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**Minet et al.**

[11] **3,875,538**

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[54] **MICROWAVE BANDPASS FILTER**


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[51] **Int. Cl.** .......................... **H01p 1/20,** H01p 3/08

[58] **Field of Search** .... 333/73 C, 73 S, 84 M, 73 R, 333/84 R



[56] **References Cited**

UNITED STATES PATENTS

2,532,993 12/1950 Carter .............................. 333/73 C

3,345,589 10/1967 Di Piazza .......................... 333/73 R



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[57] **ABSTRACT**

Microwave filter of strip transmission line structure. It comprises a main rectilinear strip conductor and a plurality of open-ended strip line stubs all having one half wave length at the mid frequency of the filter and parallel-connected to the main strip conductor. The connecting points are regularly spaced apart along the main strip conductor and, on each strip line stub, they are selectively offset with respect to the midpoint of the stub.


**6 Claims, 6 Drawing Figures**

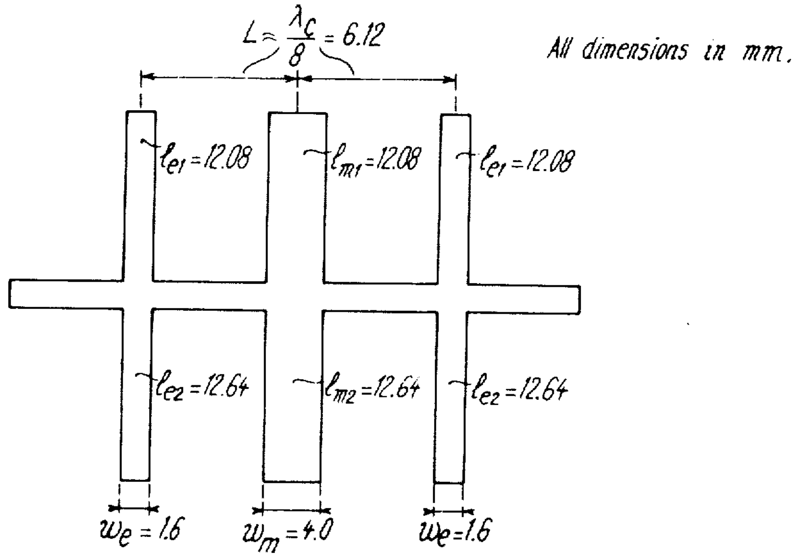


FIG.1a

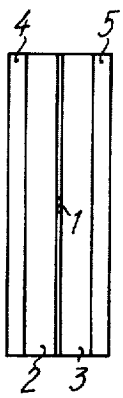



FIG.1b

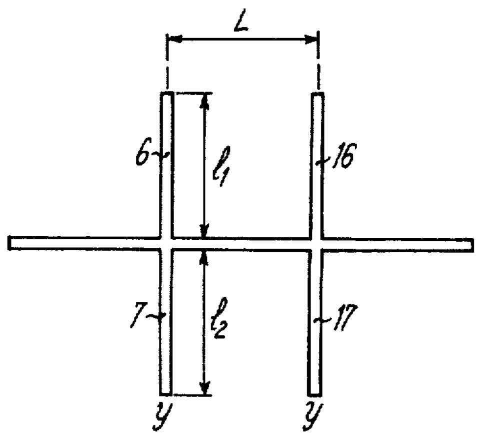
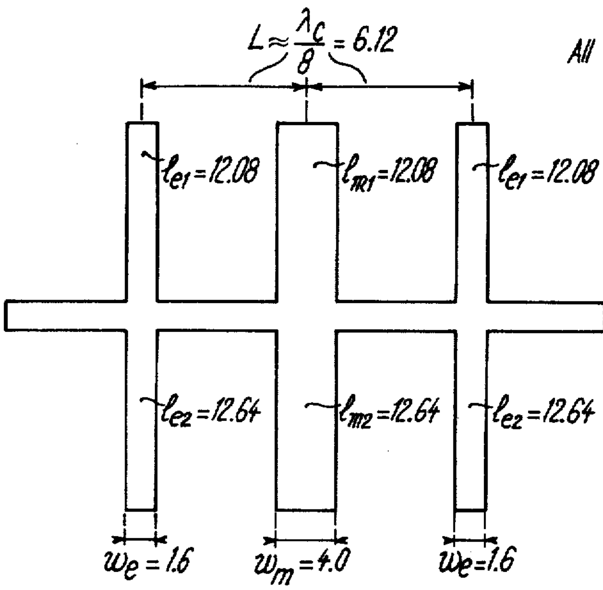



FIG.2

All dimensions in mm.



