United States Patent [19]

Caroli

[11] **3,900,806**

[45] **Aug. 19, 1975**

[54] **GROUP-DELAY EQUALIZER USING A MEANDER FOLDED TRANSMISSION LINE**

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[21] Appl. No.: **457,825**

[30] **Foreign Application Priority Data**

Apr. 13, 1973 Italy 49461/73

[52] **U.S. Cl.** ..... **333/28 R**; 333/31 R; 333/84 M

[51] **Int. Cl.** **H01p 9/00**; H03h 7/16

[58] **Field of Search** ..... 333/28 R, 31 R, 84 M

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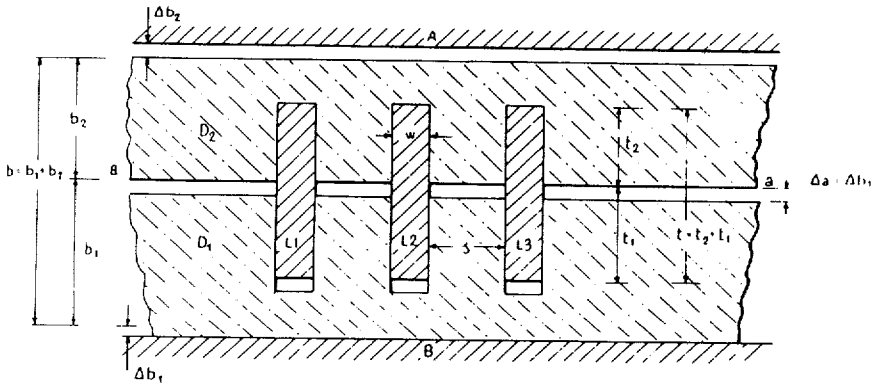
Primary Examiner—Paul L. Gensler

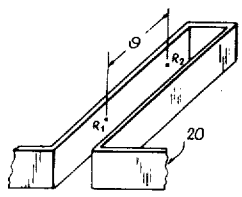
Attorney, Agent, or Firm—Hill, Gross, Simpson, Van Santen, Steadman, Chiara & Simpson

[57] **ABSTRACT**

A group-delay equalizer for microwave frequencies, comprising a meander folded transmission line, comprising means for separately changing the electric wave lengths of said folded transmission line associated with two different modes of propagation of the electromagnetic energy along said line.

