# STUDY OF MICRO-WAVE FILTERS (PART II)

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ABSTRACT

Starting from a single cavity resonator, the theory of filters employing a number of these units either directly coupled or coupled by quarter wavelength lines is given. The equivalence is established between the directly coupled and the quarter wavelength coupled systems. The expressions for the insertion loss of the filters employing three and four cavity resonators are given. The design procedure for obtaining a filter with three cavities and having specified characteristics is described. Finally the experimental characteristics obtained from three cavity filters, both directly coupled and quarter wave coupled and fabricated indigenously, are discussed.

## INTRODUCTION

IN a previous paper[1] the authors have discussed the behaviour and design of a single cavity resonator which forms the fundamental unit in the design of more complex filters having broad pass bands and high off-band attenuations. These filters are obtained either by coupling these individual cavities directly or by quarter-wavelength coupling sections. The directly coupled filters have the advantage of having smaller lengths and also larger rejections in the off-band. The reasons for this are being discussed.

The multicavity filters are, in general, of two types. In the first a number of identical cavities are coupled to give a filter with high rejection outside the pass band but with dips or ripples in the pass band whose magnitude is an increasing function of the number of the cavities used. This is referred to as Chebyschev filter. The second type of he filter is the maximally flat type designed to eliminate the ripples within the pass band. This type has been popularised and fully discussed by Mumford[2]. However, in this type the cut-off at the edges of the pass band is not as sharp as in the Chebyschev type.

The theory of microwave filters may be approached in one of two ways—the first directly by transmission line theory and the second by synthesis from conventional low-frequency circuits. The latter method has been discussed extensively and methods are available for designing filters with specified characteristics[3]. However, such a practice is very complicated and has its own limitations. Levy[4] has, therefore, developed a direct transmission line theory for these filters, in order to avoid the dangers inherent in drawing analogies between conventional low-frequency circuits and microwave elements and to avoid the resulting mathematical complications. Levy has shown by this direct transmission line theory that the maximally flat and the Chebyschev filters are special cases of a generalized symmetrical filter, and using this theory, filters with better characteristics than either of the two types could be obtained.

Both the direct coupled and the quarter wave coupled filters were designed in the manner indicated by Levy and Potok[5]. These were fabricated indigenously and their design and experimentally obtained characteristics are given later.

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## THEORY

### *Quarter Wave coupling sections*

For obtaining a filter with flat top characteristics giving high rejections outside the pass band, it is necessary to couple two or more cavities in cascade. For microwave filter the coupling sections consist of short length of waveguides. It is required to find the exact length of the coupling section between any two cavities which give perfect transmission between the cavities at the mid-band frequency.

Fig. I shows the part of a quarter wave coupled filter consisting of two unequal cavities, specified by the subscripts 1 and 2. All susceptances considered here are normalized with respect to the waveguide characteristic admittance, as in the earlier paper and the same symbols are also being used here. Here the first cavity consists of two normalized susceptances, $b_1$ separated by a distance $l_1$. The transfer matrix of this cavity which may be designated as $(b_1 l_1 b_1)$ can be shown to be equal to ,

$$[\, b_1\, l_1\, b_1 \,] = \begin{vmatrix} o & o \\ jb_1 & 1 \end{vmatrix} \begin{vmatrix} Cos\beta l_1 & jSin\beta l_1 \\ jSin\beta l_1 & Cos\beta l_1 \end{vmatrix} \begin{vmatrix} 1 & o \\ jb_1 & 1 \end{vmatrix} = \begin{vmatrix} p_1 & jq_1 \\ j\gamma_1 & p_1 \end{vmatrix} \quad \ldots \quad \ldots \quad (1)$$

where $\beta$ is the phase change co-efficient inside the cavity and is given by $2\pi/\lambda g$, $\lambda g$ being the guide wavelength.

