United States Patent

[11] 3,617,955

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[54] TEMPERATURE COMPENSATED STRIPLINE FILTER

9 Claims, 8 Drawing Figs.

[52] U.S. Cl. ..... 333/73 S, 333/84 M

[51] Int. Cl. H03h 7/02, H05k 1/00

[50] Field of Search ..... 333/84, 84 M, 73 C, 73 W, 6; 334/78; 310/8.9

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Primary Examiner—Herman Karl Saalbach
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ABSTRACT: In a stripline filter that comprises a resonant length of stripline, the dielectric material is selected to have a dielectric constant with a negative temperature coefficient that is a direct function of the coefficient of linear thermal expansion of the stripline structure thereby substantially offsetting the frequency shifts caused by thermal expansion.

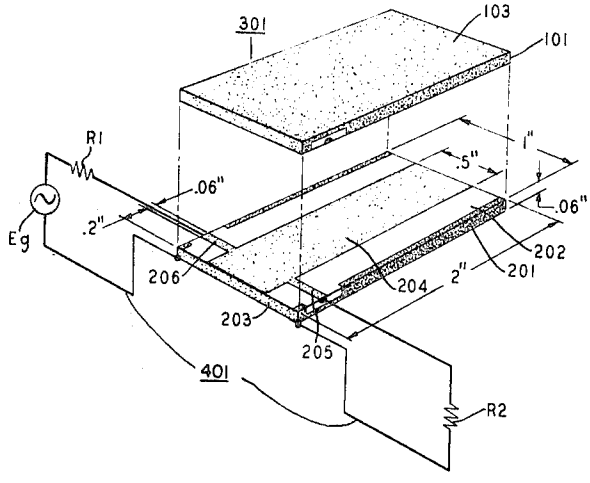


FIG. 1

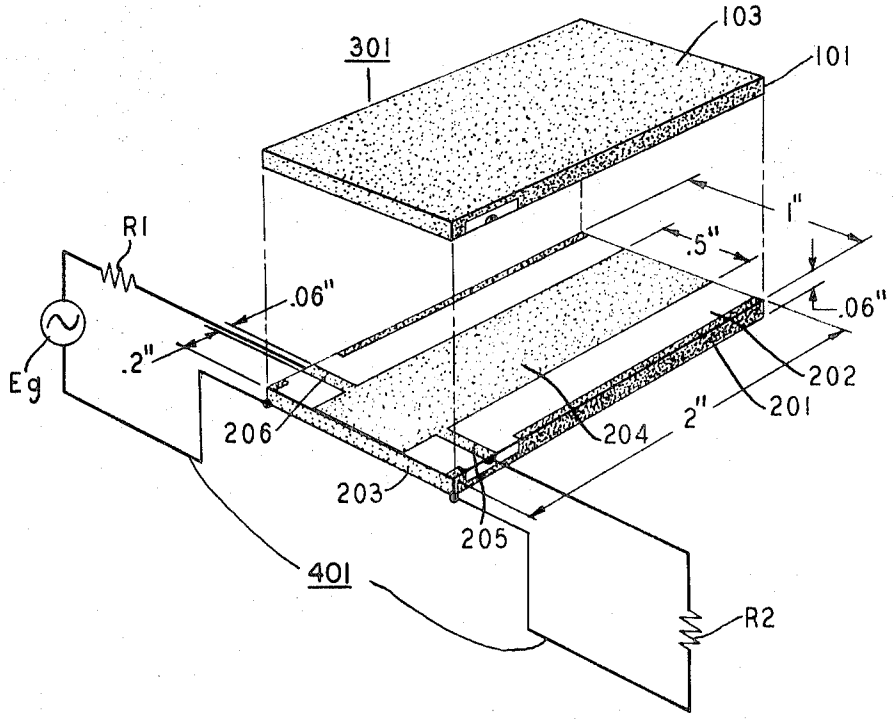
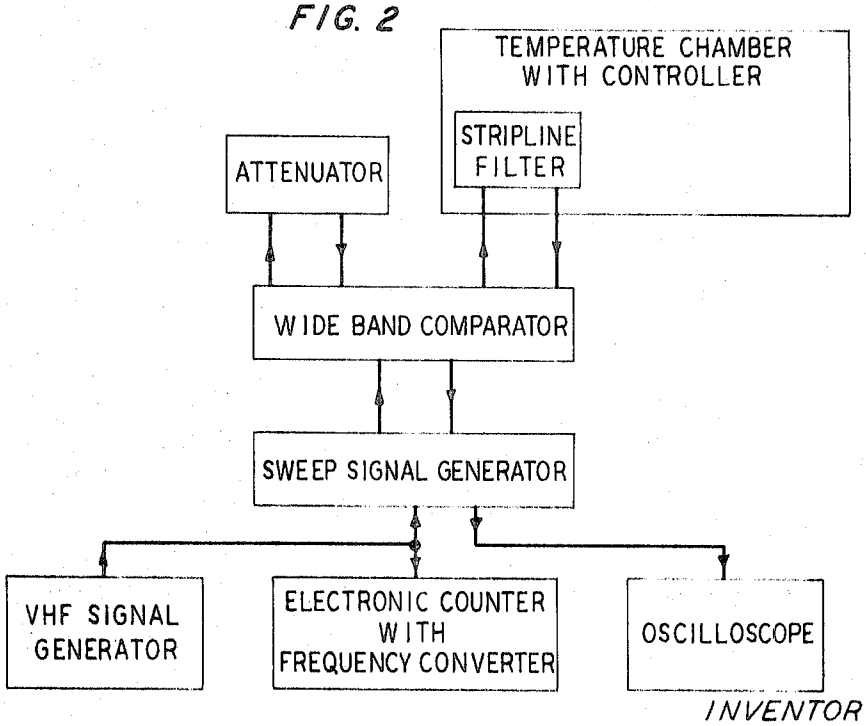


