March 1, 1966

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3,238,477

HIGH-IMPEDANCE RADIO FREQUENCY COAXIAL LINE HAVING FERRITE SLEEVE IN DIELECTRIC SPACE

Filed April 30, 1963

FIG. 1

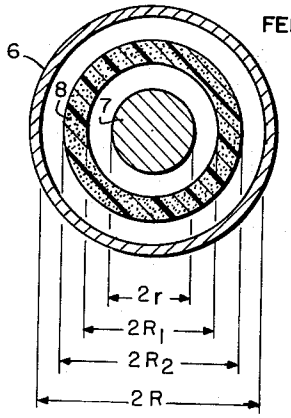


FIG. 2

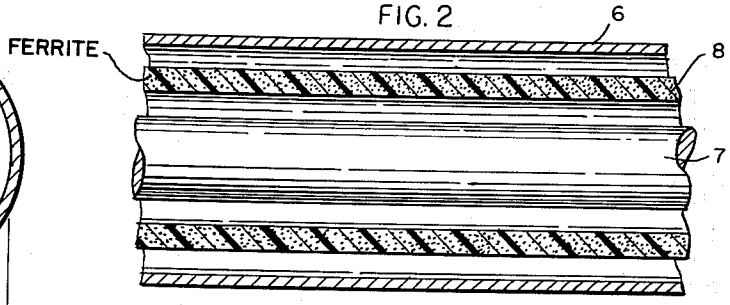


FIG. 3

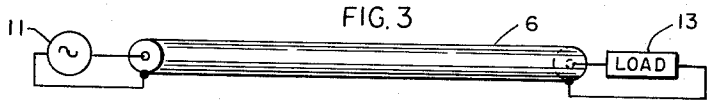
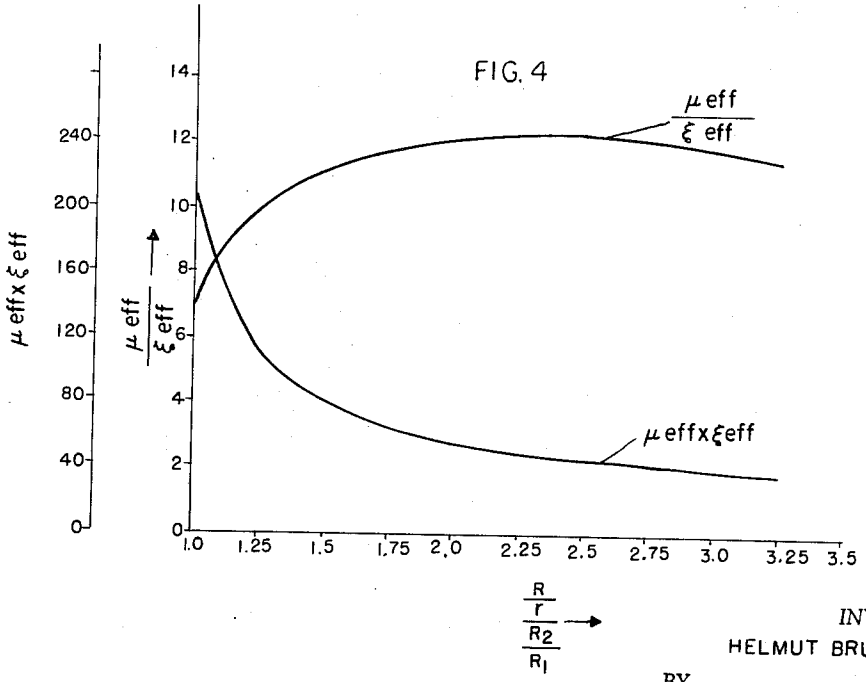


FIG. 4



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3,238,477

Patented Mar. 1, 1966

3,238,477

HIGH-IMPEDANCE RADIO FREQUENCY COAXIAL LINE HAVING FERRITE SLEEVE IN DIELECTRIC SPACE

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Filed Apr. 30, 1963, Ser. No. 277,427
3 Claims. (Cl. 333—96)

(Granted under Title 35, U.S. Code (1952), sec. 266)

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 radio frequency devices such as transmission lines and transformers and more particularly to a novel and useful means by which such devices may be provided with a high characteristic impedance.

