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VARIABLE FERROMAGNETIC ATTENUATOR HAVING A CONSTANT PHASE SHIFT FOR A RANGE OF WAVE ATTENUATION

Filed May 7, 1965 2 Sheets-Sheet 1

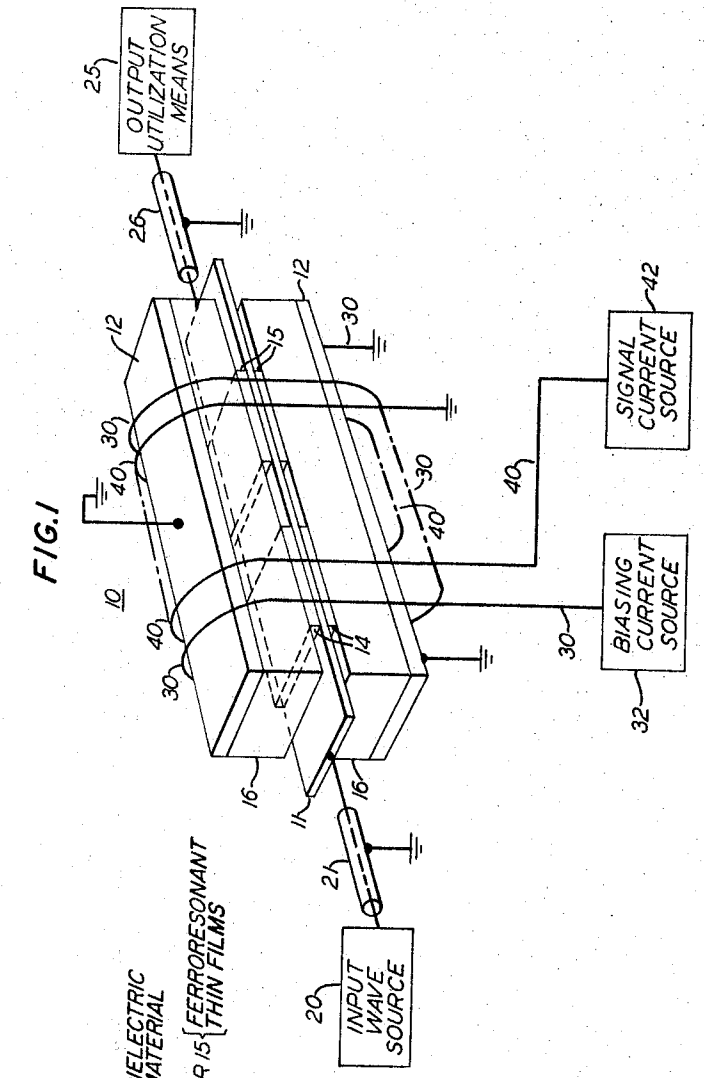


FIG. 1

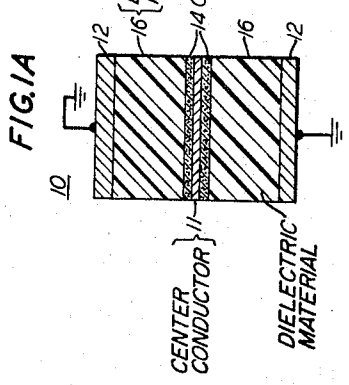


FIG. 1A

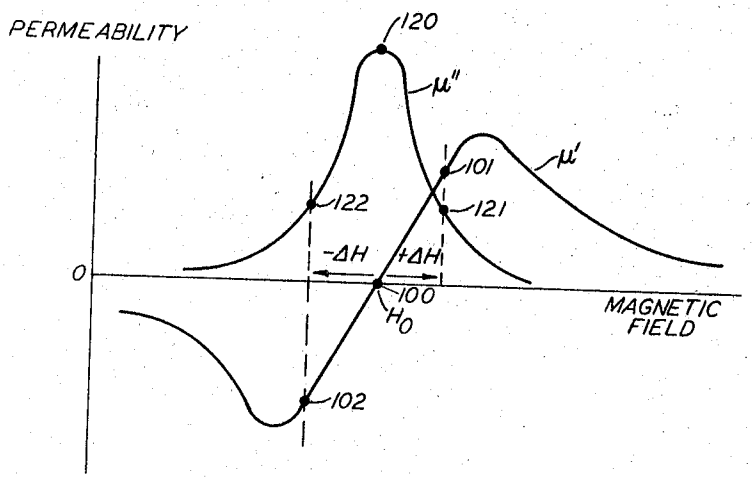
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FIG. 2



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VARIABLE FERROMAGNETIC ATTENUATOR HAVING A CONSTANT PHASE SHIFT FOR A RANGE OF WAVE ATTENUATION

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16 Claims. (Cl. 333—81)

This invention relates to electromagnetic wave propagating arrangements and, more specifically, to a circuit combination which is characterized by an electronically variable wave attenuation without any attendant variable phase perturbation.

