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[54] **TEMPERATURE-COMPENSATED WAVEGUIDE**
RESONATOR
2 Claims, 5 Drawing Figs.

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H03n 13/00, H01p 1/30
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834, 82, 83 T, 73 W, 73

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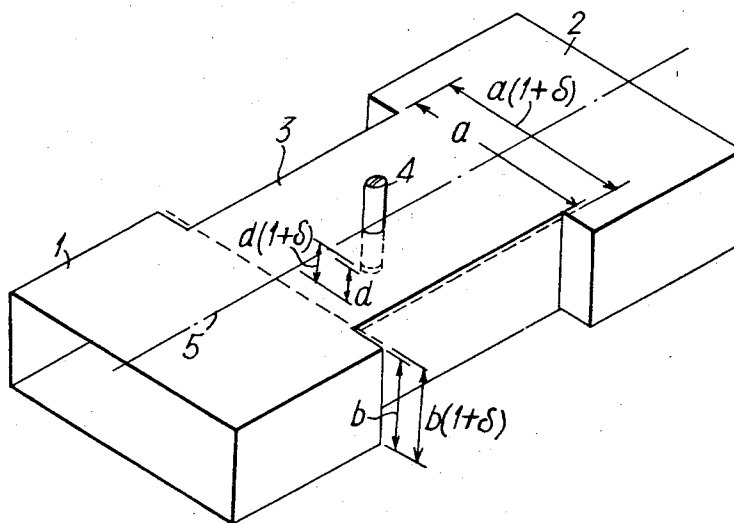
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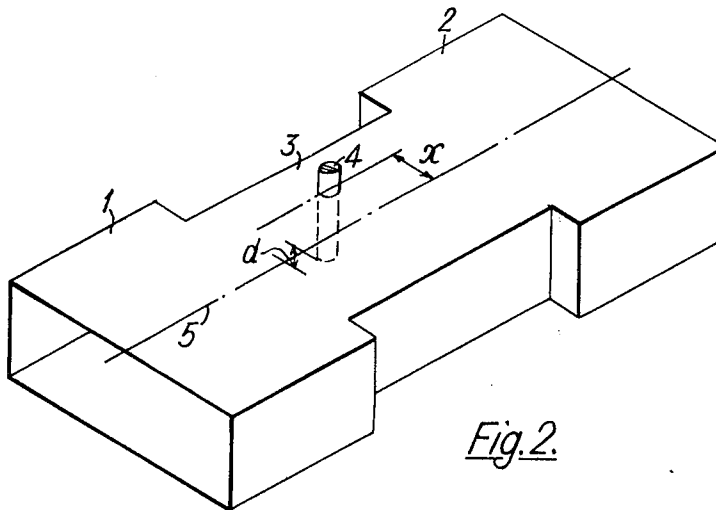
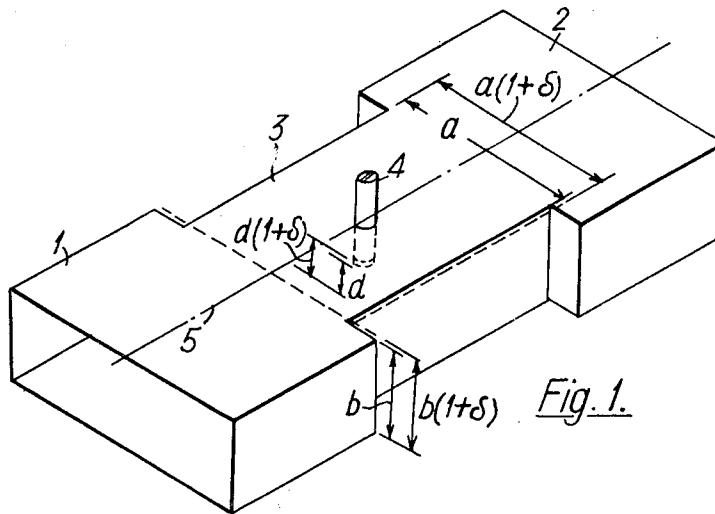
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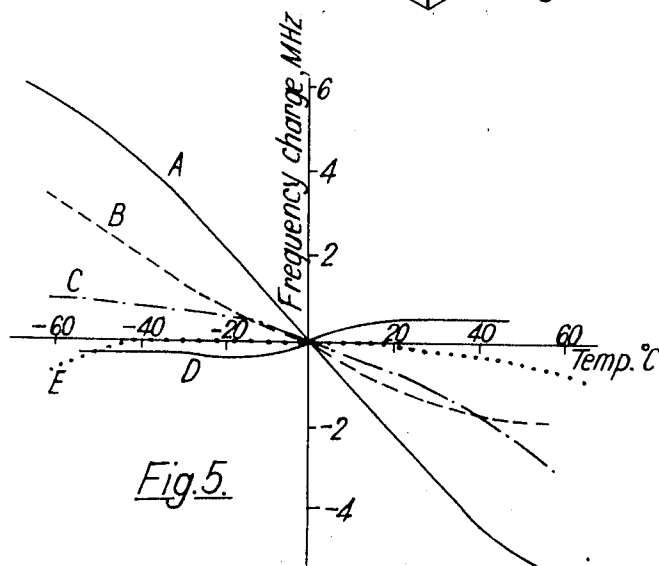
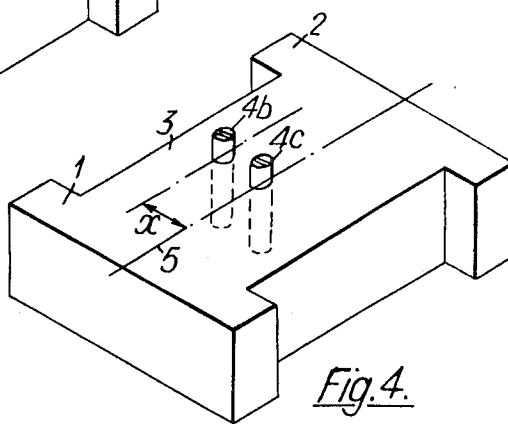
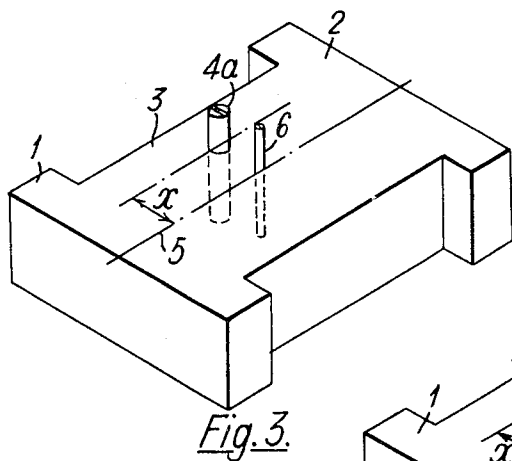
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ABSTRACT: An evanescent H-mode rectangular waveguide resonator having a tuning screw mounted on one broad wall is temperature compensated by having said screw physically penetrate close to the opposite broad wall of said waveguide. Said penetration provides significant end-loading capacitance. In one preferred embodiment, said screw is offset from the longitudinal centerline of said waveguide to achieve both the required tuning capacitance and the required penetration. In another preferred embodiment, to further improve temperature compensation, a silver-plated Swedish iron screw having a lower coefficient of expansion than the material of the waveguide, (i.e., copper) penetrates close to the opposite broad wall.