FIG. 2



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FIG. 3

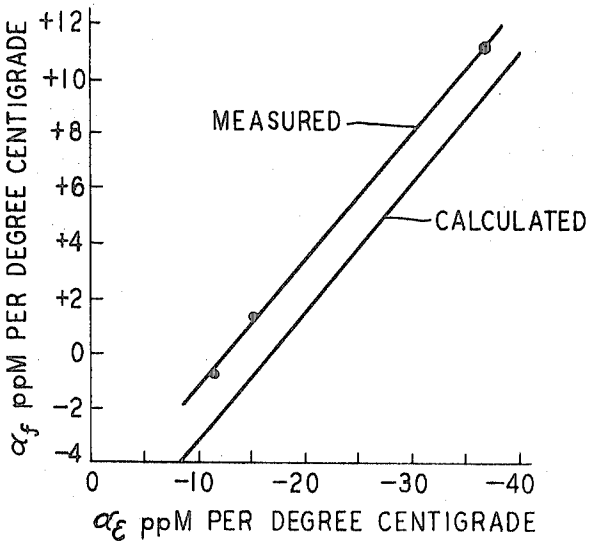


FIG. 4

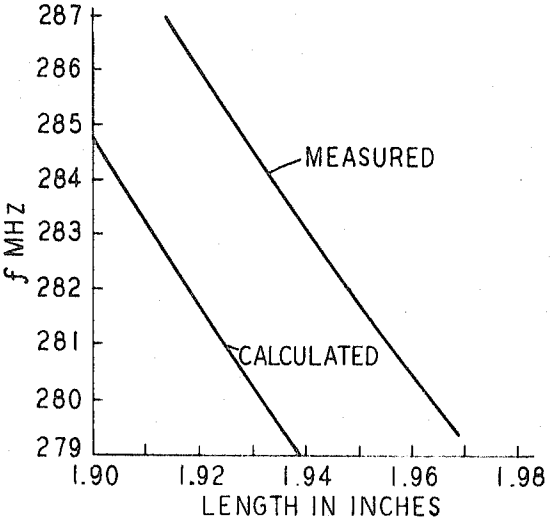


FIG. 5

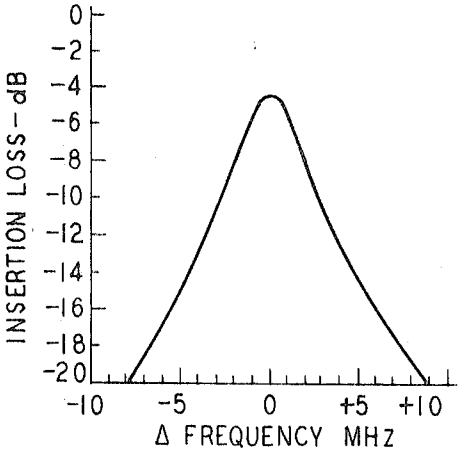


FIG. 6A

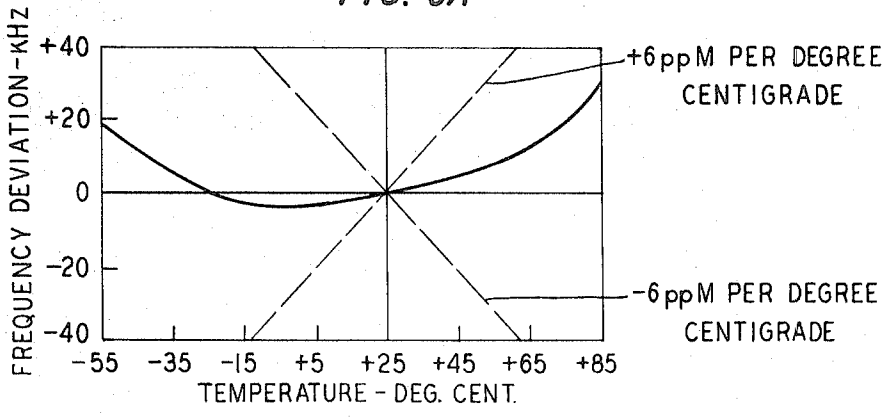


FIG. 6B

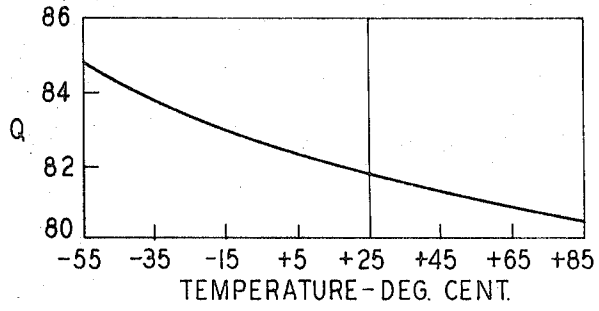
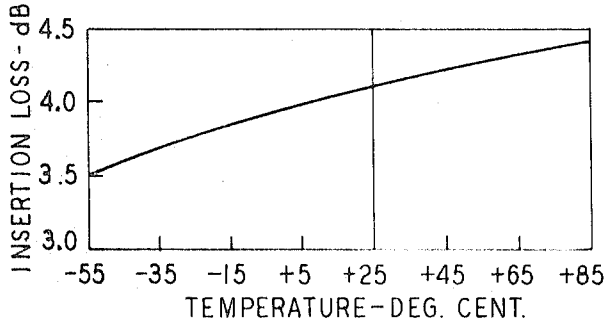


FIG. 6C



TEMPERATURE COMPENSATED STRIPLINE FILTER

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to stripline filters and, more particularly, to such filters that include means for compensating for temperature-induced frequency shifts.

2. Description of the Prior Art

Virtually all forms of electrical communication require the capability of transmitting or receiving a relatively narrow band of frequencies while simultaneously suppressing all other frequencies. To meet this need, a wide variety of filters has been developed, including lumped element LC filters for use at lower frequencies as well as coaxial lines, strip transmission lines and conductively bounded waveguide structures for use at higher frequencies.

The current trend in VHF-UHF communication circuits, including circuits requiring filters, is in the direction of integrated or thin film circuit technology, owing to the significant advantages provided thereby in terms of enhanced uniformity in fabrication an marked reduction in size. Both of these advantages are critically important at higher frequencies in view of the severe restrictions imposed on parasitics and signal path lengths by design parameters which typically call for the limitation of phase shifts to within a fraction of a degree. Although most conventional filters, owing to the very nature of their structures, are essentially incompatible with the newer microelectronic technology, one exception is provided by stripline filters which are well adapted to combinations with both thin film and integrated circuitry.

Stripline filters are ideally formed from a combination of two dielectric wafers each coated on one side and on one end with a conductive layer. On the opposite side each wafer is coated with a longitudinal thin conductive strip and a connecting pair of transverse conducting tabs. The filter is assembled by superimposing the wafers with the respective strips and tabs aligned and in intimate contact. One illustrative filter of this type is disclosed by J. J. Golembeski in his U.S. Pat. application, Ser. No. 645,376, filed June 12, 1967.