High characteristic impedance, K, is desirable for radio frequency transmission lines in many applications. Conventional transmission lines of high K and small size usually have high loss factors, low power handling capacity and poor stability. One embodiment of the present invention comprises a coaxial transmission line which is free of these deficiencies to a high degree. The same principles are be utilized to provide a radio frequency transformer with improved broadband characteristics.

Briefly stated, an illustrative embodiment of the present invention comprises a coaxial transmission line in which the space between inner and outer conductors is only partially filled with a ferrite dielectric. It has been found that this structure results in a higher characteristic impedance than would be obtained with an air-dielectric line or with a line completely filled with ferrite. A mathematical analysis is given by which this effect can be optimized and predicted in terms of the line dimensions.

It is therefore an object of this invention to provide novel and improved high impedance radio frequency devices.

A more specific object of the invention is to provide a high impedance radio frequency transmission line of the coaxial type.

Other objects and advantages of the present invention as well as an illustrative embodiment thereof will be found in the following detailed description, in which:

FIGS. 1 and 2 are end and side sectional views respectively of a coaxial transmission line constructed according to the teachings of this invention.

FIG. 3 illustrates the use of such a line in a transmission system.

FIG. 4 is a graph useful in designing a line of the type illustrated.

FIGS. 1 and 2 illustrate a coaxial transmission line which embodies the novel features of this invention. The line consists of outer conductor 6, inner conductor 7, and ferrite dielectric 8. According to the teachings of the present invention, the tubular ferrite dielectric 8 does not fill the entire space between the inner and outer conductors. In the illustrated embodiment there are air gaps between the inner conductor and the ferrite and the center conductor and the ferrite. This structure results in a line of high characteristic impedance, as will become apparent from the following mathematical analysis. The line dimensions are shown in FIG. 1, $2r$ is the dimension of the inner conductor, $2R_1$ is the inner diameter of the ferrite dielectric tube, $2R_2$ is the outer dimension thereof, and $2R$ is the inner diameter of the outer conductor. Although the ferrite material within theline has been termed a "dielectric," it should be noted that this material also has magnetic properties, since its relative permeability is greater than unity, and it is the combination of its dielectric and magnetic properties which affect the parameters of a line containing ferrite.

The relative effective permeability, μ_{eff}, and the dielectric constant, ϵ_{eff}, of a coaxial transmission line which is partially filled with ferrite are determined by the relative permeability, μ_r, dielectric constant, ϵ_r, of the ferrite itself as well as the dimensions of the coaxial line. For the coaxial line of FIGS. 1 and 2, it can be shown that:

$$\mu_{eff}=1+\frac{(\mu_r-1)\cdot ln\left(\frac{R_2}{R_1}\right)}{ln\left(\frac{R}{r}\right)} \tag{1}$$

and:

$$\epsilon_{eff}=\frac{1}{1+\frac{(\epsilon_r-1)\cdot ln\frac{R_2}{R_1}}{\epsilon_r\cdot ln\left(\frac{R}{r}\right)}} \tag{2}$$

These values of effective permeability and dielectric constant in turn determine the effective characteristic impedance, K_{eff}, of the line, according to the following relation:

$$K_{eff}=\sqrt{\frac{\mu_{eff}}{\epsilon_{eff}}}\cdot K_{air}=\sqrt{\frac{\mu_{eff}}{\epsilon_{eff}}}\cdot\frac{K_{fs}}{2\pi}\cdot ln\left(\frac{R}{r}\right) \tag{3}$$

wherein K_{air} is the characteristic impedance of the same line when filled only with air and K_{fs} is the characteristic impedance of free space, a constant equal to 377 ohms. The effective propagation velocity, v_{eff}, of such a line is given by the following relation:

$$v_{eff}=\frac{c}{\sqrt{\mu_{eff}\cdot\epsilon_{eff}}} \tag{4}$$

wherein c is the velocity of light.