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TEMPERATURE-COMPENSATED WAVEGUIDE RESONATOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to temperature compensation of waveguide resonators.

2. Description of the Prior Art

Conventional resonant waveguide cavities are relatively temperature sensitive and where high temperature-frequency stability is necessary, it becomes essential to employ as the manufacturing material a metal with a very low thermal coefficient of expansion, such as a nickel steel invar. This is a relatively expensive material which is also difficult to work. Said disadvantages add significantly to the cost of producing a resonator.

SUMMARY OF THE INVENTION

It is an object of the invention to provide an improved evanescent H-mode waveguide resonator.

According to the invention there is provided a temperature-compensated resonator comprising a section of evanescent H-mode waveguide and capacitive screw-tuning means for providing significant end-loading capacitance.

BRIEF DESCRIPTION OF THE DRAWINGS

The above-mentioned and other objects of this invention will become apparent by reference to the following description in conjunction with the accompanying drawings, in which:

FIG. 1 shows an evanescent mode rectangular waveguide resonator with a single capacitive tuning screw on the longitudinal centerline of the guide,

FIG. 2 shows an evanescent mode rectangular waveguide resonator with a single capacitive tuning screw offset from the longitudinal centerline of the guide,

FIG. 3 shows one arrangement of an evanescent mode rectangular waveguide resonator with two capacitive tuning screws,

FIG. 4 shows an alternative arrangement of an evanescent mode rectangular waveguide resonator with two capacitive tuning screws,

FIG. 5 shows frequency change vs. temperature characteristics for various types of waveguide resonators.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

For the purpose of this specification, an evanescent H-mode waveguide resonator is defined as a length of rectangular waveguide which has a cutoff frequency above the frequency of the incident H-mode and has capacitive tuning screw means extending into the guide from a broad wall of the guide.

Evanescent mode waveguide cavities function on different principles, as described in "Waveguide Band-pass Filters using Evanescent Modes," G. F. Craven, Electronics Letters, Vol. 2, No. 7, July 1966, pp 25-26, and therefore their frequency-temperature dependence is also different.

Referring to FIG. 1, energy present in the dominant H₀₁ mode in propagating waveguide 1 is transferred to propagating waveguide 2 by evanescent mode cavity 3 having a capacitive tuning screw 4 on the longitudinal centerlines 5 of the guide.

The resonant frequency of an evanescent mode cavity is determined by the conjugate match condition, i.e., the capacitive reactance, of the obstacle in the guide, the screw 4, must be equal, but opposite in sign, to the inductive characteristic of the guide. The resonant frequency, f_0 , is then given by

$$f_0 = (1/2\pi Z_0 C_0) \quad (1)$$

The resonant frequency is independent, to a first order, of the guide length and merely depends on the cross-sectional dimensions. This, of course, assumes that the value of C_0 is temperature invariant, an assumption which simplifies the

preliminary analysis. The effect of the variation of C_0 with temperature will be considered later.

The characteristic impedance of waveguide in the H₀₁ rectangular guide is given by

$$Z_0 = \frac{bA}{a\sqrt{1 - (\lambda/\lambda_c)^2}} \quad (2)$$

where

a = guide width

b = guide height

λ = free space wavelength

λ_c = cutoff wavelength = $2a$

A = constant

In the present application, $\lambda/\lambda_c > 1$ and therefore Z_0 is imaginary. Equation (1) is derived on this basis and only the value of $|Z_0|$ is required. Therefore $\sqrt{-1}$ will be dropped from the following mathematical analysis.

Rearranging equation (2) and introducing δ , the fractional change in dimensions resulting from temperature change, the resulting characteristic impedance Z'_0 is given by

$$Z'_0 = \frac{b(1+\delta) \cdot A}{a(1+\delta)\sqrt{\{\lambda/2a(1+\delta)\}^2 - 1}} \quad (3)$$

from equation (1) the modified resonant frequency is given by

$$f_0(1-\Delta) = \frac{a(1+\delta)a\sqrt{\{\lambda_0/2a(1+\delta)\}^2 - 1}}{b(1+\delta)2\pi C_0 \cdot A} \quad (4)$$

where λ_0 = resonant wavelength.