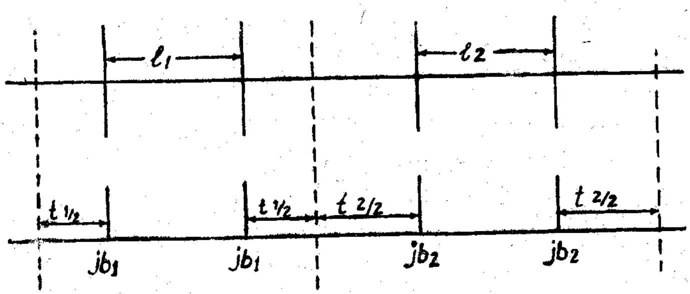


FIG. 1 : Section of a Quarter wave coupled Filter

$$p_1 = Cos\,(\beta l_1) - b\,Sin\,(\beta l_1) \quad \ldots \quad (2)$$

$$q_1 = Sin\,(\beta l_1) \quad \ldots \quad (3)$$

$$\gamma_1 = 2b_1\,Cos\,(\beta l_1) + (1 - b_1^2)\,Sin\,(\beta l_1) \quad \ldots \quad (4)$$

From the definition of insertion loss, $L$, it can be shown as in the earlier paper[1] that,

$$L = 1 + \tfrac{1}{4}\; j\,(q_1 + \gamma_1)^2 \quad \ldots \quad (5)$$

and that the phase shift through the single cavity resonator is,

$$\Psi = ayc\;tan\;\; (q_1 + \gamma_1)\,/\,2p_1 \quad \ldots \quad (6)$$

The midband frequency, corresponding to $L = 1$, is now obtained by equating $q_1$ to $\gamma_1$ in the eqn. (5). Hence from eqns. 3 and 4, at the midband frequency,

$$tan\,(\beta l_1) = 2/b_1 \quad \ldots \quad (7)$$

The transfer matrix of this cavity when enclosed by lines of length $t_{1/2}$ on either side is given by,

$$\begin{vmatrix} Cos\,(\beta t_1/_2) & j\,Sin\,(\beta t\,_1/_2) \\ jSin\,(\beta t_1/_2) & Cos\,(\beta t_1/_2) \end{vmatrix} \begin{vmatrix} p_1 & jq_1 \\ j\gamma_1 & p_1 \end{vmatrix} \begin{vmatrix} Cos\,(\beta t_1/_2) & j\,Sin(\beta t_1/_2) \\ j\,Sin(\beta t_1/_2) & Cos(\beta t_1/_2) \end{vmatrix} = \begin{vmatrix} p_1{}^1 & jq_1{}^1 \\ j\gamma_1{}^1 & p_1{}^1 \end{vmatrix} \quad .. \quad .. \quad (8)$$

where,

$$p_1{}^1 = p_1\,Cos\,(\beta l_1) - \tfrac{1}{2}\,(q_1 + \gamma_1)\,Sin\,(\beta t_6) \quad .. \quad .. \quad .. \quad .. \quad (9)$$

$$q_1{}^1 = p_1\,Sin\,(\beta t_1) + \tfrac{1}{2}\,(q_1 + \gamma_2)\,Cos\,(\beta t_1) + \tfrac{1}{2}\,(q_1 - \gamma_1) \quad .. \quad .. \quad (10)$$

$$\gamma_1{}^1 = p_1\,Sin\,(\beta t_1) + \tfrac{1}{2}\,(q_1 + \gamma_1)\,Cos\,(\beta t_1) - \tfrac{1}{2}\,(q_1 - \gamma_1) \quad .. \quad .. \quad (11)$$

Hence, the overall transfer matrix for the two filter sections in cascade as shown in Fig. I., is

$$\begin{vmatrix} p_1{}' & jq_1{}' \\ s\gamma_1{}' & p_1{}' \end{vmatrix} \begin{vmatrix} p_2{}' & jq_2{}' \\ j\gamma_2{}' & p_2{}' \end{vmatrix} = \begin{vmatrix} p_1{}'p_2{}' - q_1{}'\gamma_2{}' & j\,(p_1{}'\,q_2 + q_1{}'\,p_2{}') \\ j(\gamma_1{}'p_2{}' + p_1{}'\gamma_2{}') & p_1{}'\,p_2{}') - \gamma_1{}'\,q_2{}' \end{vmatrix} \quad .. \quad (12)$$