Dividing Equation 1 by Equation 2, the following relation obtains:

$$\frac{\mu_{eff}}{\epsilon_{eff}}=\left[1+\frac{\mu_r-1}{ln\left(\frac{R}{r}\right)}\cdot ln\frac{R_2}{R_1}\right]\left[1+\frac{\epsilon_r-1}{\epsilon_r\cdot ln\left(\frac{R}{r}\right)}\cdot ln\frac{R_2}{R_1}\right] \tag{5}$$

The product of Equation 1 and 2 is as follows:

$$\mu_{eff}\cdot\epsilon_{eff}=\frac{\left[1+\frac{(\mu_r-1)\cdot ln\left(\frac{R_2}{R_1}\right)}{ln\left(\frac{R}{r}\right)}\right]}{\left[1+\frac{(\epsilon_r-1)\cdot ln\left(\frac{R_2}{R_1}\right)}{\epsilon_r\cdot ln\left(\frac{R}{r}\right)}\right]} \tag{6}$$

It can be seen from Equation 3 that the effective characteristic impedance of a line partially filled with ferrite is greater than that of the same line with an air dielectric by a factor equal to the square root of Equation 5. Similarly, the velocity of propagation in such a line is inversely proportional to the square root of Equation 6.

FIG. 4 is a plot of μ_{eff}/ϵ_{eff} and $\mu_{eff}\cdot\epsilon_{eff}$ versus the ratio of R/r to R_2/R_1 of the coaxial line of FIGS. 1 and 2 when partially filled with a ferrite which is commercially known as type Q_2, having relative permeability, μ_r, of 38.3 and dielectric constant, ϵ_r, of 5.37. From FIG. 4, it can be seen that if

$$\frac{\frac{R}{r}}{\frac{R_2}{R_1}}$$

is equal to 1, corresponding to a coaxial line completely filled with ferrite, the value of μ_{eff}/ϵ_{eff} is approximately 7. The characteristic impedance of such a line is then in-

creased by a factor equal to the square root of 7 compared to an air-dielectric line. For values of

$$\frac{\frac{R}{r}}{\frac{R_2}{R_1}}$$

greater than 1, corresponding to lines only partially filled with ferrite, the value of μ_{eff}/ϵ_{eff} increases, reaches a rather broad maximum, and then decreases, as can be seen in FIGURE 4.

A general relation for the proportion of air and ferrite which maximizes the characteristic impedance for a given line is obtained by equating the derivative of the quotient μ_{eff}/ϵ_{eff} with respect to R_2/R_1 or R/r to zero. In either case, it is found that the maximum occurs when:

$$ln\left(\frac{R_2}{R_1}\right)=\frac{1}{2}\left[\frac{\epsilon_r}{\epsilon_r-1}-\frac{1}{\mu_r-1}\right]\cdot ln\frac{R}{r} \qquad (7)$$

The abcissa in FIG. 4 indicates the portion or percentage of the space between the inner and outer conductors which is occupied by the ferrite dielectric. For example, the maximum value of μ_{eff}/ϵ_{eff} and hence also the maximum characteristic impedance of the line occurs at

$$\frac{\frac{R}{r}}{\frac{R_2}{R_1}}$$

approximately to 2.5. However, the maximum of this curve is a broad one and all of the values between 2.0 and 3.0 are substantially equal to the maximum. Assuming a coaxial line with $R=10$ and $r=1$, the maximum characteristic impedance occurs if the ferrite tube has an outer diameter four times its inner diameter. There are several ferrite tube dimensions which satisfy this relation. The ferrite tube may be tightly fit over the inner conductor with a single air gap between the ferrite and outer conductor, or the air gap may be solely between the inner conductor and the ferrite tube or two air gaps may be provided as shown in FIG. 1. In the above example with $R=10$ and $r=1$, the ferrite tube may have an inner diameter of 1 and outer diameter of 4, an inner diameter of 2 and outer diameter of 8, or an outer diameter of 10 and inner diameter of 2.5. All of these ferrite tube sizes satisfy the criterion for maximum characteristic impedance and the particular values chosen will depend on other design considerations. For example, R can be chosen larger than R_2 by an amount just equal to the manufacturing tolerances. Most of the radial air gap is then between the inner conductor and the ferrite. This design minimizes the magnetic flux density in the ferrite and results in maximum power handling capability, but also results in maximum volume and weight of ferrite. If the cost or weight of the ferrite is the limiting factor, the ferrite tube should be designed to fit tightly around the inner conductor.