A basic problem that limits the full exploitation of the advantages of stripline filters is that of temperature instability, although this problem has been met in part in the prior art by taking elaborate precautions to ensure that precisely equal amounts of conductive material are deposited on both sides of each wafer, thereby to cancel out the frequency shifts that would otherwise result from uneven, temperature-induced individual wafer flexure. This expedient, however, does not compensate for frequency shifts that result from temperature-induced expansions and contractions in the wafer size. One known means of compensating for this latter effect is to terminate the open end of the filter by a capacitor that has a temperature coefficient opposite to that of the basic filter structure. This solution is far from ideal, however, owing to the fact that it complicates the filter structure and, even more importantly, after the filter is fully assembled, it is impossible to employ the very useful technique of adjusting the midband frequency by grinding away small amounts from the open end of the line.

Accordingly, a general object of the invention is to improve the selectivity and temperature stability of stripline filters.

SUMMARY OF THE INVENTION

The foregoing object and additional objects are achieved in accordance with the principles of the invention by a stripline filter in which temperature-induced changes in the frequency characteristics of the filter are either eliminated or markedly reduced by the employment of a temperature compensating dielectric material having a dielectric constant with a negative temperature coefficient. More specifically, in accordance with the principles of the invention, it can be shown that ideal temperature compensation in a stripline filter is achieved if the temperature coefficient of the dielectric constant is a direct function, namely, twice the absolute value, of the coefficient of linear thermal expansion of the stripline structure.

In accordance with the invention, specific materials have been discovered which, when employed in the construction of a stripline filter, provide the desired temperature coefficient relation. Such materials include ceramics whose chief constituents are barium titanate and barium zirconate. These ceramics have the additional advantage of exhibiting virtually no change with age in properties of interest. Moreover, such material provides a suitable substrate for thin film or integrated circuitry and, as a result, a filter in accordance with the invention is readily adapted for combination with microelectronic circuit forms. X

Brief Description of the Drawing

FIG. 1 is an exploded perspective view of a stripline filter in accordance with the invention in combination with an illustrative schematic circuit diagram of filter input and output circuitry;

FIG. 2 is a block diagram of a combination of test equipment employed for taking measurements of a stripline filter in accordance with the invention;

FIG. 3 is a plot of temperature-coefficient-of-frequency versus temperature-coefficient-of-dielectric-constant for stripline filters in accordance with the invention;

FIG. 4 is a plot of frequency versus length for a stripline filter in accordance with the invention;

FIG. 5 is a plot of insertion loss versus frequency for a stripline filter in accordance with the invention;

FIG. 6A is a plot of frequency deviation versus temperature for a stripline filter in accordance with the invention;

FIG. 6B is a plot of Q versus temperature for a stripline filter in accordance with the invention; and

FIG. 6C is a plot of insertion loss versus temperature for a filter in accordance with the invention.

Detailed Description

As shown in FIG. 1, a filter **301** in accordance with the invention includes a combination of two substantially identical wafers **101** and **201** and, accordingly, only the lower wafer **201** will be described in detail. The main body portion **202** is a nonconductive substrate which, ideally, should be lossless and should exhibit no variation in length or dielectric constant with temperature changes. To ensure compatibility with integrated circuitry, the material should also be suitable as a substrate for associated thin film circuit patterns. Additionally, it is desirable for the substrate to have a large dielectric constant.

It should be noted at this point that all known substrate or dielectric materials are "nonideal" in that they are, in fact, temperature dependent both as to length and as to dielectric constant. The principles of the invention, however, provide the means for offsetting the effects of the dependency indicated and of approximating the ideal case to an extent limited only by the prevailing state of the art in material fabrication technology and measurement.

The bottom surface of the wafer **201**, which corresponds to the top surface of the wafer **101**, is coated with a conductive film **103** which is extended around the cover end **203**. The top surface of the substrate **202** is covered in part by a longitudinal strip of conductive film **204** and by integral transverse connecting tabs **205** and **206**. The conductive film may be formed by any one of a number of processes as by depositing a thin layer of copper, for example. When the filter **301** is assembled, the two wafers **101** and **201** are placed in aligned juxtaposition so that the copper strips **204**, **205** and **206** on each of the wafers are in alignment and in intimate contact with the corresponding portions of the other wafer. In its assembled condition, the filter **301** has a slight air gap, not shown, between the dielectric or substrate portions **202** of the two wafers, which gap is roughly equal to twice the thickness of the deposited copper strips **204**. A typical thickness for this gap is on the order of 0.0004 inches. The gap may be filled with a suitable low-loss material. Other illustrative dimensions in inches are shown in FIG. 1.