Hence, from eqn. (5), the insertion loss for the two filter sections in cascade is given by,

$$L = 1 + \tfrac{1}{4}\,[q_1{}'\,\gamma_2{}' - \gamma_1\,q_2{}']^2 + \tfrac{1}{4}\,[p_1{}'\,(q_2{}' - \gamma_2{}') + p_2{}'\,(q_1{}' - \gamma_1{}')]^2 \quad .. \quad (13)$$

If the midband frequencies of both the cavities be made to coincide, then

$$\tan\,(\beta l_1) = 2/b_1 \text{ and } \tan\,(\beta l_2) = 2/b_2 \quad .. \quad .. \quad .. \quad .. \quad (14)$$

as the conditions given by eqn. (14) make $q_1{}' = \gamma_1{}'$ and $q_2{}' = \gamma_2{}'$ in the eqn. (13) and make $L'$ equal to unity.

In order to obtain the design procedure for the filters employing two or more cavities, the principle is adopted that any two pairs of cavities are critically coupled for having sharp off-band attenuations. The conditions given by eqn. (14), however, are not sufficient for the required critical coupling between the cavities. For this, ($L$-1) must be quadratic in the deviation $\delta f$ from the midband frequency. It is readily proved that for critical coupling, the additional conditions, $p'_1 = p_2{}' = 0$, are required which 0 on being combined with eqn. (14) give at the midband frequency,

$$tan\,(\beta t_{i/2}) = b_{i/2}\,,\ i = 1, 2 \quad .. \quad .. \quad .. \quad (15)$$

when $O < \beta t_i < \pi/_2$ is chosen for $b_i$ negative. In the usual case of high Q cavities used with these filters $b_i$ is very large and the critical coupling length corresponding to $\frac{1}{2}\,(t_1 + t_2)$ is nearly equal to a quarter wave length and at the resonant frequency,

$$\beta t_i = \beta l_i - \pi/_2\,,\ i = 1, 2 \quad .. \quad .. \quad .. \quad (16)$$

*Equivalence between direct and quarter wave couplings*

A quarter-wave coupled filter may be transformed into a direct coupled version by replacing the adjacent susceptances of each cavity and the quarter wave coupling by a single large susceptance. Only the two susceptances at the extreme ends of the original remain identical. If two networks have the same insertion loss and the phase shift at a single frequency, their behaviour is then very similar at that frequency.

Hence, the single large susceptance is chosen to give the same insertion loss as the quarter wave coupling section, so that the adjacent cavities remain critically coupled. The phase shift difference are compensated by increasing the lengths of the cavities in the directly coupled case.

Consider now the quarter wave coupling section with extra lengths of the line $t_i/_2$ on either side as shown in Fig. 2. It can be shown by the usual method that the insertion loss of this configuration is given by,

$$L = 1 + \tfrac{1}{4}\,[\,b_1/_2\,\sqrt{b_2^2 + 4}] + b_2/_2\,\sqrt{b_1^2 + 4}]^2 \qquad \ldots \qquad \ldots (17)$$

The section shown in Fig. (2), consists of two parts, one consisting of the susceptance $jb_1$ at the centre of the line of length $t_1$ and the other of the susceptance $jb_2$ at the centre of the line of length $t_2$. Levy as shown that the phase change in each section is equal to $\pi$. The phase change of the single susceptance, $jb_1$ is given by *arc tan* $(b\tfrac{1}{2})$ and that due to the length $t_1$ is given by eqn. (15). Hence,

$$arc\,tan\,(b_1/_2) + arc\,tan\,(-b_1/_2) = \pi \qquad \ldots \qquad \ldots (18)$$

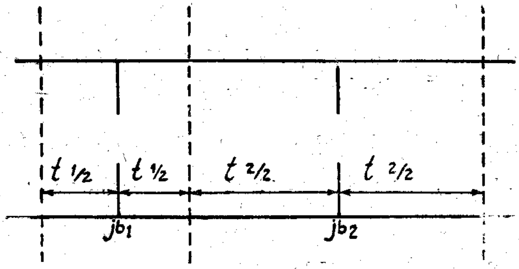


Fig. 2. Quarter Wave coupling Section with extra lengths of Line $t^2/2$

The total phase change through the system of fig. (2) is obviously equal to $2\pi$.