2 Claims, 18 Drawing Figures





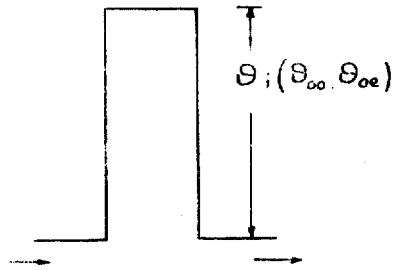


Fig. 1

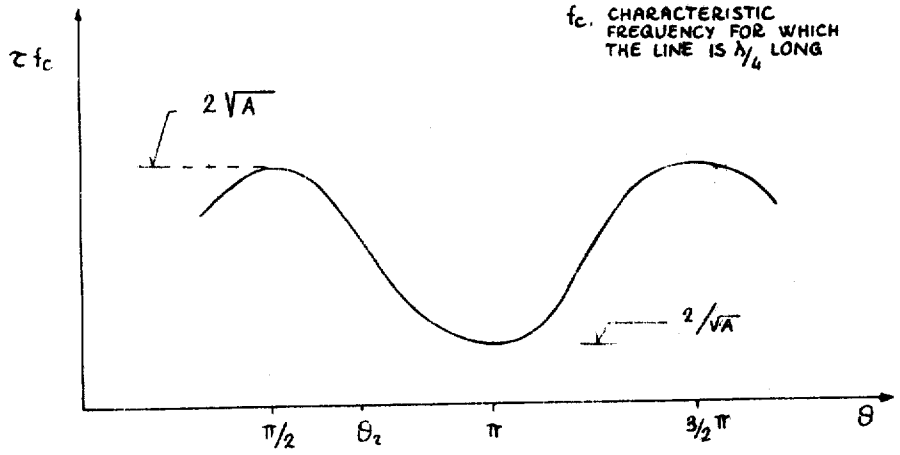


Fig. 3

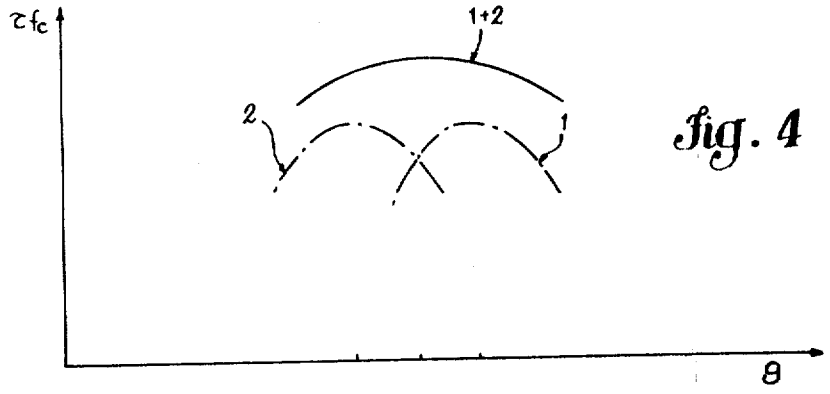


Fig. 4

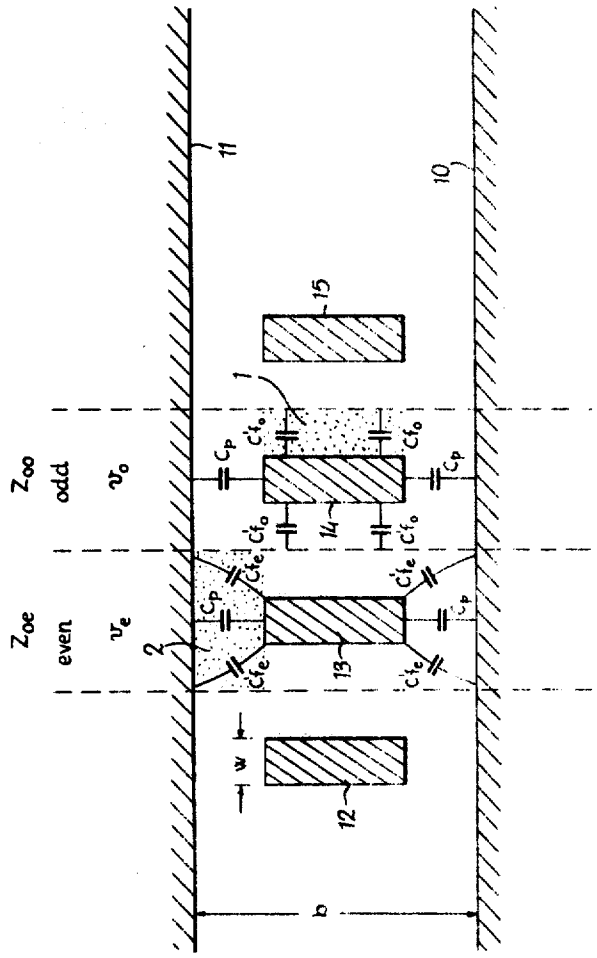


fig. 2

