FREQUENCY SELECTIVE ATTENUATION APPARATUS

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ABSTRACT

The specification discloses a frequency selective or gain equalizing attenuator having a highly controllable profile of attenuation versus frequency of microwave energy propagated along a transmission line. Spaced a quarter-wavelength apart, a pair of resonant stubs are coupled to the line through resistive loss elements. Depending upon the frequency of the incident energy and the length of the stubs, the coupling of the lossy elements to the line varies as the stub reactance varies from short to open and, accordingly, provides a predetermined desired attenuation characteristic. The overall discontinuities on the transmission line caused by the stubs and lossy elements substantially mutually cancel each other because of their symmetry and quarter-wave spacing along the transmission line. A full reading of the specification is recommended for details of the concepts involved.

8 Claims, 6 Drawing Figures
FREQUENCY SELECTIVE ATTENUATION APPARATUS
This application is a continuation-in-part of U.S. Pat. application Ser. No. 807,632, filed Mar. 17, 1969, under the same title.

BACKGROUND OF THE INVENTION

1. Field of the Invention
This invention relates generally to microwave apparatus and more particularly to transmissive structure exhibiting frequency dependent attenuation with respect to microwave energy being propagated therethrough.

Although the invention finds particularly advantageous application in the field of providing gain equalization in cooperation with active devices such as traveling-wave tube amplifiers and the like and although, in the cause of brevity and clarity of presentation, much of the following discussion and description of examples of the invention relate particularly thereto, it is expressly to be understood that the advantages of the invention are equally well manifest in other branches of the microwave field and in other radio fields wherein, for any purpose, a particular attenuation profile of loss as a function of frequency is desired.

2. Discussion of the Prior Art
With particular reference, therefore, to microwave systems utilizing active, gain producing or microwave generating devices, the efficiency and effectiveness of the system typically is significantly dependent upon the degree to which the magnitude of effective gain of the device is constant over a desired band of operation. Accordingly, considerable effort is often expended to maximize the bandwidth over which the effective gain remains within predetermined limits. Such efforts generally include compromising maximum gain, as at band center in order to achieve an optimum of bandwidth within the desired gain limits.

This approach of attempting to match, in a "reciprocal" manner, the gain of the active device with attenuation by a passive device over a desired band is termed "equalizing," and the passive apparatus, "equalizer."

The providing of an equalizer which achieves a satisfactory gain leveling effect without introducing an undesired insertion loss, intolerable VSWR, or phase distortion nonlinear dispersion effects in a device which is mechanically compact, simple and reliable, thermally stable, and electrically versatile and adjustable to various needs and applications presents severe difficulties which have not heretofore been solved in a practical, repeatable device which can be used by field personnel in operational systems.

In the prior art, one of what is considered the best approaches has resulted in the development of apparatus utilizing a four port 3 db. hybrid coupler complex. Two ports function as input-output terminals while the other two isolated ports are terminated in "balanced" reactive loss elements. So long as the insertion losses, the degree of unbalance, and the dispersion effects remain acceptable for a particular application, a degree of equalization may be achieved by such a circuit. However, the insertion loss at and edges due to losses and inherent unbalance in the hybrid is high. In addition, the apparatus suffers transmission line losses with the interconnecting circuitry. Furthermore, the hybrid is typically in a strip line configuration utilizing (lossy) dielectric materials and causing thermal difficulties when the device is affixed to the body or housing of the active device, or otherwise disposed in a thermally severe environment, or when higher power handling is required. More particularly, suitable 3 db. hybrid couplers have typically 1 db. maximum coupling unbalance over an octave band. This inherently causes a VSWR of approximately 1.2; then an additional 1.2 VSWR is typically suffered in the coupling into and out of the device. In addition, the balance between loads at the "isolated" ports is significantly less than perfect which results in additional VSWR increases. The minimum insertion loss is typically 0.6 db. or greater, and the resulting overall VSWR is 1.5 or greater.

The 3 db. hybrid approach, as well as others, also exhibits other disadvantages such as those pointed out earlier above, and have not resulted in a satisfactory solution to the problems enumerated.

Accordingly, it is an object of the present invention to provide microwave frequency sensitive attenuation apparatus which is not subject to these and other disadvantages and limitations of the prior art.

It is another object to provide such apparatus which achieves equalization over a broad band with very low minimum insertion loss, very low VSWR, and very small non-linear dispersion effects.

It is another object to provide such apparatus which is readily adjustable by field personnel with respect, noninterdependently, to magnitude and frequency disposition of maximum attenuation and frequency disposition of each band edge.