The circuit **401** in which the filter **301** is shown connected in FIG. **1** includes a signal source E_g which applies an input by way of a resistance **R1**. The filter output is applied across a load **R2**. Input and output connections to the filter are made by way of the tabs **206** and **205**, respectively. Although substantially smaller in size, the filter structure is the equivalent of a resonant quarter wavelength air dielectric transmission line section.

The point of attachment of the tabs **205** and **206**, for specified termination impedances, establishes the loaded Q of the filter. Moving the tabs nearer the shorted end raises the loaded Q but also raises the insertion loss at the center frequency since Q and insertion loss are related as follows:

$$IL = -20 \log (1 - {}^{Q}L/Q_O), (1)$$

where

IL = insertion loss at center frequency

Q_O = unloaded Q of the filter

Q_L = loaded Q of the filter.

A postassembly adjustment of the midband frequency of the stripline filter may be accomplished by grinding away a small amount from the open end of the line.

In accordance with the invention, a particular approach in investigating the parameters that contribute to the temperature dependency of the center frequency of prior art filters provides insight into the problem of determining the conditions required to produce a filter with a temperature coefficient with respect to frequency that approaches 0. Assuming that the central conductor is totally immersed in dielectric which fills the space between ground planes of infinite extent, it is know that the velocity of propagation in a stripline filter may be expressed as

$$v = C/\epsilon X ½, (2)$$

where

C = velocity of electromagnetic wave propagation in a vacuum

ϵ = relative dielectric constant of the medium.

Thus the frequency f for which the length, l, is one-quarter wavelength is

$$f = C/4l\epsilon ½ (3)$$

The rate of change of frequency with respect to temperature, T, will be

$$\frac{df}{dT} = -f\left(\frac{1}{2\epsilon}\frac{d\epsilon}{dT} + \frac{1}{l}\frac{dl}{dT}\right). \quad (4)$$

Substituting the temperature coefficient of frequency,

$$\alpha_f \equiv \frac{1}{f}\frac{df}{dT},$$

the temperature coefficient of the dielectric constant,

$$\alpha_\epsilon \equiv \frac{1}{\epsilon}\frac{d\epsilon}{dT},$$

and the coefficient of linear thermal expansion of the stripline structure,

$$\alpha_l \equiv \frac{1}{l}\frac{dl}{dT},$$

equation (4) can be written as

$$\alpha_f = -\frac{1}{2}\alpha_\epsilon - \alpha_l. \quad (5)$$

If $\alpha_f = 0$ then $\alpha_\epsilon = -2\alpha_l$.

From the foregoing, it can be concluded that if α_ϵ can be chosen to be negative and twice the value of α_l, the resonant frequency will necessarily be independent of temperature. Although the dimensional changes of the line depend upon the mechanical properties of the conductor material as well as those of the dielectric material in a stripline filter in accordance with the invention, the dielectric has a far greater cross section and hence its expansion properties predominate. For practical purposes, it is a valid conclusion, therefore, that in a stripline filter, frequency dependence on temperature may be substantially eliminated by selecting a dielectric with the temperature coefficient of the dielectric constant conforming to the requirements indicated.

In accordance with he invention, it has been found that ceramics whose chief constitutes are barium titanate and barium zirconate have the necessary properties to provide stripline filter substrate wafers with dielectric-constant temperature-coefficients that eliminate temperature dependence of the resonant frequency through a useful filter frequency range. One such material is identified as the NPOOO-A ceramic of the American Lava Corporation. Moreover, ceramics whose chief constitutes are barium titanate and barium zirconate are commonly employed in the manufacture of ceramic capacitors, and the temperature coefficient of capacitance can be adjusted in a known manner by changes in the formulation of the ceramic. Suitable dielectric material having the following illustrative ranges of properties has been fabricated.