Now from eqns (5) and (17), the value of the single susceptance say $b'$, capable of giving the same insertion loss as the coupling section shown in fig. (2), may be shown to be equal to

$$b' = \tfrac{1}{2}\,b_1\,\sqrt{b_2^2 + 4} + \tfrac{1}{2}\,b_2\,\sqrt{b_1^2 + 4} \qquad \ldots \qquad \ldots \qquad \ldots (19)$$

The phase shift due to the single susceptance $jb'$ is given by $\Psi^1 = arc\,tan\ \ b'/_2$ .. (20)

$$= \pi - \phi^1, \text{ from eqn (18)}, \qquad \ldots \qquad \ldots \qquad \ldots \qquad \ldots (21)$$

where $\phi^1 = arc\,tan\,(-b'/_2)$ .. ... .. .. .. (22)

It is easy to see now that the phase shift given by the susceptance $jb'$ placed at the centre of the line of length $t'$, as shown in fig. (3), is equal to $\pi$, where $\beta t^1$ is equal to $\phi^1$.

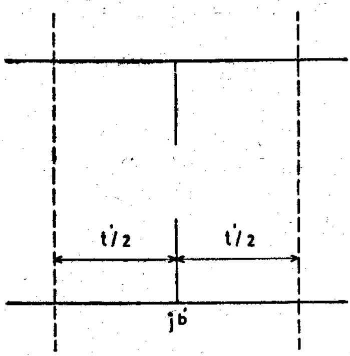


Fig. 3. The Equivalent Susceptance with Extra-lengths of Line $t'/_2$

Hence the section shown in fig. (3) is electrically equivalent to the system shown in fig. (2).

Now from eqn. (16),

$$l_i = t_i + \lambda_g/4 \quad \dots \quad (23)$$

So that the quarter wave coupled filter consisting of two unequal cavities, as shown in fig. 1, may now be represented as in fig. (4). The portion marked 'F' in this fiugre is the same as the section shown in fig. (2), so that it may be replaced by the section shown in fig. (3). On this replacement, fig. (5) is obtained which is the direct coupled version of the quarter wave coupled system.

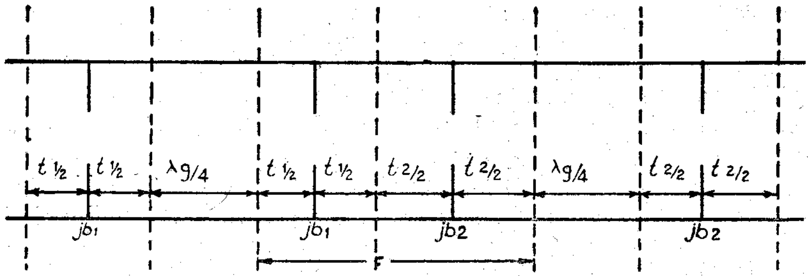


Fig. 4. A Representation of the Quarter Wave Coupled Filter.

Consider now the electrical length $\beta l_1'$ of one of the cavities of the direct coupled filter shown in fig. (5).

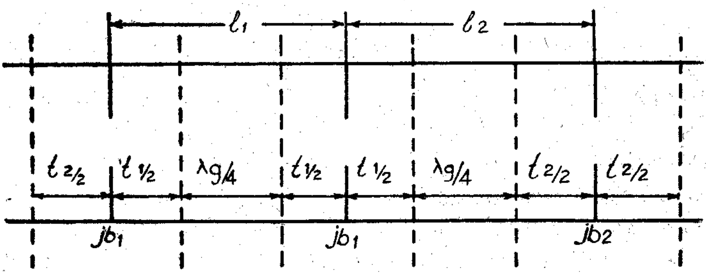


Fig. 5. The Equivalent Direct Coupled version of a Quarter Wave Coupled Filter.

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$$\beta l_1' = \tfrac{1}{2}\left[(\pi/2 + \beta t') + (\pi/2 + \beta t_1)\right] \quad \dots \quad (24)$$

$$= \tfrac{1}{2}(\beta l' + \beta l_1), \text{ from eqn. (16)} \quad \dots \quad (25)$$

$l'$ in the above equation is the resonant length of the cavity having the bounding susceptances equal to $jb^1$.