It is another object to provide such apparatus which is mechanically exceedingly compact, rugged, reliable, and readily repeatable on an economic, standard production basis.

SUMMARY OF THE INVENTION

Very briefly, these and other objects are achieved in accordance with the structural aspects of one example of the invention which includes a length of transmission line having two or more resonant stubs spaced therealong at integer quarter-wavelength interval(s). The stubs connect, effectively, the line to lossy elements to a degree determined by the reactance of the stubs which is a function of frequency. Means may be provided for adding lumped reactance at discrete locations along the resonant stubs to affect the profile of the equalization characteristic, for varying the overall length of the stubs, and to affect the end and midband frequencies essentially independently of each other. Varying the impedance of the main transmission line will also affect the maximum attenuation of energy, at or near midband i.e., that which is shunted to the lossy elements for absorption.

Further details of these and other novel features of the invention and is operation include, for example, means for maintaining a desired impedance match to the overall transmission line while various adjustments are made, as well as additional objects and advantages of the invention which will become apparent and be best understood when considered in connection with the accompanying drawings which are presented by way of illustrative example only.

OUTLINE OF THE DRAWINGS

FIG. 1 is a highly simplified schematic diagram of an example of microwave attenuation apparatus constructed in accordance with the principles of the present invention;

FIG. 2 is a graph plotting attenuation on the ordinate as a function of frequency on the abscissa illustrating the electrical operation of the structure of FIG. 1;

FIG. 3 is a simplified, partially cutaway, view illustrating certain structural concepts associated with the schematic view of FIG. 1;

FIG. 4 is a cutaway view of a portion of a further example of apparatus embodying the principles of the invention;

FIG. 5 is a schematic diagram of an alternative example of the invention; and

FIG. 6 is a pair of graphs, like that of FIG. 2, having a common abscissa and illustrating the operation of the structure of FIG. 5.

DESCRIPTION OF PREFERRED EMBODIMENTS

With specific reference now to the figures in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion only, and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principle and structural concepts of the invention. In this regard, no attempt is made to show structural details of the apparatus in more detail than is necessary for a fundamental understanding of the in-
vention. The description taken with the drawing will make it apparent to those skilled in the microwave art how the several forms of the invention may be embodied in practice.

Specifically, the detailed drawing is not to be taken as a limitation upon the scope of the invention which is defined by the appended claims forming, along with the drawing, a part of this specification.

In FIG. 1, the example of an equalizer 8 illustrated schematically includes a transmission line 10 having a pair of input terminals 12, 14 which may be coupled to the output terminals of a "source" device 16 which may include an oscillator or an amplifier or another such device which is tunable over a frequency band. Although, however, the source 16 may be narrow-band or broadband, its output magnitude with respect to frequency is not satisfactorily level, over that bandwidth, for nominal or optimum effectiveness by a particular utilization device 18, which may be adapted to be coupled to the output terminals 20, 22 of the equalizer 8.

Between the input and output terminals 12, 20 of the equalizer circuit, the transmission line 10 is shown having three segments 24, 26, 28 having characteristic impedances $Z_2$, $Z_3$, $Z_4$, respectively. Each of the segments is approximately one-quarter wavelength at center frequency and each impedance is indicated independently variable. The length of the mid segment 26 is defined by the connection points 30, 32 to each of which is attached a resistance load 34, 36, respectively. A resonant line 38, 40 is then attached to resistance 34, 36, respectively. In this example, these lines are shown grounded whereby microwave energy converted to heat in the loads 34, 36 may be readily transferred to and dissipated by the body or housing portions of the apparatus. The resonant lines do not necessarily need to be grounded, depending upon the response and power requirements.

Accordingly, for purposes of controlling whether the lossy lines are effectively coupled to or uncoupled from the line 10 and at what frequencies, the effective length of the lines 38, 40 are of the character to be an even number of quarter-wavelengths for frequencies where the connection is desired so as to achieve maximum attenuation (e.g., at the frequency or frequencies of maximum output of the "source" device 16) and an odd number of quarter-wavelengths for frequencies where no connection or attenuation is desired (e.g., at the bandwidth edges of the device 16). If the lines 38, 40 are not grounded, the frequencies of maximum and minimum attenuation will be reversed, e.g., an even number of quarter-wavelengths will produce minimum attenuation while an odd number will provide maximum attenuation.