	Maximum Variation from Nominal	Average Variation	Maximum Variation within a Lot
ϵ	31±4	±2	±0.6
α_ϵ	(−15±10)×10 ^{6}/° C	±10×10 ^{6}/° C	±5×10 ^{6}/° C
α_l	(10.2±5)×10 ^{6}/° C	±0.5×10 ^{6}/° C	±0.5×10 ^{6}/°C

The FIGS. for variation within a particular lot represent the limiting accuracy of instrumentation. Additionally, it should be noted that the coefficient of linear expansion α_l listed in the above table is based on measurements made at 25° C. and 1,000° C. For the range of temperature near room temperature, the measured value is 8.4×10^{16}/° C.

The properties of primary interest are the maximum variation from nominal of α_ϵ and α_l, since these determine the deviation from a_f=0 which must be tolerated and the variation within a particular lot of ϵ, since this variation sets a maximum on the amount of frequency adjustment needed.

From equation (5) a variation of $\pm10\times10^{-6}$/° C. in α_ϵ will result in a variation of $\pm5\times10^{-6}$/° C. in a_f. An additional $\pm0.5\times10b^{-6}$/° C. variation in a_f will result from the $\pm0.5\times10^{-6}$/° C. variation in α_l. Thus a proper choice of the nominal value of α_ϵ will result in a variation of $\pm5.5\times10^{-6}$/° C. in a_f which must be tolerated.

The center frequency of a filter in accordance with the invention is finally set by an adjustment in the filter length. Solving equation (3) for l gives $l = C/4f\epsilon ½$; (6)

and for a constant f

$$dl = -l/2\epsilon d\epsilon. (7)$$

Thus an uncertainty of 1.2 in ϵ as shown in the table requires grinding the open circuit end of the line a maximum of 0.038 inch for some fixed length in the neighborhood of 2 inches to yield an exact 283 mHz. center frequency.

Although stripline filters in accordance with the invention may be fabricated by a variety of methods, one method found to be effective is as follows: The ceramic plates or wafers are cleaned by scrubbing in a detergent solution, followed by rinsing in water and then in acetone. Copper is vacuum evaporated onto the ceramic to a thickness in excess of 1,500 A and then electroplated to a thickness of 0.001 inch. To form the center strip and tabs shown in FIG. **2**, the excess copper is removed by etching.

The plates may be cemented together with epoxy or other suitable adhesive along the edges and center of the copper strip. One adhesive material found to be particularly effective was bis-phenol A polycarbonate produced by the Mobay

Chemical Company. The polycarbonate is applied as a chloroform solvent lacquer to both of the copper surfaces to be joined. After vacuum drying to assure that no solvent remains, the plates are joined by heat sealing.

Apparatus employed in measuring the characteristics of a filter constructed as above is shown schematically in FIG. 2. The measuring process involves primarily the use of a sweep generator, an oscilloscope and an attenuator. During the measurements the stripline filter is placed within a temperature variable chamber. This technique permits the determination of the center frequency, bandwidth and insertion loss of the filter over the appropriate temperature range.

Filters have been constructed from three groups of ceramic material with slight different α_ϵ, and measurements made over the temperature range of −55° C. to +85° C. show an essentially linear frequency change with temperature. FIG. 3 shows the measured temperature coefficient of frequency a_f as a function of the temperature coefficient of the dielectric constant α_ϵ. Note that the value of α_ϵ equals -13×10^{16}/° C. for $a_f=0$ differs slightly from the predicted value of α_ϵ equals -16.8×10^{16}/° C., based on $\alpha_l = 8.4\times10^{16}$/° C. This difference is attributable to the fact that the center conductor is not completely immersed in the dielectric material. The airgap through which the fringing field passes increases slightly as the adhesive expands from increasing temperature, thus raising both the transmission velocity and the center frequency.

The plot of FIG. 4 shows the results of successive measurements taken after each reduction of the filter length by grinding the open end. A curve based on the relation of equation (3) and the measured dielectric constant for the material is also used for comparison, and the measured frequency, as indicated, is slightly higher than the predicted frequency, owing to the airgap in the measured filter. In adjusting these filters to particular frequency, it was found that the removal of each 0.001 inch from the open circuit end raised the frequency by 15 kHz.