Hence from eqn. (7)

$$\beta l_1' = \tfrac{1}{2}(arc\ tan\ 2/b_1 + arc\ tan\ 2/b') \quad \dots \quad (26)$$

similarly $\beta l_2' = 1/2\,(arc\ tan\ 2/b_2 + arc\ tan\ 2/b') \quad \dots \quad (27)$

This process may clearly be repeated, at every stage the resulting electrical length of each cavity is the mean of the two values of arc tan $2/b$ of the bounding susceptances.

It may be noted here that the lengths of the individual cavities are more here than those of the corresponding cavities in the equivalent quarter wave version. Levy has shown that $Q$ factor of the direct coupled filter is higher than that of the corresponding quarter wave version and as a result the off-band attenuation is greater in the direct coupled version.

*General theory and the derivation of the expression for the insertion loss of the coupled filter*

As already mentioned, the multiple cavity type of filters usually described in literature are in general of two types, namely the maximally flat type and the Chebyschev type. In the maximally flat type the cavities are designed in such a way that the insertion loss through out the pass band is zero. This filter consists of a number of cavities ($n$) arranged in such a way that the rth cavity has a 3db$\Phi_r$ given in terms of the overall $\Phi_T$ by the expression,

$$\Phi_r = \Phi_T \sin\left( (2\gamma - \frac{1}{2\pi}) \times \pi \right) \quad \ldots \quad (28)$$

and the insertion loss of the filter is given by,

$$L = 1 + (2\delta f / f_\circ \; \Phi_T)^{2n} , \quad \ldots \quad (29)$$

where $\delta f$ is the frequency deviation from the resonant frequency $f_\circ$. From above, the insertion loss at the edges of the band,

$$L = 1 + (2\triangle f / f_\circ \cdot \Phi_T)^{2n} \quad \ldots \quad (30)$$

In the other type, *i.e.* in the Chebyschev type, a certain amount of variation in the reflection loss is permitted in the pass band. However, the off-band attenuation of this type of filter is higher than that of the maximally flat type. The insertion loss of this filter is given by[6],

$$L = 1 + [\, x\, Un\, (x)\, ]^2 \quad \ldots \quad (31)$$

where $x = \Phi_{L1}\, 2\triangle f / f_\circ$ and $Un(x)$ is the rationalized Chebyschev polynominal of the second kind and of degree ($n$ — 1), $n$ is the no. of cavities and $\Phi_{L1}$ is the loaded $\Phi$ of each cavity. The total $\Phi$ of the filter is larger than that of the individual cavity by a calculable amount and is a function of the number of cavities, used. There is a limit to the number of cavities, however, that may be employed as the magnitude of dips within the pass band goes on increasing with number of cavities. This make the Chebyschev type of filter impractical for most applications.

The two types of filters mentioned above may be considered as special cases of generalized filter where the $\varphi$ factors of the individual cavities are related arbitrarily. The theory of this generalised filter has been given by Levy[4], the outlines of which are being presented below.

This theory is based on the equivalence of a cavity resonator with a lumped susceptance placed at the centre of some specified length of line. The values of these parameters are calculated such that the insertion loss and the phase shift of the two systems remain the same at the midband frequency. The error introduced by this equivalence is only due to the variation of the specified line length with frequency, which can be shown to be very small even in the case of comparatively wide band filters.

It may be shown that a single cavity having the susceptances $jb$ separated by a length '$l$' and flanked by the critical coupling length $\frac{1}{2}(\beta l - \pi/2)$ as given by eqn. (16), may be replaced by the single susceptance $2jx$ centred at a line of length $\lambda g/4$. Hence, the multicavity filter is now represented by a cascade admittances $2jx$ flanked by coupling lengths equal to $\lambda g/8$ Each section of the cascade may be shown to be represented by the transfer matrix[6],

$$[\, X\, ] = \begin{bmatrix} -X & j\,(1 - X\,) \\ j\,(1 + X\,) & -X \end{bmatrix} \quad \ldots \quad (32)$$

where $$X = b\,[\, \cos\,(\beta l) - \tfrac{1}{2}\, b\, \sin\,(\beta l)\,] \quad \ldots \quad (33)$$

From eqn. (33), it may be shown that for small variations of $\beta l$ about the resonant value, $x$ is proportional to $\delta\beta l$, and hence when terms of the order of $(\triangle f)^2$ may be neglected,

$$x = 2\Phi_x \; \triangle f / f_o \quad \ldots \quad (34)$$

where $\Phi_x$ is the loaded $\Phi$ of the cavity. From the above it may be seen that the value of $x$ is '1' at $3db$ points as the insertion loss of this equivalent susceptance $2\,j\,X$ is equal to $[1 + x]^2$.