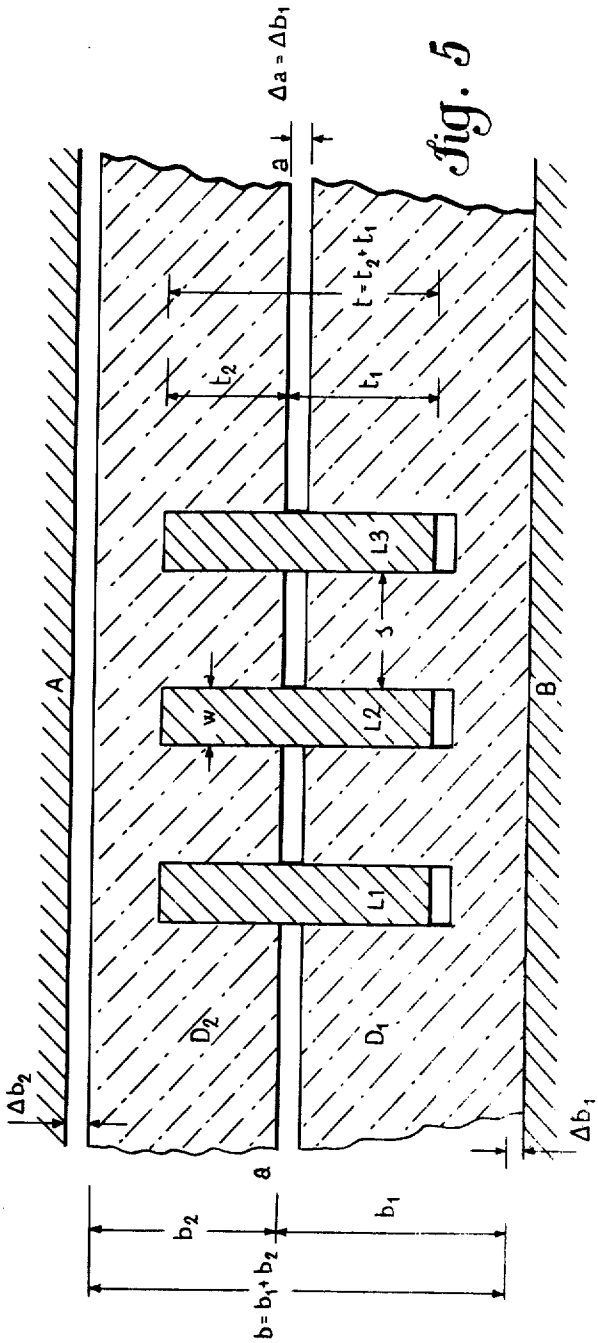


Fig. 5

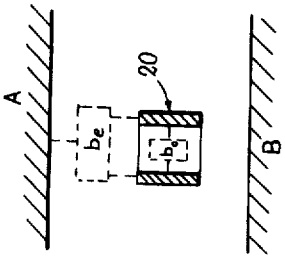


Fig. 7

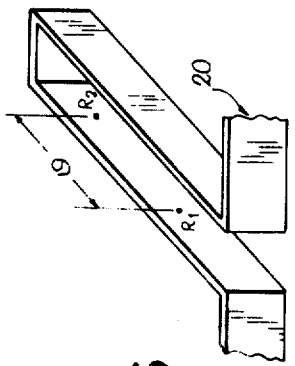
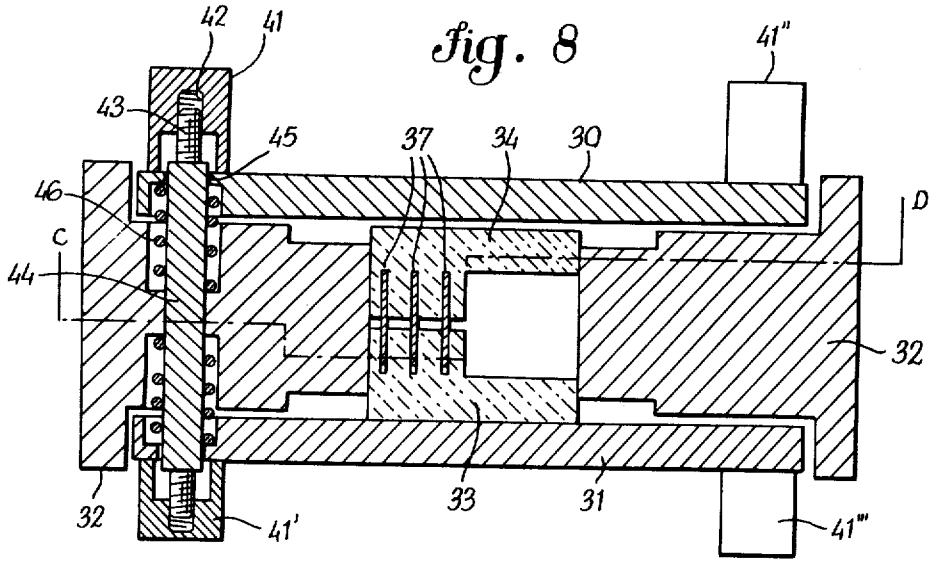


Fig. 6

Fig. 8


42
41
41"
43
45
37
34
30
46
C
D
44
32
33
31
32
41'
41'"

