} = \epsilon_{1a}$ by virtue of the slot and air gaps. In region 1*b* the medium has high effective values $\mu_{1b} = \epsilon_{1b}$ because of the diminished or negligible slot and negligible cylindrical air gap. Finally, in region 2 the effective relative values are nearly unity by proper design.

The effective relative values of this stacked arrangement are, therefore,

$$\mu_s = \epsilon_s = \frac{1}{2}\left[\mu_{1a} + 1(\mu_{1b} - \mu_{1a})\frac{y}{t}\right] \qquad (6)$$

In one embodiment the application of Equation 5 showed that

$$\mu_s = \epsilon_s = 3.7 + 6.3\frac{y}{t}$$

This resulted in a constant impedance line stretcher whose electrical length or delay can be varied over a 2.7 to 1 range with a maximum electrical length of about 10 times its physical length. It is interesting to note that inasmuch as this range of adjustment is accomplished by sliding the inner medium through the small distance t, the axial thickness of a single ferrite-ceramic element, the delay line in accordance with the present invention will be much shorter than other delay lines such as that shown in co-pending Brueckmann application Ser. No. 315,093. A traverse control, such as a screw thread mechanism with a calibrated dial may be utilized in a conventional manner to adjust the delay.

Although the slot width of the propagation medium 46 is shown to be angular, that is, bounded by radially disposed surfaces, it need not be so limited. A slot of uniform width, for example, may be utilized and the relationship of values of μ_{eff} and ϵ_{eff} to the slot width can be established empirically or theoretically.

In FIG. 3, the μ_{eff} and ϵ_{ff} are controlled by axially shifting the propagation medium **46** while the ceramic rings are fixed in position. This same result can be achieved by making the slugs **66** of ceramic ring **64** axially shiftable and maintain in fixed position both the ceramic rings **64** and the propagation medium **46**. This can be achieved by utilizing a control bar **70** as shown in FIG. 7. The control bar **70** is wedge-shaped in cross section and is dimensioned to fully complement longitudinal slot **61** both in length and depth and to completely occupy the space between the ceramic rings **64** and propagation medium **46**. As shown, control bar **70** is comprised of alternate slices of a ferrite body **72** and a plastic body **74** each having the axial dimension *t*. The ferrite body **72** and plastic body **74** are of the same material, respectively, as that of the ferrite in ferrite-ceramic element **48** and the plastic spacers **60**. Any suitable means may be utilized to axially shift control bar **70** through the axial distance *t*. The resulting line has controllable impedance and controllable electrical length as hereinabove described.

While the delay line of FIGS. 3–5 shows the propagation medium **46** to comprise ferrite-ceramic elements as shown in FIG. 1, it is to be understood of course, that the ferrite body **52** and ceramic body **50** may be interchanged in the ferrite-ceramic elements **48** without effectively changing the operation of the line **30**. In this connection, the dimension D′ (FIG. 5B) may be derived in accordance with the following equation:

$$\ln\frac{D'}{\delta}=\frac{\epsilon_2}{\epsilon_2-1}\cdot\ln\frac{D}{d}\left[1-\frac{\epsilon_1^{-1}}{\epsilon_1}\cdot\frac{\ln\frac{\delta}{d}}{\ln\frac{D}{d}}\cdot\frac{1-\frac{\phi'}{2\pi}}{\epsilon_{1b}-\frac{\phi'}{2\pi}}\right] \quad (7)$$

where ϵ_{1b} is that shown in FIG. 6. As hereinabove noted, D′ is the same as the inside diameter of ceramic rings **64** except for a small negligible clearance.

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, the basic principle of radial stratification may be applied as well to two wire lines, strip lines, tapered lines, etc.

What is claimed is:

1. A variable low-loss delay line comprising a coaxial transmission line having an outer conductor and an inner conductor, an RF propagation medium concentric with said conductors and comprising a plurality of axially spaced radially stratified ferrite-ceramic elements, each of said elements including a slot bounded by radial surfaces, said slots being axially aligned, said propagation medium being adapted to be axially positioned along said inner conductor, and means intermediate said outer conductor and said propagation medium operatively associated with said propagation medium whereby when said propagation medium is at one extreme axial position, a cylindrical air gap exists between each of said ferrite-ceramic elements and said outer conductor, and respective ferrite-ceramic element slot gaps exist between said conductors, and when said propagation medium is in the opposite extreme axial position, each of the radially stratified ferrite-ceramic elements extend as a solid body from said inner conductor to said outer conductor.