A plurality of electronic wave transmission embodiments, such as coaxial cables, waveguides, strip lines and the like, are employed in high frequency systems to propagate wave energy. To effect various desired circuit operations in the high frequency spectrum of interest, prior art transmission structures have been loaded with ferromagnetic and/or dielectric materials to employ the bulk properties of these substances. In addition, an external magnetic field has been utilized to bias the ferromagnetic material included in such a structure to a particular value of permeability.

In particular, the ferroresonant effect exhibited by suitably biased ferrite elements has heretofore been employed in waveguides or the like to partially absorb, and thereby attenuate, a wave translating therethrough. However, attendant to the attenuation produced by such prior art arrangements, there is associated an undesirable shifting of phase of the propagating wave. Where variable attenuating embodiments are utilized, the appurtenant variable wave phase shift has been found particularly objectionable.

It is therefore an object of the present invention to provide an improved electromagnetic wave attenuating arrangement.

More specifically, an object of the present invention is the provision of a wave attenuating arrangement which produces a constant phase shift for a range of wave attenuation.

It is another object of the present invention to provide a wave attenuating embodiment which may be relatively simply and inexpensively fabricated, and which is highly reliable.

These and other objects of the present invention are realized in a specific, illustrative electronically variable electromagnetic wave attenuating embodiment which does not alter the relative phasing of a propagating wave. The arrangement includes a wave transmission structure loaded with two ferromagnetic thin film elements characterized by a permeability with field-sensitive real and imaginary components.

A first winding is coupled to the two thin film elements in a like sense to quiescently bias these elements to a zero relative phase shift, maximum attenuation point on their respective permeability characteristics. In addition, a signal winding is coupled in an opposite polarity relationship to the two thin film elements to selectively reduce the wave absorption properties thereof. As the operating points for the two thin film elements are symmetrically displaced about their quiescent condition under the action of the signal winding, these elements generate canceling phase perturbations for any given wave attenation.

It is thus a feature of the present invention that an electromagnetic wave attenuating arrangement include a wave transmission embodiment loaded with two ferromagnetic thin film elements, magnetizing field biasing circuitry coupled to the two film elements in a like sense, and signal magnetizing field circuitry coupled to the two thin film elements in an opposite polarity relationship.

It is another feature of the present invention that an electromagnetic wave attenuator include a wave propagating structure loaded with first and second ferroresonant elements characterized by a magnetic field-sensitive permeability which includes a wave absorbing imaginary component and a phase shifting real component, constant magnetic field circuitry for biasing each element to ferroresonance, and magnetic signal source circuitry for supplying magnetic fields of an equal amplitude and an opposite polarity to the ferroresonant elements.

A complete understanding of the present invention and of the above and other features, advantges and variations thereof may be gained from a consideration of the following detailed description of an illustrative embodiment thereof presented hereinbelow in conjunction with the accompanying drawing, in which:

FIG. 1 is a schematic diagram of an illustrative electromagnetic wave attenuating arrangement made in accordance with the principles of the present invention;

FIG. 1A is a cross-sectional diagram of a wave propagating structure **10** included in FIG. 1; and

FIG. 2 illustrates the relationship between permeability and the applied magnetic field for a plurality of ferromagnetic thin film elements **14** and **15** included in FIG. 1.

Referring now to FIG. 1, there is shown a specific illustrative electronically variable electromagnetic wave attenuating arrangement which does not affect the relative phasing of an associated translating wave. The arrangement includes a wave propagating structure **10** comprising a center conducting sheet **11** and two grounded conducting planes **12** respectively disposed on either side of the sheet **11**. Between the center conductor **11** and each of the grounded planes **12** there are interposed two ferromagnetic thin film elements **14** and **15**, and a dielectric material **16** such as glass. The particular organization of the propagating structure **10**, which is known as a strip line, is illustrated in cross-sectional form in FIG. 1A.

An input wave source **20** is included in the FIG. 1 arrangement to supply electromagnetic wave energy to the input end of the strip line **10** via a coaxial cable **21**. Similarly, a coaxial cable **26** is employed to connect the output end of the line **10** to an output utilization means **25**.