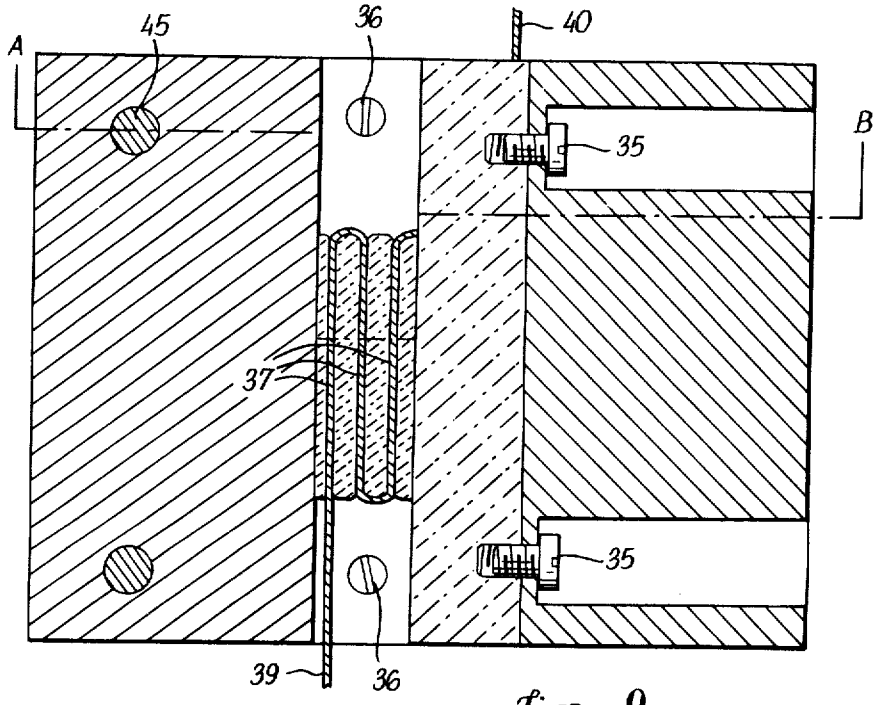

45
36
40
A
B
35
37
35
39
36

Fig. 9

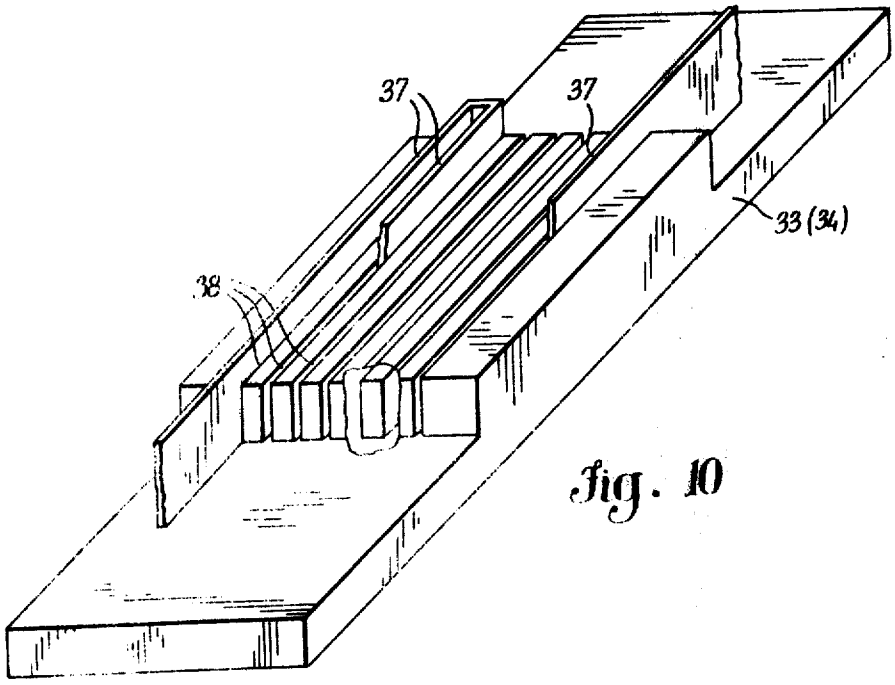


Fig. 10

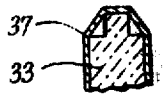


Fig. 11a

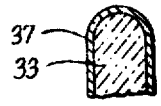


Fig. 11b

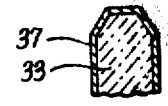


Fig. 11c

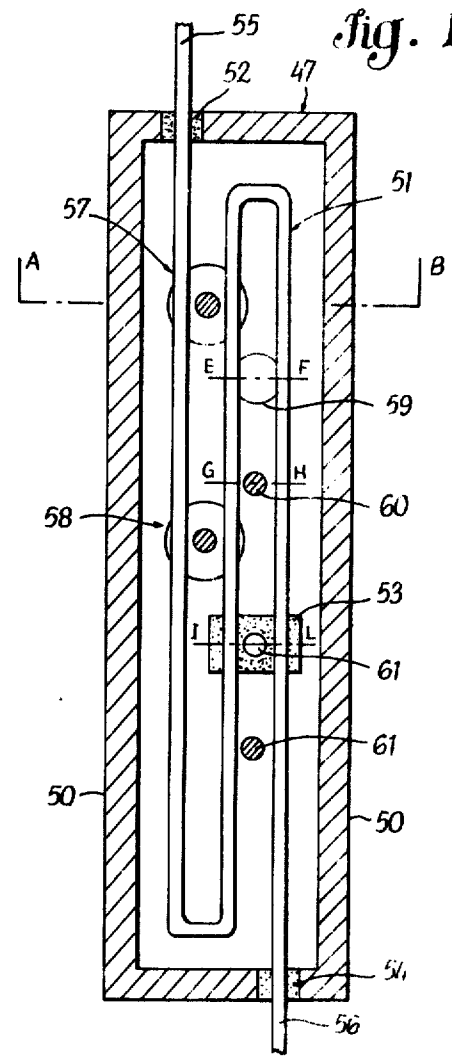


Fig. 12

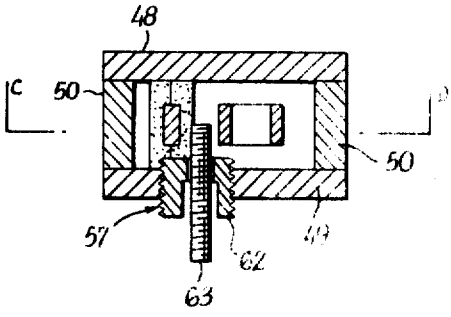


Fig. 13

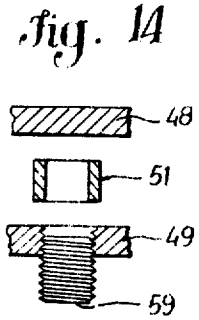


Fig. 14

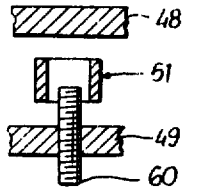


Fig. 15

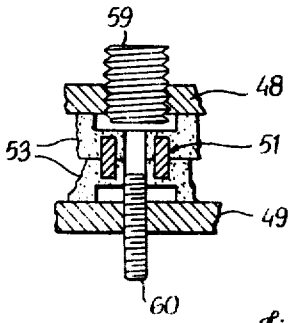


Fig. 16

GROUP-DELAY EQUALIZER USING A MEANDER FOLDED TRANSMISSION LINE

The present invention relates to an improvement in the group-delay equalizers for micro-wave frequencies.

More particularly, the present invention relates to devices for equalizing the group-delay characteristics introduced by transmission media, such as wave guides or radio-frequency filters in circuits.

Depending upon the specific utilizations, there is a remarkable variation in the necessary operating parameters. In slopes or linear components:

1. Group-delay introduced by transmissive media in dispersive guide. Typical application: Transmission of messages with digital modulation, with desired bandwidths of (500–1000) MHz and group-delay variations up to the order of some tens of nanoseconds.

2. Group-delay, introduced by branching circuits for the oscillations which between the input port and the output port are reflected by circuits (generally passband filters) showing a reactive impedance variable with the frequency. Typical application: Branching circuits in the radio relays or repeaters with desired bandwidths in the order of 25 MHz and variations of the group-delay from about 0 to about 10 nanoseconds.

In Parabolic component:

Group-delay introduced by RF filters and RF amplifiers. The applications can be: wide band (>10%) or narrow band (<1%). In each case, the variation of group-delay is typically in the range of nanoseconds.

The typical field of utilization of the device according to this invention is therefore as follows:

a. as a component in transmission systems with millimeter waves for equalizing wide band group-delays;

b. as a component for equalizing group-delays in connection with micro-wave components in frequency bands usually not greater than (5–6) GHz.

In the prior art, problems of the related kind were solved at least partially with wave guides having progressively variable cross-sectional areas in connection with circulators or hybrids, with the possible addition of adjusting means consisting of a movable sheet of dielectric.

Other known systems provide for the use of circulators or hybrids in connection with reactive circuits. One known solution is that proposed by the U.S. Pat. No. 3,277,403 of S. B. Cohn, entitled "Microwave dual mode resonator apparatus for equalizing non linear phase angle of other components" of October 4, 1966.