Also plotted on the graph of FIG. 4 is the product $\mu_{eff}\cdot\epsilon_{eff}$ which determines the propagation velocity of the line according to Equation 4. The propagation velocity is seen to increase with increasing characteristic impedance. This fact is important where the inventive concepts disclosed herein are embodied in such devices as delay lines or shorted or open stubs. FIG. 4 enables the designer to predict the physical length of line necessary to achieve a desired electrical length or delay.

The physical explanation of the maximum exhibited by the characteristic impedance of the disclosed coaxial line is the fact that as the amount of ferrite therein is decreased, both μ_{eff} and ϵ_{eff} decrease but ϵ_{eff} decreases faster than μ_{eff} up to a certain point. The ferrite has been illustrated in tubular shape since this shape results in ease of analysis and construction, however other shapes can be used without departing from the teachings of the present invention. For example, the ferrite may contact both the inner and outer conductors of the coaxial line with material removed from the ferrite in the form of longitudinal slots or recesses. With this structure the ferrite also serves as a support for the center conductor.

The design principles which have been applied herein to coaxial lines may be also applied to other types of transmission lines comprising two or more conductors, for example, so-called strip transmission lines or balanced shielded lines. The inner and outer surfaces of the ferrite are then no longer cylinders, but take the shape of equipotential surfaces of the electrostatic field. The relation between the air gaps and the characteristic impedance of such transmission lines when partially filled with ferrite is more difficult to derive mathematically, however it can be derived empirically.

FIG. 3 illustrates a transmission system including a source of radio frequency energy **11** and a load **13**, interconnected by a coaxial line **6** of the type illustrated in FIGS. 1 and 2. As is well known, the impedance of energy source **11**, the transmission line and the load impedance are all interrelated by considerations of maximum power transfer, reflections and standing wave ratio. Thus it can be seen that the high and controllable characteristic impedance of the transmission line disclosed herein permits much more flexibility in the choice of energy sources and loads in systems such as those of FIG. 3.

The above design principles can be applied by analogy to radio frequency transformers, especially to those for use at the higher frequencies. A shorted coaxial stub partially filled with ferrite may be considered as a tubular core with a one-turn winding thereon, the winding comprising the inner and outer conductors of the stub. This winding can be converted to a multi-turn winding by slicing the conductors along the stub axis and connecting the strips so obtained in series instead of parallel, without changing the basic field configuration. The addition of a second winding on this core renders this stub a transformer. The same factors which produce a high characteristic impedance in the stub will yield a high open-circuit impedance for the transformer, which in turn will result in a broadband characteristic for the transformer.

While the invention has been illustrated by a specific embodiment, many modifications therein will occur to those skilled in the art without departing from the inventive concepts disclosed herein. Accordingly the invention should be limited only by the scope of the appended claims.

What is claimed is:

1. A high-impedance coaxial transmission line comprising, an inner conductor and a coaxial outer conductor, the space between said inner and outer conductors being partially filled by a tubular-shaped type Q_2 ferrite dielectric, the ratio of the quotient of the inner diameter of said outer conductor and the diameter of said inner conductor to the quotient of the outer and inner diameters of said ferrite dielectric being approximately 2.5.

2. A high-impedance transmission line comprising, an inner conductor and an outer conductor coaxial therewith, a tubular-shaped type Q_2 ferrite dielectric partially filling the space between said inner and outer conductor, said dielectric being coaxial with said conductors, the ratio of the quotient of the inner diameter of said outer conductor and the diameter of said inner conductor to the quotient of the outer and inner diameters of said ferrite dielectric being approximately 2.5, a source of radio frequency energy connected between said inner and outer conductors at one end of said transmission line and a load connected between said inner and outer conductors at the other end of said transmission line.

3. A high-impedance coaxial transmission line comprising, a cylindrical inner conductor, a hollow cylindrical outer conductor coaxial therewith, a hollow cylinder of ferrite positioned between said inner and outer conductors and coaxial with each of said conductors, the ratio of the quotient of the inner diameter of said outer conductor

and the diameter of said inner conductor to the quotient of the outer diameter of said cylinder of ferrite and the inner diameter of said cylinder of ferrite being approximately 2.5

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