Consider now the equivalent representation of a symmetrical three cavity filters having the 3db $\Phi$ values as $\Phi_x$, $\Phi_y$, $\Phi_x$, as shown in fig. (6). The susceptance '$y$' is also related to $\Phi_y$ by,

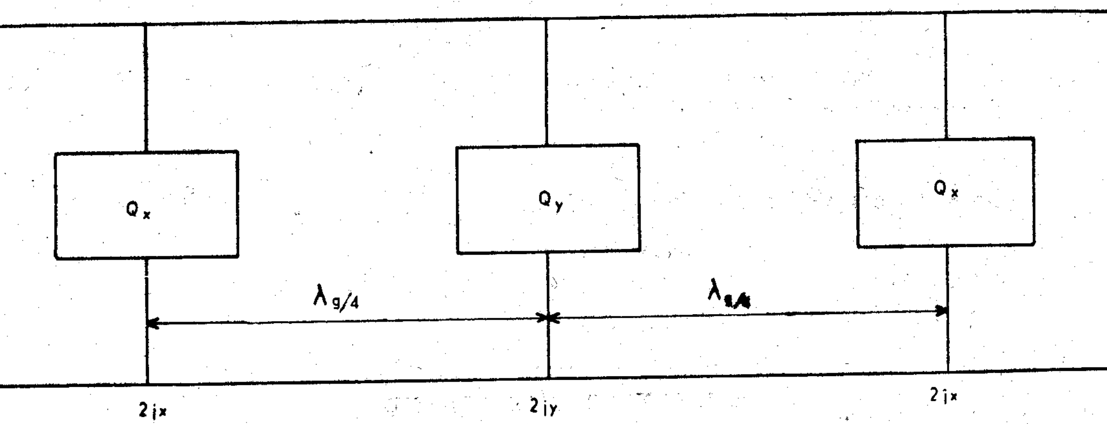


Fig 6—Three Cavity generalised Filter

$$y = 2\,\Phi_y \; \triangle f / f_o \quad \ldots \quad (35)$$

Now, the overall transfer matrix of the system shown in fig. (6) is $[\,x\,]\,[\,y\,]\,[\,x\,]$. This matrix may be expanded by using the eqns. (32) & (33) and the insertion loss of this sytem is shown to be, $L = 1 + [\,4\,x^2y - 2x + y\,]^2$ .. (36)

or putting $\Phi_x \,/\, \Phi_y = k$,

$$L = 1 + 16k^4\,y^2 \left( y^2 - \frac{2k-1}{4k^2} \right)^2 \quad \ldots \quad (37)$$

Consider now the variation of L with y in the eqn. (37). The insertion loss is unity at the centre frequency, $(y = y_o = o)$, it rises to a maximum at

when $y = y_1 = \sqrt{2k-1}\;/\;2\sqrt{3k}$ .. (38)

$L = L_1 = 1 + (2k-1)^3\,/\,27k^2$ .. (39)

The insertion loss goes to a minimum again $(L = 1)$ at $y_2 = \sqrt{2k-1}/\sqrt{3k}$ after which it goes on increasing steadily to infinity with the increase in value of $y$ and the value of $L = L_1$ is reached again at $y_3 = \sqrt{(2k-1)/2k}$. The quantities $L_1$ and $y_3$ are very important as they enable one to arrive at a suitable design as explained later.

It may be noted that the Chebyschev filter is the special case of this general filter and corresponds to the case when $K = 1$ when the insertion loss given by eqn. (37) is now,

$$L = 1 + [y\,(4y - 1)^2 = 1 + [y\;U_3\,(y)]^2 \quad \ldots \quad (40),$$

this is the same as eqn. (31) for Chebyschev filters. $y_1$ for this is equal to (0·76). Similarly, the maximally flat filter corresponds to the special case of $K=1/2$ when $y_1$ becomes equal to unity.