A further solution of the problem has been proposed in the literature by Jones and Bolljahn (E. M. T. Jones, J. T. Bolljahn: "Coupled Strip Transmission Filters . . . ", I.R.E. Microwave, April 1956). In this publication, reference is made to an all pass structure with a line folded between two ground planes.

The present invention aims to solve the problem of equalizing the characteristics of group-delay in terms of the frequency with a device of the all pass structure with a folded line capable of operating with wide band (>10%), with reduced overall dimensions, and adjustable for permitting the necessary flexibility of use of the device and for compensating the manufacture tolerances which can become severe at the opening frequencies. The solution according to this invention allows also to obtain with reduced overall dimensions said equalization of group-delay with narrow band (<1%) at relatively low frequencies (<4GHz) where the use of dual mode circularly polarized cavity reactance elements would imply excessively large mechanical overall dimensions (see the above mentioned U.S. Pat. No. 3,227,403).

The present invention will be now described with reference to one embodiment thereof described by way of example, and with reference to the attached drawings, wherein:

FIG. 1 shows the base unit of a meander folded line for introducing the symbols used in the specification;

FIG. 2 diagrammatically shows the static capacitances correlated to two propagation modes (odd and even respectively) for lines coupled to each other and located between two ground planes;

FIGS. 3 and 4 are diagrams showing the trend of the group-delay versus the electric lengths of the transmission line;

FIG. 5 shows diagrammatically a sectional view of a folded line between two ground planes;

FIGS. 6 and 7 show further views of folded lines;

FIG. 8 shows a first sectional view taken along the plane A-B of FIG. 9 of an embodiment of the equalizer according to this invention of the uniform line type;

FIG. 9 shows a second sectional view according to the plane C-D of FIG. 8;

FIG. 10 shows a perspective view of the module of dielectric material used in the structure shown in FIGS. 8 and 9;

FIGS. 11*a*, *b*, *c* show examples of embodiment of the detail A shown in FIG. 10;

FIG. 12 shows a first sectional view taken along the line C-D of FIG. 13 of an embodiment of the equalizer according to this invention with a lumped loading line;

FIG. 13 shows a second sectional view taken along the plane A-B of FIG. 12;

FIGS. 14, 15 and 16 show respectively partial sectional views taken along the planes E-F, G-H and I-L as shown in FIG. 12.