For one filter constructed in accordance with the invention employing ceramic material with $\alpha_\epsilon = -12\times10^{16}$/° C., the 25° C. insertion loss versus frequency between 50 ohm terminations was measured. The results are illustrated by the plot of FIG. 5. The insertion loss at the center frequency is 4.1 db. and the Q is 81.6, which indicates an unloaded Q of the filter of 217. For the filter indicated, FIGS. 6A, 6B and 6C show the center frequency deviation, the Q, and the insertion loss, respectively, plotted against temperature from −55° to +85° C. The overall temperature characteristic of the center frequency has some upward curvature at both ends of the temperature range which corresponds to the downward curvature of the dielectric constant of polycarbonate at these temperatures. The deviation, however, is well within the ±6 p.p.m./° C. which was established as an acceptable range.

It is to be understood that the embodiment described herein is merely illustrative of the principles of the invention. Various modifications thereto may be effected by persons skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A stripline filter comprising a combination of dielectric material supporting a plurality of conductive paths, the length of said filter being inversely proportional to the product of the square root of the dielectric constant of said dielectric material and the frequency of said filter, wherein the temperature coefficient of the dielectric constant of said dielectric material is negative and is substantially twice the absolute value of the coefficient of linear thermal expansion of the overall structure of said filter.

2. Apparatus in accordance with claim 1 wherein said dielectric material is a ceramic.

3. Apparatus in accordance with claim 2 wherein the chief constitutes of said ceramic are barium titanate and barium zirconate.

4. A stripline filter comprising, in combination, a pair of dielectric wafers each having a coating of conductive material on one side and on one end thereof; a longitudinal conductive strip and a connecting pair of transverse conductive tabs on the other side thereof; said wafers being placed in juxtaposition with said strip and said tabs on each of said wafers being in registry an in intimate contact with said strip and said tabs on the other of said wafers; the length of said filter being inversely proportional to the product of the square root of the dielectric constant of the material of said wafers and the frequency of said filter; said material of said wafers having a temperature coefficient of its dielectric constant that is negative and substantially equal in absolute value to the absolute value of twice the coefficient of linear thermal expansion of the overall structure of said filter.

5. Apparatus in accordance with claim 4 wherein the material of said dielectric wafers comprises a ceramic having barium titanate and barium zirconate as the chief constituents thereof.

6. Apparatus in accordance with claim 4 wherein the chief constituents of said ceramic material are barium titanate and barium zirconate.

7. Apparatus in accordance with claim 5 wherein the chief constituents of said ceramic material are barium titanate and barium zirconate.

8. A stripline filter comprising a pair of superimposed dielectric wafers composed of a ceramic material, the length of said filter being inversely proportional to the product of the square root of the dielectric constant of said ceramic material and the frequency of said stripline filter, wherein the temperature coefficient of dielectric constant of said ceramic material is negative and is substantially twice the absolute value of the coefficient of linear thermal expansion of the overall structure of said filter.

9. Stripline filter comprising a combination of dielectric material and pairs of conducting material, wherein the length of said stripline filter is inversely proportional to the product of the square root of the dielectric constant of said dielectric material and the frequency of said filter, said dielectric material being composed of a ceramic material whose temperature coefficient of dielectric constant is negative and is substantially twice the absolute value of the coefficient of linear thermal expansion of the overall structure of said filter.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,617,955 Dated November 2, 1971

Inventor(s) Joel C. Masland

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 21, change "an" to --and--.

Column 2, line 11, delete "X".

Column 3, line 15, change "^{Q}L" to --Q_L--;

line 35, change "C/εX1/2" to --$C/\varepsilon^{1/2}$--.

Column 4, line 10, change "he" to --the--;

lines 11 and 18, change "constitutes" to --constituents--;

line 35, change "FIGS." to --figures--;

line 40, change "10^{16}" to --10^{-6}--;

line 48, change "$10b^{-6}$" to --10^{-6}--;

Column 5, line 21, change "16/°C" to -- -6/°C--, both occurrences;

line 39, change "10^{16}" to --10^{-6}--.

Claim 3, line 13, change "constitutes" to --constituents--.

Claim 4, line 21, change "an" to --and--.

RM PO-1050 (10-69)

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* U.S. GOVERNMENT PRINTING OFFICE : 1969 O—366-334

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,617,955 Dated November 2, 1971

Inventor(s) Joel C. Masland PSH PAGE - 2

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Claim 6, line 34, change "4" to --8--.

Claim 7, line 37, change "5" to --9--.

Claim 9, line 49, change "Stripline" to --A stripline--.

Signed and sealed this 30th day of May 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

ORM PO-1050 (10-69)

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