Assuming that δ is small and therefore squared and higher power terms can be neglected

$$f_0(1-\Delta) = \frac{a\sqrt{(\lambda_0/2a)^2 - 1 - 2\delta}}{2\pi C_0 \cdot A \cdot b(1+\delta)} \quad (5)$$

And, since $\lambda = V/f$ where V = velocity of light

$$\lambda_0(1+\Delta) = \frac{V2\pi C_0 A b(1+\delta)}{a \left[\left\{ (\lambda_0/\lambda_c)^2 - 1 \right\} \left\{ 1 - \frac{2\delta}{(\lambda_0/\lambda_c)^2 - 1} \right\} \right]^{1/2}} \quad (6)$$

Using the binomial expansion of expand the second term in braces,

$$\lambda_0(1+\Delta) = \frac{V2\pi C_0 A b(1+\delta)}{a \left\{ (\lambda_0/\lambda_c)^2 - 1 \right\}^{1/2} \left\{ 1 - \frac{\delta}{(\lambda_0/\lambda_c)^2 - 1} \right\}} \quad (7)$$

Bearing in mind that from equation (1)

$$\lambda_0 = \frac{V2\pi C_0 b A}{a \left\{ (\lambda_0/\lambda_c)^2 - 1 \right\}^{1/2}} \quad (1a)$$

we have

$$\lambda_0(1+\Delta) = \frac{\lambda_0(1+\delta)}{1 - \frac{\delta}{(\lambda_0/\lambda_c)^2 - 1}} \quad (8)$$

From small δ this is given accurately by

$$\lambda_0(1+\Delta) \approx \lambda_0 \left\{ 1 + \delta \left(1 + \frac{1}{(\lambda_0/\lambda_c)^2 - 1} \right) \right\} \quad (9)$$

Thus except for operation close to cutoff the change in wavelength $\Delta\lambda_0$ is in the range

$$\delta < \Delta\lambda_0 < 2\delta$$

This change is a result wholly of the change in the guide width and its effect on the guide characteristic impedance.

The effect of capacitance change on the resonant wavelength is straightforward and evident from equation (1a)

$$\Delta\lambda_0 = \Delta C_0 \quad (10)$$

The way in which C_0 changes depends on the type of construction employed. In the construction shown in FIG. 1, three effects occur. If the temperature increases,

- a. the length of the tuning screw increases,
- b. the guide height increases,
- c. the area of the capacitance, i.e., the cross-sectional area of the tuning screw, increases.

If the screw penetration is such that the end of the screw is remote from the opposite (bottom) guide wall, the end loading capacitance is negligible. The effect (a) will then predominate. The normalized reactance of a capacitive screw in waveguide varies in the following way

$$X_c \propto \cot \theta \quad (11)$$

where $\theta = 2\pi l/\lambda$ (l = inserted length of screw).

Thus as θ increases with temperature the reactance will fall, i.e., the effective value of C_0 increases. This change will increase the resonant wavelength, i.e., the change in wavelength resulting from the effects on capacitance and inductance will be cumulative.

If the screw end is close to the bottom guide wall the end-loading capacitance is significant. The gap, d , between the end of the screw and the bottom wall of the guide then changes to $d(1+\delta)$ as a result of the difference between the length expansion of the screw and the height expansion of the guide, for an increase in temperature. Since the guide height is the greater, if the material employed in guide and screw is the same, e.g. copper or brass, the gap increases. Considered on its own the capacitance would then tend to decrease, with a corresponding effect on the resonant wavelength. This would offset the effect of temperature on guide dimensions and their consequent effect on resonant wavelength.

The relationship between the capacitance of a parallel plate capacitor and its various parameters is given by the well-known expression.

$$C \propto (KA/d)$$

where

K = dielectric constant

A = area

d = spacing of plates

This simple relationship does not hold exactly in determining end-loading capacitance in evanescent waveguide, where d is the gap between the end of the capacitive screw and A is the cross-sectional area of the screw. For example, C. K. Mok (Electronics Letters, Vol. 4, No. 3, 9th Feb. 1968, pp. 43-44) shows that as the width (area) of a capacitive obstacle in evanescent waveguide increases it ultimately becomes an inductance. However, the area of the obstacle has an important effect and consequently this is a parameter which must be considered when the screw size to obtain an optimum penetration is chosen.