All dimensions in mm.

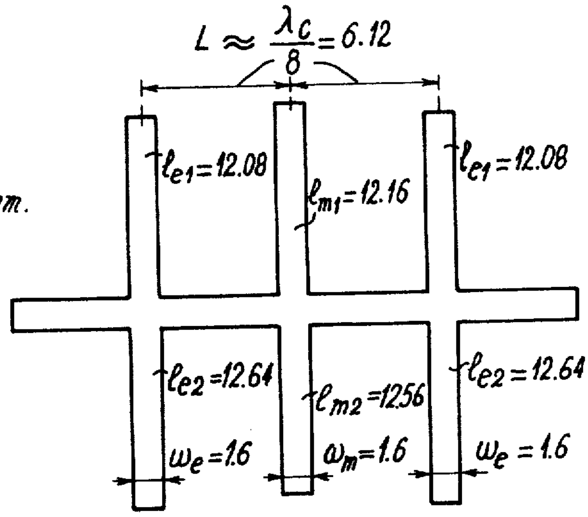



FIG. 3

All dimensions in mm.

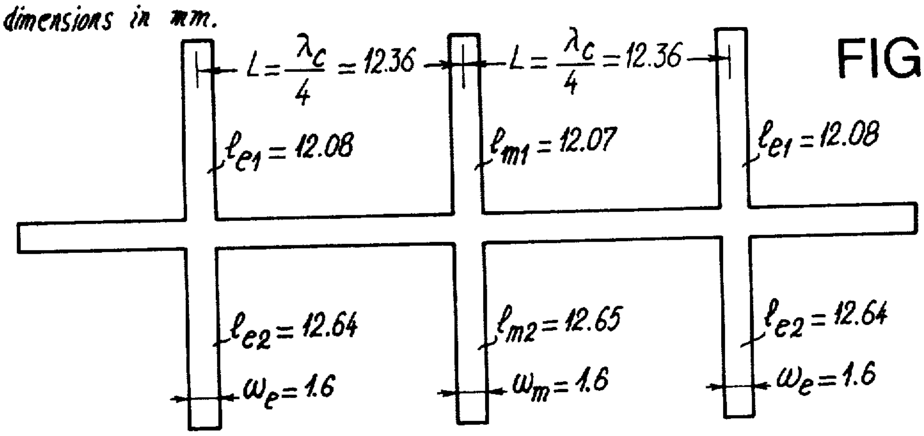



FIG. 4

All dimensions in mm.

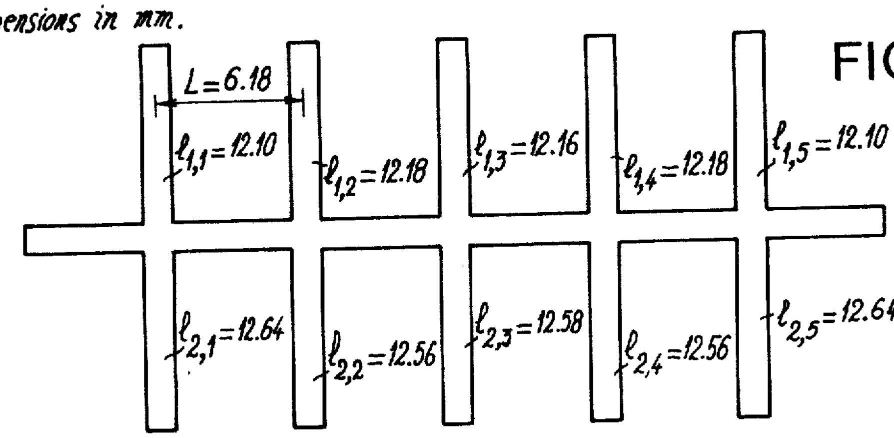



FIG. 5

## MICROWAVE BANDPASS FILTER

The present invention generally concerns microwave filters and more particularly microwave bandpass filters of strip-line structure.