2. The low-loss delay line in accordance with claim **1**, wherein the ferrite body of each of said elements respectively encompasses and abuts associated ceramic bodies.

3. The low-loss delay line in accordance with claim **1** wherein the ceramic body of each of said elements respectively encompasses and abuts associated ferrite bodies.

4. A variable low-loss delay line comprising a coaxial transmission line having an outer conductor and an inner conductor, an RF propagation medium concentric with said conductors and comprising a plurality of spaced ferrite-ceramic elements, each of said elements comprising a ceramic body and a ferrite body concentrically arranged with said conductors along a common radial plane to effect a radially stratified structure between said conductors, said ferrite body encompassing and abutting said ceramic body, said ferrite-ceramic elements each including a slot bounded by radial surfaces extending from said inner conductor, said slots being longitudinally aligned, and a plurality of longitudinally spaced ferrite slugs extending from said outer conductor towards said inner conductor and dimensioned so as to fully complement said slots when in register therewith, said propagation medium being adapted to move axially along said inner conductor such that respective slots are in register with associated ferrite slugs when said propagation medium is in one extreme axial position, and respective slots are out of register with said ferrite slugs when said medium is in an opposite extreme axial position.

5. The delay line in accordance with claim **4** wherein said ferrite-ceramic elements are separated by plastic spacers having a permeability and a dielectric constant substantially equal to unity.

6. A variable low-loss delay line comprising a coaxial transmission line having an outer conductor and an inner conductor, an RF propagation medium concentric with said conductors and comprising a plurality of radially stratified ferrite-ceramic elements axially separated by plastic spacers, each of said ferrite-ceramic elements comprising a ceramic body proximal said inner conductor, and a ferrite body affixed to said ceramic body, said propagation medium being adapted to be axially positioned along said inner conductor, each of said ferrite-ceramic elements and said spacers having axially aligned slots bounded by radial surfaces extending from said inner conductor to form an integrated longitudinal slot along said inner conductor, a plurality of spaced ceramic rings, one for each of said ferrite-ceramic elements, affixed to the inner periphery of said outer conductor, respective ferrite slugs depending from respective ceramic rings and longitudinally aligned with said longitudinal slot, said rings and said slugs being so dimensioned such that when said ferrite-ceramic elements and said ceramic rings are in register, respective slugs complement associated slots of said ferrite-ceramic elements and respective ceramic rings encompass associated ferrite-ceramic elements to form a solid body between said conductors, and when said ceramic rings and said ferrite-ceramic elements are out of register, a cylindrical air gap exists between each of said ferrite-ceramic elements and said outer conductor and respective ferrite-ceramic element slot gaps exist between said conductors.

7. The low-loss line in accordance with claim **6** wherein said ferrite-ceramic elements have an axial dimension, *t*, the spacing between said ferrite-ceramic elements being said dimension *t*, and the axial dimension of said rings is said dimension *t*.

8. A variable low-loss delay line comprising a coaxial transmission line having an outer conductor and an inner conductor, an RF propagation medium concentric with said conductor and comprising a plurality of axially spaced ferrite-ceramic elements, each of siad elements comprising a ceramic body encompassed by a ferrite body concentrically arranged with said conductors along a common radial plane to effect a radially stratified structure between said conductors, said ferrite-ceramic elements each including a slot bounded by radial surfaces extending from said inner conductor, said slots being longi-

tudinally aligned, a plurality of longitudinally spaced ceramic rings, one for each of said ferrite-ceramic elements, affixed to said outer conductor with said coaxial line, respective rings being in register with respective ferrite-ceramic elements, and an axially moveable bar dimensioned to fully complement said longitudinally aligned slot and disposed intermediate said longitudinal slot and said ceramic rings, said bar comprising spaced sections of ferrite separated by plastic spacers, the effective relative permeability and the permittivity of said propagation medium being determined by the axial distance the bar ferrite sections are within each of said ferrite-ceramic slots.

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