With reference now to the drawings, and particularly to FIG. 1, a folded line can be considered as a quadripole of two-port structure of the all pass type with image impedance corresponding to Z_o at all frequencies. It is capable of introducing a group-delay variable with the frequency since the phase of the oscillation between the input port and the output port is a non-linear function of the electric length of the line.

The symbols as follows will be now introduced, useful for the subsequent specification of this invention.

With reference to FIG. 1, let us assume:

f_c the frequency for which is $\theta = \lambda/4$

θ the electric length of the line;

Z_{oo}, Z_{oe} the characteristic impedances associated with the two modes of propagation along the line, "odd" and "even" respectively;

θ_{oo}, θ_{oe} the electric lengths of the line associated to the two odd and even modes of propagation

$$K = \frac{Z_{oo} - Z_{oe}}{Z_{oo} + Z_{oe}}$$

characteristic parameter or coupling coefficient;

$$A = (1 + K) / (1 - K).$$

It can be demonstrated that when $\theta_{oo} = \theta_{oe} = \theta$ we shall have

$$\tau = 2\sqrt{A}\,\frac{1}{1+\frac{A}{\tan^2\theta}}\,\frac{1}{\sin^2\theta}\,\frac{1}{4f_c} \qquad (1)$$

where τ is the group delay. In FIG. 3 there has been shown the trend of the group delay τ versus θ expressed by the relation (1) for a given f_c.

As the features of the structure of FIG. 1 arise from the "directional" properties of two coupled lines, this structure can be used twice to sum the contributions represented by the relation (1) relative to one element with a single folding. The checking of the values which appear in the relation (1) leads to the result that by a suitable selection of said values it will be possible to synthesize various characteristics of the group-delay versus the frequency.

The example of the above appears in the FIG. 3 wherein it can be noted that it is possible to change the slope of the characteristic of group-delay frequency introduced into the circuitry by changing the value taken by the θ at the operative frequency, in other words by changing the value of the characteristic frequency f_c.

Also the non linear component or almost parabolic component can be adjusted by operating a part (for instance one-half) of the structure with determined values of the electric length θ. This possibility is shown in the diagram of FIG. 4.

However, the fact that we must have θ_{oo} 32 θ_{oe}, as it appears from the literature, and the fact that it is practically impossible to obtain a mechanical adjustment of the length of the line, the adjustment of the device becomes a problem (besides the actuation for fixed frequencies with acceptable tolerances), and therefore will limit the practical embodiments to nonadjustable structures.

Notwithstanding the above, according to the present invention, the adjustment is still possible if a method is discovered for embodying adjusting means capable of varying separately the two propagation velocities relative to the even and odd modes, such as by a mechanical adjustment of the dielectric structure connected to the folded line, and/or by the adjustment of lumped discontinuities embodied by metallic or dielectric elements, that is operating with non-uniform and non-homogeneous lines.

In the following disclosure, by way of clearness but not for limiting purposes, reference will be made to a non-homogeneous uniform line to a homogeneous and non-uniform line.

First case: uniform and non-homogeneous line

Let us consider the structure of FIG. 2 wherein have been diagrammatically shown two ground planes, electrically conductive and denoted by the numeral references **10,11** spaced apart from one another through a distance b. Between these ground planes **10,11** is located in a substantially centered location the folded line, consisting of a strip, shown in sectional view and referenced as **12,13,14,15** for an example of an indefinite repetitive structure.

In the conductor sections **13, 14**, the static capacitances have been respectively shown relative to the even and odd modes of propagation along the line.

With reference to this Figure, it is therefore possible to observe that the partial or total presence of a dielectric in the zone **1**, as shown by a shadow and/or in the symmetrical zone, affects primarily the characteristic impedance Z_{oo} and the velocity v_o relative to the odd mode, and the value of $C_{oo} = 4C'f_o + 2C_p$, will be altered by the effect on the value of $C'f_o$.

On the contrary, the total or partial presence of dielectric in the region **2** near the ground planes (shown in FIG. 2 by the same criteria as the region 1) affects essentially the characteristic impedance Z_{oe} and the velocity V_e of the even mode, and the value of $C_{oe} = 4C'f_e + 2C_p$ will be altered. Also, the value of the capacitance C_p will easily take account of this fact when the unit is designed or adjusted. In fact, however, in case of $w/b << 1$, corresponding to the cases of practical interest, and for values of coupling between the lines like those necessary in the practical cases, the contribution of C_p will be negligible. Consequently, a variation of the amount of dielectric present in the above indicated regions (**1** and **2**) allows the values of the electric lengths of the lines associated to the two even and odd propagation modes to be separately changed.