The theory of this generalized filter may be extended for the case of four cavities or more. For the four cavity filter, let the $3db\ \Phi_s$ of the individual cavities be $\Phi_x$ , $\Phi_y$ $\Phi_y$ $\Phi_x$ and let $K = \Phi_x / \Phi_y$ as before. Levy has shown that the insertion loss is given by :—

$$L = 1 + 4y^4 \left[ (4y^2 - 1)^2 k^2 - (2k - 1) \right]^2 \quad \ldots \quad \ldots \quad \ldots (41)$$

Here also, the insertion loss is at a minimum at the centre frequency rising to a maximum given by,

$$L = L_1 = 1 + (k^2 + 2k - 1)^4 / 16k_4 \quad \ldots \quad \ldots \quad \ldots (42)$$

Corresponding to $$y = y_1 = \frac{\sqrt{k^2 + 2k - 1}}{2\sqrt{2k}} \quad \ldots \quad \ldots \quad \ldots (43)$$

The insertion loss goes to a minimum again at $y : \sqrt{\frac{k_2 + 2k - 1}{2k}}$ and beyond this value of $y$ it goes on increasing steadily and passes through $L = L_1$ at

$$y = y_3 = 0{\cdot}55 \sqrt{k^2 + 2k - 1}/k$$

## DESIGN OF THE FILTER

### *Design of the individual Cavities*

The theory and design of a single cavity have been fully discussed in the part I of this paper. As will be shown in the following section, the major requirement of the cavity is to have a specified value of $\Phi$ at the required resonant frequency. In the eqn. (23) of ref. (1), the $\Phi$ of the cavity is expressed in terms of the terminating susceptance and the resonant length '$\beta l$'. Now, from eqn. (7) of this paper $\beta l$ can also be expressed in terms of $b$. Hence the value of $b$ required to correspond to the value of $\Phi$ is obtained.

In practice, this susceptance is obtained either from the use of irises or from the use of posts. The parameters of these irises or posts, can be calculated respectively from eqns. (24) & (25) of ref. (1). The experiments mentioned in ref. 1 were done with cavities employing irises and a discrepancy between theoretical and experimental values of $\Phi$ was found specially for the higher value of $\Phi$. It may be mentioned, however, that from practical considerations the use of posts is preferred to the use of irises as will be seen later.

In the case of posts also the theoretical values of $\Phi$ obtained from eqns. (23) & (25) of ref. (1) show considerable discrepancy with the experimental values, the reasons for this being the approximations used in the derivation eqns. (23) & (25). Hence, it is suggested that as a basic approach one should not use the theoretical but the empirical value of $\Phi$ for the design. This is achieved by plotting an experimental curve of $\Phi(\lambda_g / \lambda_o)^2 V_s\ l/\lambda_g$ at the mid frequency required, $l$ corresponding to the resonant length of the cavity and $\lambda_o$ being the free space wavelength. This curve is shown in Fig. (7) and is the Fig. (6) of ref. (5). From this value of '$l$' one can easily obtain the value of '$b$', which may be correlated to the diameter of the post required by using eqn. (25).

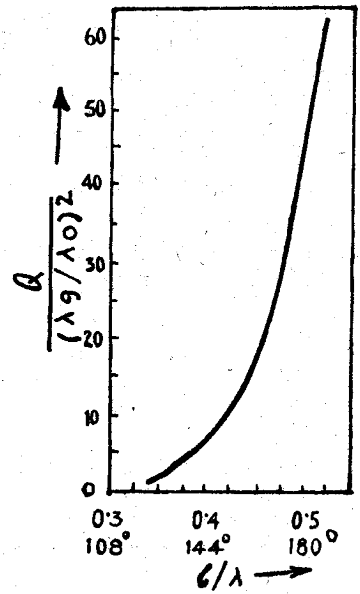


Fig. 7. Relation between Q $(\lambda_g/\lambda_o)^2$ and post coupling $l/\lambda_g$.