The distance d has to be quite small if the capacitance is to be significant. Obviously, the length of the screw and the guide height will then be nearly identical and, if they are of the same material, the expansions will be nearly identical. However, since the height is always marginally greater its expansion will always be greater and d will always increase. Thus, provided a suitable distance d is chosen and a suitable obstacle width is used, a certain degree of temperature compensation is obtained.

The simplest way in which d can be reduced is by offsetting the screw by a distance x from the guide center towards the guide sidewall, as shown in FIG. 2. The screw penetration will then have to be increased in order to achieve the desired susceptance. In this way an appropriate value of d can be obtained.

An alternative arrangement is shown in FIG. 3, in which there is an offset main tuning screw 4a penetrating close to the opposite (bottom) guide wall, with a fine tuning screw 6 located at the guide centerline.

A further alternative arrangement is shown in FIG. 4, in which there is an offset first main tuning screw 4b and a centerline second main tuning screw 4c. Temperature compensation is obtained by the relative penetration of the two screws.

The offset capacitive tuning screw is preferably made of a material having a lower temperature coefficient of expansion from that of the material of the waveguide. This results in a greater change in d with temperature, the differential changes in screw length and waveguide height allowing compensation to be achieved with reasonable gaps between the screw and the bottom guide wall. Otherwise the value of d tends to be rather small.

Measurements of frequency change vs. temperature for a number of conditions are shown in FIG. 5. Curve A shows the behavior of a conventional resonant cavity constructed in 2 in. $\times$ 3/4 in. copper waveguide.

Curve B represents the corresponding behavior of a 4 GHz. evanescent cavity built in X-band copper guide of 0.9 in. $\times$ 0.4 in. with a 2 BA copper tuning screw, as in FIG. 1. The value of d (0.042 in.) is in the range where some compensation is possible and some incidental compensation probably occurs.

Curve C shows the behavior of a similar evanescent mode waveguide resonator to that of FIG. 1, having a 2 BA centrally located capacitive tuning screw with the same value for d but made from silver-plated Swedish iron. Swedish iron has a lower coefficient of expansion ($12 \times 10^{-6}/^\circ\text{C.}$) than copper ($16 \times 10^{-6}/^\circ\text{C.}$).

In curve D, the 2 BA silver-plated Swedish iron screw has been located halfway between the guide center and the sidewall, as in FIG. 2. The value of d (0.028 in.) is then such that overcompensation occurs.

In curve E, a fine tuning screw (6 BA) of copper has been introduced at the center of the guide, as in FIG. 3, and the main 2 BA tuning screw of silver-plated Swedish iron withdrawn slightly, the compensation is then nearly exact.

It should be emphasized that the amount of offset of the main tuning screw and the choice of its size, i.e., its cross-sectional area, are determined largely on an experimental basis and that for example offsetting the screw halfway between the guide center and the sidewall is in no way mandatory.

The essential requirement is to so arrange the capacitive screw tuning means so as to obtain a significant end-loading capacitance, which varies with temperature in an opposite sense to the variation in the capacitance C_0 and the guide inductance, so that compensation is achieved.

We claim:

1. A temperature-compensated resonator comprising a section of evanescent H-mode waveguide and a single capacitive tuning screw on the broad longitudinal center line of said section of evanescent H-mode waveguide for providing significant end-loading capacitance, said tuning screw is of a material having a lower coefficient of expansion than that of the material of said section of evanescent H-mode waveguide.

2. A temperature-compensated resonator, according to claim 1, wherein said waveguide section is made of copper and wherein said tuning screw is made of silver-plated Swedish iron.