A biasing winding **30** is inductively coupled to the film elements **14** and **15** in a like sense and connected to a biasing current source **32**. Also, a signal winding **40**, connected to a signal current source **42**, is coupled to the film elements **14** in the same polarity as the biasing winding **30**, and further inductively linked with a like number of turns to the film elements **15** in a polarity opposite to the biasing winding **30**. It is noted that the windings **30** and **40** are only partially illustrated in FIG. 1 to preserve the clarity thereof.

The ferromagnetic thin film elements **14** and **15** are characterized by a frequency sensitive permeability μ which includes a bipolar real component μ' and an imaginary component μ'', as shown in FIG. 2, wherein

$$\mu=\mu'-j\mu'' \tag{1}$$

where j is the operator $\sqrt{-1}$, with the magnitude of μ being given by

$$|\mu|=\sqrt{(\mu')^2+(\mu'')^2} \tag{2}$$

The imaginary component μ'' of the composite film permeability μ is a narrow, peaked curve which is symmetrical about a magnetic field H_o at which the film elements **14** and **15** are ferroresonant. The real permeability component μ' is zero at the ferroresonant field H_o, and characterized by symmetrically shaped positive and negative portions respectively disposed to the right and left thereof.

When employed in conjunction with the various well-known field and wave translation equations which char-

acterize wave propagation in the regions between the center conductor **11** and the grounded conductors **12**, the film permeability μ is multiplied by $j\omega$, where ω is the angular frequency of an incident wave of interest. Hence, the unipolar imaginary permeability portion μ'' produces wave attenuation, and is designated the absorption permeability component. Correspondingly, the real permeability component μ' is essentially reactive in nature (capacitive to the right of H_0; inductive to the left thereof), and shifts the phase of a wave traveling through the film medium.

In overall qualitative terms, the biasing winding **30** and biasing source **32** are adapted to supply a magnetizing field of amplitude H_0 to the films **14** and **15**, thereby quiescently biasing these elements to a point **100** of zero real permeability, and to the peak point **120** on the imaginary film permeability component μ''. With these conditions obtaining, an input wave suppled by the FIG. 1 input source **20** to the output utilization means **25** via the line **10** will undergo maximum absorption, or attenuation, while not being subject to any relative phase shift since the film reactive permeability component is zero. It is noted that the term relative phase shift, or more simply phase shift, as used herein refers to any shifting of the phase of a propagating wave other than the phase lag necessarily associated with the transit time of electromagnetic wave traveling through a given length of the FIG. 1 strip line **10**.

Responsive to a signal current supplied thereto by the associated source **42**, the signal winding **40** supplies a magnetizing field ΔH to the film elements **14** in the same sense as the applied bias field H_0, and also supplies a like amplitude field ΔH to the films **15** in a sense opposite to the bias field H_0, as shown in FIG. 2. Specifically, the energized signal winding **40** drives the film elements **14** to points **101** and **121** on the corresponding real and imaginary film permeability characteristics, while the film **15** permeability operating points attain the corresponding values shown therefor by the points **102** and **122** in FIG. 2. Because of the above-noted symmetry of the FIG. 2 curves, the imaginary permeability component values at the points **121** and **122** are equal in sign and magnitude, while the real component values at the points **101** and **102** are equal in amplitude, but opposite in sign.

With the above magnetizing field conditions prevailing, the absorption permeability components given by points **121** (films **14**) and **122** (films **15**) are less than the corresponding quantity **120** which characterized the films **14** and **15** when only the bias field H_0 was present. Accordingly each of the films **14** and **15** absorbs relatively less power from the incident propagating wave and, therefore, the wave attenuation effected by the loaded strip line **10** is reduced below its quiescent value.

However, since the films **14** and **15** real permeability component values respectively indicated by the points **101** and **102** correspond to equal-valued capacitive and inductive reactances, the incident wave supplied to the line **10** by the source **20** is delayed in phase by the film elements **14**, and advanced in phase in an equal amount by the film elements **15**. Hence, the propagating wave translates through the FIG. 1 attenuating structure in precisely the same phase relationship whether or not a signal field ΔH is present to displace the film operating points from their quiescent values at the points **100** and **120** shown in FIG. 2.

Generalizing, it is observed from the above that the FIG. 1 arrangement will produce more or less wave attenuation as the signal magnetizing field ΔH is respectively decreased or increased from the value therefor shown in FIG. 2. However, associated with any selected attenuation value, the reactive effects attributable to the corresponding variably-biased film real permeability components will in every case produce equal and opposite, canceling dynamic wave phase perturbations. Hence, an incident wave will propagate through the line **10** from the source **20** to the utilization means **25** with the same relative phasing independent of the particular wave attenuation produced by the loaded line **10** under control of the energizing winding **40**.