In operation, microwave energy traversing the equalizer along the transmission line 10 and impinging upon the connection point 30 sees a choice of paths, one along the mid segment 26, and one along the resistance load 34. That portion of the incident energy which traverses the latter path is substantially absorbed while that continuing along the line 26 remains substantially unaffected. The proportional relation between these portions of the incident energy is, of course, determined by the ratio of the path conductances seen at the point 30. Accordingly, at midband, for example, where maximum effective connection occurs, by varying the load resistance the attenuation of the incident energy is varied. In a practical example, using a value of 70 ohms at each of the loads 34, 36, and a 50 ohm main line 10, the attenuation will be 5.80 db. and will reduce to 4.18 db. when the load resistance is increased to 100 ohms.

In addition, if the load resistance is held constant and the characteristic impedance $Z_e$ of line 26 is changed, the amount of attenuation will also change. As an example, if the load resistance is maintained at 70 ohms and the value of $Z_e$ varied from 38.5 ohms to 58.8 ohms, the attenuation will vary between 5.66 db. and 6.66 db., respectively.

As indicated above, the discontinuity introduced at point 30 is substantially cancelled by reflection of the like discontinuity a quarter-wavelength away at point 32. However, this is only true for a particular value of load resistance and characteristic impedance of $Z_e$. If $Z_e$ is varied to modify the attenuation, the resulting discontinuity can be corrected by varying $Z_e$ at the same time and by the appropriate amount. When this is done, the resulting VSWR is below 1.19 over the 4.56 to 6.66 db. range in the total frequency band as shown by the curve 50 of FIG. 2 over the octave from 2 to 4 GHz., the current distribution on the resonant lines may be distorted to produce the desired open circuit at the band edges.

Referring to FIG. 3, an example of the invention is illustrated in which the indicated current distribution is accomplished by incorporating a plurality of characteristic impedances along the resonant lines. In the figure the equalizer 8 having a body portion 52 shown without its cover, includes an input terminal 54 and an output terminal 56 interconnected by a transmission line 58 having three segments 60, 62, 64 with connection points 66, 68 therebetween defining the length of the mid section 62. The two resonant lines 70, 72, each as indicated, are spaced from the line 76 affixed to the points 66, 68, again spaced one-quarter wavelength along the transmission line 58. The degree of effective connection of the loads 74, 76 to the line 58 is controlled by the electrical length of the resonant lines 70, 72. The desired current distribution in this particular example is achieved by dividing each of the stub lines into two quarter-wavelength segments 78, 80 and 82, 84, respectively, at mid-band frequency, and providing different characteristic impedances for the grounded segment 78, 82 as compared with the nongrounded segments 80, 84. By providing a characteristic impedance of 11 ohms for the grounded segments 78, 82 and a characteristic impedance of 33 ohms in the nongrounded segments 80, 84, a resonance at 2, 3, and 4 GHz. is achieved. In effect the line will be open circuit at 2 and 4 GHz., i.e., one-quarter wavelength and three-quarters wavelength electrically, respectively; while at 3.0 GHz. it will be short circuit, i.e., one-half wavelength long. Various combinations of impedances and line lengths can be used to obtain the desired response.

Also illustrated in FIG. 3 is a schematic example of structure for achieving the desired adjustment or control of Zfor the midsection 62, and of $Z_e$ for the segments 60, 64. The diameters of the segments and their spacing from a stepped, movable wall portion 86 determines their characteristic impedances; and these parameters are selected whereby movement of the wall 86 in adjusting $Z_e$ causes a corresponding, compensating change in $Z_e$ so that the terminals 54, 56 continue to see the predetermined desired characteristic impedance of the external transmission lines or other structures.

In FIG. 4, an alternative example of the invention is illustrated in which the equalizer 8 which operates between 7 GHz. and 11 GHz. includes a strip transmission line 90 having three segments designated $Z_e$, $Z_e$, $Z_e$. The magnitudes of the impedances are determined by the disposition laterally of a grounded tab element 92 which is spaced in juxtaposition above the strip line 90. At each end of the strip segment $Z_e$ a junction line 94, 96 is affixed and extends centrally through a respective resonant stub line 98, 100 disposed parallel to and symmetrically to either side of a septum 101. Each of the stubs is, in this example, cantilevered from a shorting block 102 which is slideable laterally with respect to the body 104 of the equalizer as suggested by the rack and pinion arrangement 106.