In the most general case, a practical embodiment of means for changing the capacitive loading would render necessary the study of the electric field between the two lines in the partial presence of dielectric. For the cases of practical interest, it is possible to proceed to a strict real dimensioning of a structure partially filled with a dielectric, by using the methods for the determination of the capacitances of $C'f_e$ and $C'f_o$ as appeared in the literature.

In connection therewith, let us consider the FIG. 5. In this Figure the structure comprising the line folded between two ground planes is substantially entirely filled with a dielectric. This structure comprises the ground conductor planes A,B; the dielectric blocks **D1,D2** and the conductor of the folded line denoted by **L1,L2,L3 . . .**

The two blocks of dielectric material **D1, D2** can be spaced apart from one another along the plane a—a. A variation of the distance $b2$, being $b = b_1 + b_2$, obtained by spacing away the conductor plane A and leaving fixed the position of the upper face of the dielectric block **D2**, obtained by introducing an air gap Δb_2 between the conductor plane A and the upper surface of the dielectric block D_2, produces substantially a decrease of the capacitance value $C'f_e$. Correspondingly, a variation of the distance b_1, obtained by spacing away the dielectric block D_1 in the interface of a—a and introducing an air gap Δa between the two dielectric blocks by spacing away the conductor plane B together with the dielectric block D_1, produces substantially a decrease of the value of the capacitance $C'f_o$.

Then, it is possible according to this invention to have two separate adjustments, practically embodied for $C'f_e$ and for $C'f_o$ permitting the embodiment of a folded line transmission structure wherein it will be possible to adjust the values θ_{oo} and θ_{oe} satisfying the condition $\theta_{oo} = \theta_{oe}$.

As a particular case, considering the dielectric blocks D_1, D_2 as homogeneous, and with a relative dielectric constant $\epsilon_r \cong 2.3$, we shall have with reference to the symbols shown in FIG. 5 and for the case where $w/b << 1$, and

$0.6 < t/b < 0.8$

$0.15 < s/b < 0.25$

$\Delta b_1 \approx \Delta b_2 = \Delta b$, we shall have:

$$\frac{\Delta f_c}{f_c} \cong 0.4 \quad \frac{\Delta b}{b} \tag{2}$$

The above mentioned adjustments will influence also the coupling coefficient K and the image impedance Z_o as follows:

$$\frac{\Delta K}{K} \cong (1-K) \quad 2.5 \quad \frac{\Delta f_c}{f_c} \tag{3}$$

$$\frac{\Delta Z_o}{Z_o} \cong -2 \quad \frac{\Delta f_c}{f_c} \tag{4}$$

The contribution of (3) is substantially a parasitic effect of the adjustment which however can be corrected by the adjusting means. The effect of (4) is that of changing the impedance Z_o of the structure, limited, however, to a practically allowable amount which can be compensated by acting in a way substantially analogous to that as previously described, or with lumped constants on the line tracts connecting to the load.

Assuming $b = 10$ mm, the percent variation of the characteristic frequency f_c which can be expected according to (2) is:

$$\frac{\Delta f_c}{f_c} \cong 4\%/\text{millimeter}$$

Hereinafter a possible practical embodiment of the device according to this invention will be described by way of example.

Second Case: non-uniform line either immersed or not in homogeneous dielectric

Still considering the diagrammatical representation of FIG. 2 let us now have reference to FIGS. 6 and 7 showing the diagrammatical representation of a line with a single folding useful for understanding the second embodiment of this invention concerning non-uniform lines, immersed or not immersed in a homogeneous dielectric.

The line comprises a U-shaped conductor **20** located between two conductor ground planes A,B. A susceptance b_e located in the regions R_1 and R_2 allows the adjustment of the electric length θ_{oe} relative to the even mode and a susceptance b_o also located in the regions R_1 and R_2 allows the adjustment of the electric length θ_{oo} relative to the odd mode. The practical embodiment can be obtained by placing the conductor **20** forming the line in a dielectric, either air or solid, and the susceptances b_e, and b_o can be formed by metal screws or dielectric screws.

The possibility of adjusting independently the two susceptances allows the condition of equal electric length to be obtained for the modes of propagation. If $b_e = b_o = b$, the distance θ between the regions R_1, R_2 will be

$$\theta = \text{arc tan} \quad \frac{2b}{b^2-1}$$

to which corresponds an electrical length between the regions R_1, R_2 equalling $\theta_{R\ R} = \pi$

Therefore the percent variation of the electrical length which is to be obtained being η, we have

$$\theta = \frac{\theta - \pi}{\theta} = 1 - \frac{\pi}{\text{arc tan} \quad \frac{2b}{b^2-1}}$$

from which we obtain:

$$b \cong \frac{1}{2} \tan \frac{\pi}{1-\eta} \tag{5}$$

Now two practical embodiments of the group-delay equalizer for microwave frequencies will be described.