Microwave filters of strip-line structure having a plurality of shunt or series quarter wavelength stubs are known in the art. The text book "Microwave Filters, Impedance-Matching Networks and Coupling Structures" by George L. MATTHAEI, Leo YOUNG and E. M. J. JONES, Mc GRAW-HILL BOOK COMPANY discloses:

- at page 595, filters using parallel short-circuited stubs that are a quarter wave long;
- at page 596, filters using series open-circuited stubs that are a quarter wave long; and
- at page 599 filters using pairs of parallel short-circuited stubs, each stub of a pair being a quarter wave long. In this latter case, the two stubs of a pair form half-wavelength long, short circuited shunt stubs connected at their middle to the connecting line.

In all these filters the connecting lines between the stubs are always quarter wavelength connecting lines. It results that the filters are physically of large size, the length of the filter being at least equal to $(n\lambda_c/4)$ where $n$ is the number of stubs and $\lambda_c$ the wavelength in the connecting line at the midband frequency of the filter.

The principal object of the invention is the provide strip-line microwave filters of compact structure.

Another object of the invention is to provide strip-line microwave filters in which the length of the connecting lines of the stubs can be predetermined at will and particularly can be taken much shorter than the quarter wavelength.

According to the invention, there is provided a microwave bandpass filter having a main strip transmission line and a plurality of open-ended half-wave strip line stubs perpendicular to the main strip line, and forming crosses with the same, spaced apart therebetween by a predetermined distance much smaller than the half-wavelength along said main line and connected in parallel to the main line, the point of connection of the stub to the main line being offset from the mid point of the stubs by predetermined quantities.

The invention will now be disclosed in detail in relation with the accompanying drawings in which:

FIG. 1*a* and 1*b* represent a two crossed cell microwave filter;

FIG. 2 represents a three crossed cell microwave filter in which the stubs are spaced by an electric spacing different from a quarter wavelength;

FIG. 3 represents a three crossed cell microwave filter with stubs of the same length but not of the same strip width;

FIG. 4 represents a three crossed microwave filter of a known type with stubs of the same strip width but not of the same length; and

FIG. 5 represents a five crossed cell microwave filter.

FIGS. 1*a* and 1*b* show a microwave filter with two crossed cells according to the invention and which comprises a main strip transmission line having a metallic strip conductor **1** bonded to dielectric sheets **2** and **3** to the other side of which are bonded metallic ground plates **4** and **5**. The two ground plates are electrically interconnected by means not shown in FIGS. **1***a* and **1***b*.



Each cell of the filter comprises a pair of arms or stubs, **6** and **7** for the first cell and **16** and **17** for the second cell, which are located on both sides of the strip transmission line **1** and connected in parallel to the same. Each of these stubs is about a quarter wavelength long and is open-circuited and the two aligned stubs of a pair form a section of strip line which is one half-wavelength long. The two stubs of a pair have not exactly the same length or in other words the strip line sections formed by the stub pairs are not connected exactly at their mid point to the main strip transmission line. The spacing length along said main line of the connection points of the stub pairs is designated by L and the choice of its value will be explained later on.

The respective lengths $l_1$ and $l_2$ of the stubs **6** and **7** are such that:

$$l_1 = l_0\,(1-\epsilon)$$
$$l_2 = l_0(1+\epsilon) \qquad (1)$$

where $\epsilon$ is a small coefficient, much lower than unity.

From the theory of radiofrequency transmission lines, the admittance $y(F)$ of the cell divided by the characteristic admittance of the main strip transmission line, that is the normalized admittance of the cell, is given by:

$$y\,(F) = \frac{2\sinh}{\mathrm{ch}\Phi + \cosh\,(\epsilon\ \Phi)} \qquad (2)$$

where:

$$\Phi = \frac{\pi}{2Q_0} + j\,\pi\ \frac{F}{F_0}$$

- F denotes frequency, $j$ is $\sqrt{-1}$ and y is the characteristic admittance of the stubs, while $\epsilon$ is the number defined by equation (1)
- $Q_0 = \pi/4\alpha l_0$ is the Q factor of the resonator formed by the cell,
- $\alpha$ being the real part of the attenuation constant
- $F_0$ denotes the resonance frequency of the cell equal to:

$$F_0 = \frac{c}{4 l_0 \sqrt{\epsilon_r}} \qquad (3)$$

$\epsilon_r$ being the relative dielectric constant and $c$ the velocity of light.