The length of the stub lines 98, 100 is determinative of the band edge and midband resonance effects. It is also to be noted that the series inductance, introduced by the conductors 94, 96 in the regions between the strip 90 and the non-grounded ends of the stub lines 98, 100, is increased as the
shorting block 102 is moved away from the strip, which added inductance tends to lower the frequency of the midband resonance. When the block 102 is moved toward the strip, a capacitance is added in parallel with each resistive load, which has the effect of raising the frequency midband resonance. The effects of this adjustment of block 102 are illustrated in FIG. 2 by the displacement arrow 110, parallel to the abscissa, and its associated curve 110', indicating a down frequency shifting of the midband resonance while the dashed curve 110" indicates an up frequency shifting therefrom.

A first set of tuning screws 112, 114 are mounted in the body 104 at a distance approximately one-half wavelength, at the high frequency, 11 GHz, band edge, from the shorting block surface 108. Being shunted at a voltage minimum, for the high band edge frequency, adjustment of the screws 112, 114 does not affect the high frequency end of the attenuation characteristic, but exerts a wide latitude of effect on the low frequency end as indicated by the displacement arrow 116 and its associated curves 116', 116" shifted downwardly and upwardly, respectively, from the indicated nominal band edge frequency at 7 GHz. A second set of tuning screws 118, 120 is shown disposed a high frequency half-wavelength from the first set 112, 114 and may be utilized when desired to provide additional capacitive tuning of the low-frequency band edge.

A third set of tuning screws 122, 124 is disposed one-half wavelength for the low band edge frequency, from the shorting block surface 108 and thereby at a voltage minimum for the low frequency so that they have little effect on the low frequency portion of the attenuation curve, but significantly tune the upper band edge as indicated by the displacement arrow 126 and its associated shifted curves 126', 126".

In completing the discussion of FIG. 2, it may be noted that the displacement arrow 128, parallel to the ordinate, and its associated dashed curves 128', 128" indicated the effect of increasing and decreasing the magnitude of Z1 by adjustment of the tab 92 or by selection of the nature and dimensions of the lossy material 130 to which the conductors 94, 96 connect within the stub lines 98, 100. In the example shown, the material is in the form of a cylinder fitted in good thermal contact with the sleeve inner walls of the stub lines and axially bored, as shown, to receive the conductors 94, 96 also in good thermal contact. Apparatus constructed along these lines readily dissipates more than ten watts continuously without damage or performance degradation due in any manner to high temperature.

An X-band equalizer constructed along the lines of the apparatus illustrated in FIG. 4 and exhibiting the performance and versatility of adjustment shown in FIG. 2 is a few centimeters in maximum dimension, weighs only a few ounces, has a more than 10-watt absorption capability, has a maximum VSWR of less than 1.2, and has an insertion loss at the band edges of less than 0.15 db.

Additional merits of the structure described and discussed above include that more than two resonant stubs may be employed when much greater attenuation than, say, 6 db. is desired. The stubs may be spaced as above, and the impedances of the transmission line segments may again be arranged to be self-compensating. Also, a greater plurality of characteristic impedances along the lengths of the resonant stubs may be utilized, and the attenuation curve may be significantly narrowed by coupling parasitic resonant circuits lumped or distributed to the stub lines. By selection of the coupling means, the auxiliary resonators can be sharply, frequencywise, connected and disconnected from the stub lines. In addition, the structures, utilizing the principles of the invention, are generalized to include waveguide, and TEM line, helical line, lumped-constant equivalents, or the like.

Referring to FIG. 5, an alternative arrangement combination of the invention is illustrated which includes a directional coupler portion 132 having an input port 134, a main output port 136, a "coupled" output port 138, and a fourth port 140 terminated, as shown, by a resistive load 142. The output of the "coupled" port 138 is impressed upon the input terminal 12' of an equalizer portion 8', the primed reference numerals correlating with corresponding elements discussed in connection with FIG. 1, supra. Accordingly, the transmission line input port 134 is connected to the output terminal 12' by the resonant line 24', 26', 28' and the resonant lines 38', 40' connected to the segment junctions 30', 32', respectively, and including their respective resistive loads 34', 36'.

In practice, a single section coupler is thus provided with an exceedingly flat frequency response over a widely extended S-band octave range as indicated in FIG. 6. The curve 144 illustrates the typical response of a nonequalized coupler: Over the range shown, the variation is more than 2 db. Essentially the same structure combined as shown in FIG. 5 exhibits a measured response as depicted by the curve 146. The ripple, or variation, over a more than 2.75 ratio frequency range is within 0.06 db. and represents substantially an order of magnitude improvement over the best presently known prior art, even the examples thereof utilizing complex multisectional directional couplers. Furthermore, importantly, the extremely flat response is achieved without compromise to the VSWR or directivity of the coupler function.