EXAMPLE I — Equalizer with uniform line

Reference is made to FIGS. **8** to **11**. The device comprises a first plate **30** with at least the inwardly turned surface conductive, and a second plate **31** similar to the first cited plate. Between the plates **30, 31** a spacer **32** is interposed. To the plate **31** is fixed a module of dielectric material shaped as shown in FIG. **10** fixed to the plate **31** by the screws **36.** A similar module **34** is fixed by screws **35** to the spacer **32.**

The transmission line, meander folded, shown as a unit by **37,** is inserted and fixed in the grooves **38** provided in the dielectric module **33.** Two tracts of line **39,** 40 serve for the electrical connection to the connecting terminals of the device to the balance of the device.

In FIGS. 11*a*, 11*b* and 11*c* there is shown the relationship between strip transmission line **37** and the fingers of the dielectric module **33,** in the folding zone. In FIG. **11***a* the strip **37** follows a segmented fold and a portion of dielectric **33** is removed in the corners as shown. In FIG. **11***b* in the fold zone the strip **37** follows a curvilinear path and the dielectric **33** is correspondingly shaped. In FIG. **11***c*, the strip **37** is bent as in FIG. **11***a* and the dielectric **33** has a corresponding shape but without empty spaces.

The adjustment of the characteristics of the equalizer is obtained by varying the distance of the lower surface of the plate **30** with respect to the upper surface of the dielectric module **34** and changing the immersion of the dielectric block or module **33** in the line by changing the distance of the plate **31** with respect to the spacer **32** (see FIG. **5** for reference to the previous disclosure).

The adjustment of the aforesaid distances can be obtained by the bushings **41, 41', 41''** and **41'''**. The structure of these bushings and the associated mechanisms will be described with reference to the bushing **41** as both the other shown bushings and others corresponding by symmetry and not shown in the Figure, are identical. The bushing **41** in the shape of an overturned cup, bears against the outer surface of the plate **30** and is provided with an internal threading **42** which engages a threaded pin **43** forming the prolongation of a post **44** along which can slide, due to the holes **46,** the plate **30.** A contrast spring **46** tends to space away the plate **30** from the spacer **32.** The lower module **33** can have reduced dimensions with respect to the dimensions of the module **34** and if a single adjustment of the constants will be sufficient, it can also be entirely dispensed with.

Of course, it is possible to provide for the connection in series and/or parallel of more equalizers according to this invention, as well as to modify the mechanical structure of the unit in order to obtain independent adjustments of the same tract of folded line, with a longi-

tudinal division of the dielectric modules. Said alternatives are obviously capable of being designed by a person skilled in the art and will not be described in detail.

EXAMPLE 2 — Equalizer with line with sole lumped adjustments

Reference is to be made to FIGS. **12** to **16.** The device comprises a box type structure generally denoted by **47,** which is conductive at least internally, including an upper plate **48,** a lower plate **49** and a spacer **50.** Inside the box type structure **47,** the folded line **51** is supported by little blocks of low loss insulating material **52,53,54.** The line tracts **55,56** serve for connecting the equalizer to the electrical terminals for the connection to the remainder of the circuit.

FIG. **12** shows in **57,58,** adjusting susceptances in a possible embodiment thereof. In **59,60,61** said susceptances have been shown in a different possible embodiment.

As it will be better noted in FIG. **13** the susceptances **57** include a first screw element **62** which is threaded in the lower plate **49** and which presents toward the line a flat end, circular with a diameter greater than the maximum lateral dimension of the part of line on which it operates, at the center of which is screw threaded a screw **63** which can extend inside the space between the lines. The elements **62** and **63** act therefore also on the electric lengths of the folded line. FIGS. **14, 15, 16,** show partially interrupted sectional views of FIG. **12** showing the geometrical relation between the adjusting elements **59, 60** operating on the electrical lengths.

FIGS. **12** to **14** show the line of the equalizer device immersed in air. Said line could also be immersed into a homogeneous dielectric.

Furthermore, the lumped susceptances can also be practically made of conductor material or if dielectric material.

Having thus described the present invention, what is claimed is:

1. A group-delay equalizer for microwave frequencies, comprising a meander folded transmission line, and adjusting means for changing separately the electric lengths of said folded transmission line associated to two different modes of propagation of the electromagnetic energy along said line, wherein said folded line is located between two ground planes, said adjusting means comprising a first block of substantially homogeneous dielectric material into which is immersed the aforesaid strip line partially folded lengthwise, a second block of dielectric material substantially similar to said first dielectric block of which it is possible to adjust the immersion of said line; means for changing the distance of one of said ground planes with respect to the outer surface of said first dielectric block, and means for changing the distance of the other of said ground planes to which is fixed said second dielectric block in order to change the immersion of said second dielectric block into said folded line.

2. A device as claimed in claim **1,** characterized in that said blocks of dielectric material comprise different amounts of dielectric in the active zone.

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