By assuming that the cells are lossless and in the vicinity of $F_0$, expression (2) can be reduced to:

$$y(F) = jB = 4jQ_G\ \frac{F - F_0}{F_0} \qquad (4)$$

where

$$Q_G = 1/\pi\epsilon^2 \qquad (5)$$

Combination of equations (4) and (5) gives:

$$y = 4(F-F_0)/\pi\epsilon^2 F_0 \tag{6}$$

Synthesis of crossed cell filters can be made either by calculating the "amplitude-frequency" response of the filter or by using the general synthesis theory of bandpass filters. The first method can be applied to the filters comprising at most three cells since farther the calculations become inextricable. Applications of the two methods are given in the following.

Let us consider a non-dissipative filter comprising two or three crossed cells separated by sections of connecting strip line, fed at its input terminals by a signal generator and connected at its output terminals to a load, the impedance of the generator and load being respectively matched to the input and output impedances of the filter, that is to the characteristic impedance of the main strip transmission line. The attenuation A is equal to the ratio of the available generator power to the power actually delivered to the load; it can be written in the form of Tschebyscheff polynominal.

Two Crossed Cell Filter

In the case of a two cell filter, the attenuation is given by the formula:

$$A = 1 + \frac{1}{4} \frac{\cos^4\theta}{\sin^2\theta} \left[ 2 \left( \frac{b\tan\theta}{\sqrt{2}} \right)^2 - 1 \right]^2 \tag{7}$$

where $\theta$ is related to the length of the main connecting line section and to the mid frequency $F_c$ of the filter by the relationship:

$$\theta = 2\pi L/\lambda_c \tag{8}$$

where L is the physical length of the connecting line section and $\lambda_c$ the wavelength at the mid frequency $F_c$ of the filter.

The quantity b of equation (7) is given by:

$$\frac{4(F-F_0)}{\pi\epsilon^2 F_0} = b + \cot\theta \tag{9}$$

The ripple amplitude in the passband is:

$$R = \frac{1}{4} \frac{\cos^4\theta}{\sin^2\theta} \tag{10}$$

the resonance frequency drift is:

$$F_c = F_0 \left( \frac{\cot\theta}{4Q_c} + 1 \right) \tag{11}$$

and the passband is defined by:

$$\frac{\Delta F}{F_c} = \frac{2\sqrt{2}}{1 + 4Q_c \tan\theta} \tag{12}$$

Three Crossed Cell Filter

Let $l_{e1}$ and $l_{e2}$ be the lengths of the stubs of the end cells and $l_{m1}$ and $l_{m2}$ be the lengths of the stubs of the mid cell. These lengths are related to $l_0$ by the following equations:



$$l_{e1} = l_0 (1-\epsilon_e)$$
$$l_{e2} = l_0 (1+\epsilon_e)$$
$$l_{m1} = l_0 (1-\epsilon_m)$$
$$l_{m2} = l_0 (1+\epsilon_m) \tag{13}$$

Two cases are to be distinguished according to the values taken by the spacing of the stubs $\theta$ in electric degrees and the ratio $k$ of the admittance of the mid cell to the admittance of the end cells.

Case A

$k = 2$ $\theta \neq \pi/2$ wherefrom $\cos\theta \neq 0$

Then the attenuation A is given by the formula:

$$A = 1 + \frac{4\cos^6\theta}{27\sin^2\theta}(4\omega^3 - 3\omega)^2 \tag{14}$$

where:

$$\omega = \sqrt{\frac{3b}{2}}\tan\theta = \sqrt{\frac{3}{2}}\tan\theta \left[ 4\,\frac{F-F_0}{F_0}\,\frac{y}{\pi\epsilon^2} - \cot\theta \right] \tag{15}$$

The passband is defined by:

$$\Delta F/F_c = \frac{4}{\sqrt{3} \left| 1 + \frac{4y2}{\pi\epsilon}\tan\theta \right|} \tag{16}$$

The ripple amplitude in the pass band is defined by:

$$R = 1 + \frac{4\cos^6\theta}{27\sin^2\theta} \tag{17}$$

and the resonance frequency drift is defined by:

$$F_c = F_0 \left[ \frac{\pi\epsilon^2\cot\theta}{4y} + 1 \right] \tag{18}$$

In equations (15), (16) and (18), $y$ represents $y_e$ or $y_m$ and $\epsilon$ represents $\epsilon_e$ or $\epsilon_m$.