The equalized coupler combination also provides the refinement and versatility, discussed earlier hereinafter, to the coupler art; for example, it is, herewith, a relatively simple matter to tune the equalizer parameters to provide a predetermed slope in the amplitude characteristic to compensate for the response characteristic of a crystal detector which is coupled to the "coupled" port output 20'.

There have thus been disclosed and described a number of examples of microwave attenuation apparatus which achieve the objects and exhibit the advantages set forth earlier hereinafore.

We claim:
1. Frequency sensitive attenuation apparatus of the character exhibiting a frequency band of operation extending between a lower band edge, an upper band edge, and having at least one midband frequency, the apparatus comprising:
   a body member;
   input and output signal terminal means, each sharing common terminal means connected electrically to said body member;
   a length of transmission line means intercoupled between said input and output terminal means and including at least two coupling points therealong defining a transmission line mid segment therebetween having a length of approximately one-quarter wavelength, said transmission line having a predetermined characteristic impedance;
   absorptive loss means including at least two absorptive loss elements;
   loss connecting means coupled to said absorptive loss elements and disposed contiguously to and electromagnetically coupled to each of said coupling points on said transmission line means; and
   resonant stub line means including at least two resonant stubs, each stub coupled to respective ones of said absorptive loss elements for providing effective coupling of said absorptive loss elements to said transmission line means, said resonant stubs having an effective electrical length to selectively disconnect and connect said absorptive loss means from and to said transmission line means at frequencies of said band edges and at least one midband frequency, a predetermined portion of said transmission line means being partially shunted by said absorptive loss means depending upon the ratio of the magnitude of said predetermined characteristic impedance to that of said absorptive loss means and upon the frequency of the incident microwave energy.
2. The invention according to claim 1, which further includes first impedance adjusting means coupled to said line midsegment and moveably carried by said body member for controlling the magnitude of said predetermined impedance and thereby controlling said predetermined proportion of shunting and absorption of the incident energy.
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3. The invention according to claim 2 which further includes second impedance adjusting means moveably carried by said body member and coupled to said input and output transmission line segments for controlling the magnitude of the characteristic impedance of the characteristic impedance thereof to minimize further said impedance discontinuities.

4. The invention according to claim 1 in which said transmission line means includes an input segment interposed between said mid segment and said input signal terminal means and an output segment interposed between said mid segment and said output terminal means and which further includes impedance transformer means disposed between said mid segment and the other said segments to minimize impedance discontinuities seen at said input and output terminal means.

5. The invention according to claim 1 which further includes tuning means moveably affixed to said body member and electromagnetically coupleable to said resonant stub line means for distorting the microwave current distribution along the length thereof to tune said effective electrical length for frequencies of incident microwave energy spectrally contiguous to a first of said band edges while not substantially affecting said current distribution associated with frequencies spectrally near the other said band edge.

6. The invention according to claim 5 in which said tuning means includes a first reactance element disposed a predetermined integer number of quarter-wavelengths, at the frequency of one said band edge, from an end of said resonant stub line means; and a second reactance element disposed predetermined number of quarter wavelengths at the frequency of the other said band edge, from said end of said resonant stub line means.

7. The invention according to claim 1 which further includes radiofrequency directional coupler apparatus having input and coupled output port means, said input signal terminal means being coupled in radiofrequency energy receiving relation to said coupled output port means.

8. Frequency sensitive attenuation apparatus of the character exhibiting a frequency band of operation extending between a lower band edge, and upper band edge, and having at least one midband frequency, the apparatus comprising:

a body member;

input and output signal terminal means, each sharing common terminal means connected electrically to said body member;

a length of transmission line means intercoupled between said input and output terminal means and including at least two coupling points therealong defining a transmission line mid segment therebetween having a length of approximately one-quarter wavelength, said transmission line having a predetermined characteristic impedance;

absorptive loss means including at least two absorptive loss elements;

loss connecting means coupled to said absorptive loss elements and disposed contiguously to and electromagnetically coupleable to each of said coupling points on said transmission line means; and resonant means including at least two resonant elements, each element coupled to respective ones of said absorptive loss elements for providing effective coupling of said absorptive loss elements to said transmission line means, said resonant elements having an effective electrical characteristic to selectively disconnect and connect said absorptive loss means from and to said transmission line means at frequencies of said band edges and at least one midband frequency, a predetermined portion of said transmission line means being partially shunted by said absorptive loss means depending upon the ratio of the magnitude of said predetermined characteristic impedance to that of said absorptive loss means and upon the frequency of the incident microwave energy.

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