In quantitative terms, starting with the field equation

$$\gamma=\alpha+j\beta=j\omega\sqrt{\mu^{\epsilon}} \tag{3}$$

where:

γ is the propagation constant for the loaded strip line **10**,
α is the wave attenuation generated per unit film length by the film elements **14** or **15**,
β is the phase shift produced per unit film length by the film elements **14** or **15**,
ω is the angular frequency of the incident wave,
μ is defined in Equations 1 and 2, supra, and
ϵ is the effective permitivity of the medium between the strip line center conductor **11** and the outer conductors **12**, i.e., the glass **16**, it follows that the wave phase shift per unit film length for each of the films **14** or **15** is approximately given by

$$\beta=\omega\sqrt{\epsilon}|\mu|\cos\left(\frac{1}{2}\tan^{-1}\frac{\mu''}{\mu'}\right) \tag{4}$$

Since μ'' is always positive for the films **14** and **15**, while μ' takes on equal and opposite values, the phase shifts generated by the films **14** and **15** may be seen from Equation 4 to be of a like amplitude and opposite polarity. Thus, the FIG. 1 arrangement has again been shown by the above to not create any relative phase displacement in a wave propagating through the attenuating loaded strip line **10**.

It is to be understood that the above-described arrangement is only illustrative of the application of the principles of the present invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope thereof. For example, the strip line **10** illustrated in FIG. 1 may be replaced by any well-known microwave propagating structure, such as a waveguide or coaxial cable.

Also, other well-known magnetizing field supplying elements may be employed to selectively bias the thin film elements **14** and **15** to permeability operating points symmetrically disposed about the film ferroresonant field H_0. Moreover, the film elements **14** and **15** may be positioned adjacent to the grounded planes **12**, rather than contiguous to the strip line center conductor **11** as shown in FIG. 1.

What is claimed is:

1. In combination, means including first and second conductors for propagating an electromagnetic wave, two ferromagnetic elements interposed between said first and second conductors, means for supplying like biasing fields to said two elements to bias said elements to ferroresonance, and means for respectively supplying signal fields of a like amplitude to said two elements, said signal fields having in said two elements aiding and bucking polarities, respectively, with respect to said biasing fields therein.

2. A combination as in claim **1** wherein each of said ferromagnetic elements comprises a ferromagnetic thin film.

3. A combination as in claim **1** wherein said bias field supplying means comprises a biasing winding coupled to said two ferromagnetic elements and a biasing current source serially connected thereto.

4. A combination as in claim **3** wherein said signal field supplying means comprises a signal winding coupled to one of said ferromagnetic elements in the same sense as said biasing winding and coupled to the other ferromagnetic element in a sense opposite to the biasing winding.

5. A combination as in claim **4** wherein each of said ferromagnetic elements comprises a ferromagnetic thin film.

6. A combination as in claim **5** further comprising an input wave source and an output utilization means each connected to said first and second conductors.

7. In combination, a wave propagating structure for a signal wave of predetermined frequency, first and second ferromagnetic means loading said structure, first field supplying means for biasing said first ferromagnetic means to a level above that corresponding to its level for ferroresonance at said frequency, and second field supplying means for biasing said second ferromagnetic means to a level a like amount below that corresponding to its level for ferroresonance at said frequency.

8. A combination as in claim 7 wherein said first and second ferromagnetic means comprise ferromagnetic thin film elements.

9. A combination as in claim 8 wherein said wave propagating structure comprises a strip line.

10. A combination as in claim 9 further comprising an input wave source and an output utilization means each connected to said strip line.

11. A combination as in claim 7 further comprising means for electronically varying the fields supplied by said first and second field supplying means.

12. A combination as in claim 7 wherein said first and second field supplying means respectively comprise two magnetizing windings coupled to one of said ferromagnetic means in a like sense and coupled to the other of said ferromagnetic means in an opposite sense.

13. The combination in accordance with claim 7 in which said wave is propagated through said structure in a predetermined direction, and said ferromagnetic means are disposed sequentially along said structure in said direction.

14. The combination in accordance with claim 13 in which fields supplied by said field supplying means extend in said direction in said structure and in said ferromagnetic means.

15. The combination in accordance with claim 13 in which said structure includes at least one electric conductor, and said ferromagnetic means are contiguous to at least one said conductor.

16. The combination in accordance with claim 15 in which said ferromagnetic means comprise ferromagnetic thin film elements.

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