Case B

$k \neq 2$ $\theta = \pi/2$ wherefrom $\cos\theta = 0$

Then the attenuation is given by the formula:

$$A = 1 + \frac{(2-k)^2}{27k}(4\omega^3 - 3\omega)^2 \tag{19}$$

where:

$$\omega = \left[ \frac{2k}{4(2-k)} \right]^{1/2} 4 \frac{\left[ F-F_0 \right]}{F_0} \frac{y}{\pi\epsilon^2} \tag{20}$$

The passband is defined by:

$$\Delta F/F_c = \frac{\pi\epsilon^2}{\left( \frac{3k}{2-k} \right)^{1/2} y} \tag{21}$$

The ripple amplitude in the passband is defined by:

$$R = 1 + \frac{(2-k)^3}{27k} \quad (22)$$

and the resonance frequency drift is defined as previously by equation (18) and since cot $\theta = 0$ there is no drift of the resonance frequency. The resonance frequency of the filter is the same as the resonance frequency of the cells. In equations (20) and (21) $y$ represents $y_e$ or $y_m$ and $\epsilon$ represents $\epsilon_e$ or $\epsilon_m$.

Let us assume it is desired to design a passband filter having the following characteristics:

$$F_c = 4000 \text{ MHz}$$
$$\Delta F = 4 \text{ MHz}$$
$$\Delta F/F_c = 10^{-3}$$

Ripple in the passband = 0.20 dB wherefrom $R = 1.047$.

First and Second Example corresponding to Case A.

By replacing R by 1.047 in equation (17), are obtains:

$$\cos^2\theta = 0.53 \qquad \theta = 43°25'$$

By replacing $\Delta F/F_c$ and $\theta$ by their values in equation (16), one obtains:

$$y_e/\epsilon_e^2 = 1927$$

By replacing $\theta$ and $y_e/\epsilon_e^2$ by their values in equation (18), one obtains:

$$F_0 = \frac{4000}{1 + 0.000433} = 3998.27 \text{ MHz}$$

As $k = 2$:

$$y_m/\epsilon_m^2 = 2y_e/\epsilon_e^2 = 2\times1927 = 3854 \quad (23)$$

First example:

Equation (23) is satisfied by taking:

$$y_e = 1 \qquad y_m = 2$$
$$\epsilon_e = \epsilon_m = 0.0228$$

Let us select as dielectric material for the dielectric sheets of the strip-line the so-called "Rexolite 1422" having a dielectric constant $\epsilon_r = 2.3$. Then equation (3) gives for $l_0$:

$$l_0 = \frac{c}{4F_0\sqrt{\epsilon_r}} = 12.36\text{mm}.$$

equation (8) gives:

$$L = \frac{\theta}{2\pi}\lambda_e = \frac{\theta}{2\pi}4l_0 = 6.12\text{mm}.$$

and equation (13) give:

$$l_{e1} = l_{m1} = 12.08 \text{ mm} \qquad l_{e2} = l_{m2} = 12.64 \text{ mm}$$

If a value of $Z_0 = 50$ ohms is selected for the impedance of the end cell stubs and a thickness of 2 mms for the dielectric sheet of the strip-line, then: $Z_0\sqrt{\epsilon_r} \approx 80$ and the graph of page 169 of the text book referred to



in the introductory part gives a ratio width of the strip w/thickness of the dielectric sheet d equal to 0.8 for the end cell stubs and to 2 for the mid cell stubs. Thus $w_e = 1.6$ mm and $w_m = 4$ mms.

The filter is thus completely defined and is represented in FIG. 2.

Second example

Equation (23) is satisfied by taking:

$$y_e = y_m = 1$$
$$\epsilon_e = 0.0228$$
$$\epsilon_m = 0.0161$$

Then equations (13) give:

$$l_{e1} = 12.08 \text{ mm}$$
$$l_{e2} = 12.64 \text{ mm}$$
$$l_{m1} = 12.16 \text{ mm}$$
$$l_{m2} = 12.56 \text{ mm}$$

and the width of the strip does not depend on the cell concerned

$$w_e = w_m = 1.6 \text{ mm}.$$

The filter is thus completely defined and is represented in FIG. 3.

Third Example corresponding to case B

By replacing R by 1.047 in equation (19), one obtains:

$$k = 0.939$$

By replacing $\Delta F/F_c$ and $k$ by their values in equation (21), one obtains:

$$y_e/\epsilon_e^2 = 1928$$

The resonance frequency of the cells is the resonance frequency of the filter

$$F_0 = F_c$$

As $k = 0.939$

$$y_m/\epsilon_m^2 = 0.939 \times y_e/\epsilon_e^2 = 0.939 \times 1928 = 1810 \quad (24)$$

As in the first and second examples, equation (24) can be satisfied by making the end cell stubs and the mid cell stubs with the same strip lines and taking different $\epsilon_e$ and $\epsilon_m$ or by giving $\epsilon_e$ and $\epsilon_m$ the same value i.e., by giving the stubs the same length and by varying the admittance of the strip line they are made of. Only the first case will be discussed.

Consequently let us assume: $yY_e = y_m = 1$

$$\epsilon_e = 0.0228$$
$$\epsilon_m = 0.0235$$

Then equation (13) gives:

$$l_{e1} = 12.08 \text{ mm}$$
$$l_{e2} = 12.64 \text{ mm}$$
$$l_{m1} = 12.07 \text{ mm}$$
$$l_{m2} = 12.65 \text{ mm}$$

The width of the strip-line are

$$w_e = w_m = 1.6 \text{ mm}$$

and the spacing between the stubs is $L = \lambda_e/4 = 12.36$ mm.

The filter is thus completely defined and is represented in FIG. 4.

Five Crossed Cell Filter

Let us assume it is desired to design a passband filter having the same characteristics as the filter already designed, but with five cells instead of three.

The table of page 100 of the textbook already cited gives the values of the reactive elements for Tchebyscheff filters with five elements for various dB ripples. One finds:

$$g_0 = g_6 = 1 \qquad g_1 = g_5 = 1.3394$$
$$g_2 = g_4 = 1.3370 \qquad g_3 = 2.1660$$

Let us select a priori the electric length of the connecting lines equal to $\pi/4$:

$$\theta_{1,2} = \theta_{2,3} = \theta_{3,4} = \theta_{4,5} = \pi/4$$

which corresponds to a physical length of $\lambda_c/8$.

It is known that an admittance inverter having a parameter $1/\sin^2\theta$ can be formed by a line section of electric length $\theta$ connecting two identical elements having an admittance $\cot\theta$. Thus:

$$J^2_{1,2} = J^2_{2,3} = J^2_{3,4} = J^2_{4,5} = \frac{1}{\sin^2 \pi/4} = 2$$

where $J_{1,2}$ is the parameter of the admittance inverter between the first and the second cells, and so on.

The parameters of the admittance inverters are given at page 433 of the cited textbook.

$$J_{j,j+1} = \Delta F \sqrt{\frac{p_j p_{j+1}}{g_j g_{j+1}}}$$

where $p_j$ and $p_{j+1}$ are the admittance slope parameters.

The admittance inverters at the ends of the filter have a ratio or parameter equal to unity. Thus:

$$J_{0,1} = J_{5,6} = \frac{\Delta F p_1}{g_0 g_1} = \frac{\Delta F p_6}{g_5 g_6} = 1$$

which gives:

$$p_1 = p_5 = \frac{g_0 g_1}{\Delta F} = \frac{1 \times 1.3394}{10^{-3}} = 1339.4$$

Replacing $\Delta F$, $p_1$, $g_1$, $g_2$ by their values in the expression of $J_{1,2}^2$:

$$J^2_{1,2} = \Delta F \frac{p_1 p_2}{g_1 g_2} = 2$$

gives: $p_2 = p_4 = 2674$

Replacing $\Delta F$, $p_2$, $g_2$, $g_3$ by their values in the expression of $J_{2,3}^2$:

$$J^2_{2,3} = \Delta F \frac{p_2 p_3}{g_2 g_3} = 2$$

gives: $p_3 = 2166$

The admittance slope parameters are related to the admittance of the stubs by the relationship:

$$p_j = 2y_j/\pi\epsilon_j^2 \qquad (25)$$

Assuming

$$y_1 = y_2 = y_3 = 1$$

equation (25) allows to determine the values of the $\epsilon_j$ from the values of the $p_j$.

One finds:

$$\epsilon_1 = 0.0218$$
$$\epsilon_2 = 0.0154$$
$$\epsilon_3 = 0.0171$$

The resonance frequency drift is given by the formula:

$$\frac{F_c - F_{0,j}}{F_c} = \frac{\cot\theta_{j-1,j} + \cot\theta_{j,j+1}}{2y_j Q_{cj}}$$

$$\frac{F_c - F_{0,1}}{F_c} = \frac{0+1}{2 \times 1339.4} = 3.73\ 10^{-4}$$

$$\frac{F_c - F_{0,1}}{F_c} = \frac{1+1}{2 \times 2674} = 4.62\ 10^{-4}$$

$$\frac{F_c - F_{0,3}}{F_c} = \frac{1+1}{2 \times 2166} = 4.62\ 10^{-4}$$

which give the resonance frequencies of the cells

$$F_{0,1} = F_{0,2} = F_{0,4} = F_{0,5} = 3998.5 \text{ MHz.}$$
$$F_{0,3} = 3998.15 \text{ MHz}$$

from which the quarter wavelength $l_0$ and the stub spacing are deduced

$$l_0 = \frac{c}{4F_0\sqrt{\epsilon_r}} = 12.37 \text{ mm}$$

$$L = \frac{\theta_c}{2\pi F_c \sqrt{\epsilon_r}} = 6.18 \text{ mm}$$

The lengths of the stubs are deduced from the values of $l_0$ and of the $\epsilon$'s. One finds

$$l_{1,1} = l_{1,5} = 12.10 \text{ mm}$$
$$l_{2,1} = l_{2,5} = 12.64 \text{ mm}$$
$$l_{1,2} = l_{1,4} = 12.18 \text{ mm}$$
$$l_{2,2} = l_{2,4} = 12.56 \text{ mm}$$
$$l_{1,3} = 12.16 \text{ mm}$$
$$l_{2,3} = 12.58 \text{ mm}$$

For an impedance of 50 ohms, the width of the strip is taken equal to 1.6 mm and the thickness of the "Rexolite" sheet equal to 2 mm.

The filter is then completely defined and is represented in FIG. 5.

What we claim is:

1. A microwave bandpass filter of strip transmission line structure comprising a main rectilinear strip conductor, a plurality of open-ended strip line stubs all having one-half wave length at the mid frequency of the passband of said filter and parallel-connected to the main strip conductor at connecting points, said connecting points being regularly spaced apart along the main strip conductor and being, on each strip line stub, selectively offset with respect to the midpoint of the stub, and their spacing along said main conductor being

much smaller than a quarter wavelength along said main conductor at said mid frequency.

2. A microwave bandpass filter of strip transmission line structure comprising a main rectilinear strip conductor having a given width, a plurality of open-ended strip line stubs all having one-half wave length at the mid frequency of the passband of said filter and formed by a stub strip conductor having the same width as the main strip conductor and parallel-connected to the main strip conductor at connecting points, said connecting points being regularly spaced apart along the main strip conductor and, on each strip line stub, selectively offset with respect to the midpoint of the stub, the distance between the connecting point and the midpoint of a stub being different for each stub, and the spacing of said connecting points along said main conductor being much smaller than a quarter wavelength along said main conductor at said mid frequency.

3. A microwave bandpass filter of the strip transmission line structure comprising a main rectilinear strip conductor having a given width, a plurality of open-ended strip line stubs all having one-half wave length at



the mid frequency of the passband of said filter and formed by stub strip conductors having different widths and parallel-connected to the main strip conductor at connecting points, said connecting points being regularly spaced apart along the main strip conductor and, on each strip line stub, selectively offset with respect to the midpoint of the stub, the distance between the connecting point and the midpoint of a stub being the same for all the stubs, and the spacing of said connecting points along said main conductor being much smaller than a quarter wavelength along said main conductor at said mid frequency.

4. A filter as claimed in claim 1, in which said spacing is substantially equal to one-eighth of a wavelength along said main conductor.

5. A filter as claimed in claim 2, in which said spacing is substantially equal to one-eighth of a wavelength along said main conductor.

6. A filter as claimed in claim 3, in which said spacing is substantially equal to one-eighth of a wavelength along said main conductor.

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