Once again, the value of diameter obtained from the eqn. (25) of ref. (1) is only approximate as this equation is deduced on the equivalence of the post with a single susceptance. Marcuvitz[7] has shown that the equivalent circuit of the post is a $T$ Network consisting of a shunt susceptance $jb$ and two capacitive reactances $jx$, where,

$$X = - a/\lambda_g \cdot (\pi a/d)^2 \Big/ 1 + 11/_{24} (\pi d/a)^2 \quad \ldots \quad \ldots (44)$$

$$\text{and } b = - \frac{1}{a/2\lambda_g [log\ 4a/\pi d - 2 - (\pi d/2\lambda_o)^2] + X/2} \quad \ldots (45)$$

where $a$ is the width of the guide and $d$ is the diameter of the post.

Now, by the consideration of the matrix of a cavity of length $l$ and having as the terminations the $T$ network as mentioned above, it has been shown[5] that at resonance,

$$\beta l = arc\ tan \frac{2(1 - xb)}{b + x(2 - xb)} \quad \ldots \quad \ldots \quad \ldots (46)$$

The resonant length '$l$' corresponding to the specified value of $\Phi$ is known from the empirical curve given in Fig. (7) so that eqn. (46) can now be solved for the unknown quantity '$d$' which is the diameter of the post.

*Design of the Complete filter*

For the design of the filter one starts with a desired V.S.W.R. within and insertion loss outside the specified pass band. These characteristics are obtained by suitably choosing the $\Phi$ of the component cavities as explained. Consider a three cavity system *i.e.* $\Phi_x$, $\Phi_y$, $\Phi_z$ assume that they are coupled by critical lengths given by eqn. (15) so that Levy's theory as explained earlier may now be applicable.

$$\Phi_x = 24.55$$
$$\Phi_y = 41 \cdot 6$$
$$K = 0 \cdot 59$$

From these values of $\Phi_x$ and $\Phi_y$ the physical dimensions of the filter were calculated. The lengths of the first and the third cavity $l_1 = 2 \cdot 39''$

Length of the second cavity $l_2 = 2 \cdot 51''$

Diameter of the posts in the first and third cavity=0·180″.

Diameter of the posts in the second cavity=·296″.

The length of the coupling waveguide between the first and the cavity and also between the second and the third cavity=3·287″.

All these dimensions of the filter are shown in fig. 8. From the above values the parameters of the equivalent direct coupled version were also obtained, and are being presented below.

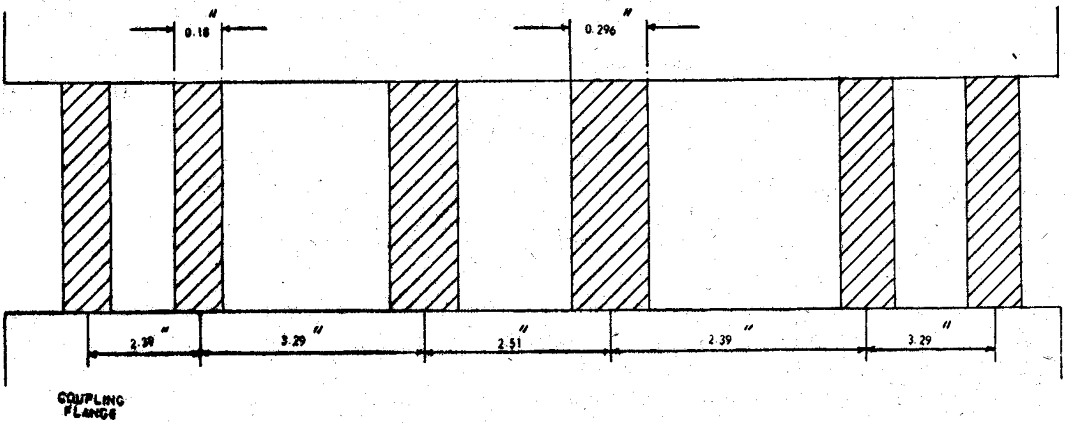


Fig. 8. Section of a Three cavity three Quarter Wave Coupled Filter.

Length of the first and the third cavity=2·51″

Length of the second cavity=2·68″

Diameter of the two posts at the end, as before=0·180″

Diameter of the two posts in middle=0·442″

The section of this direct coupled filter is shown in Fig. 9.

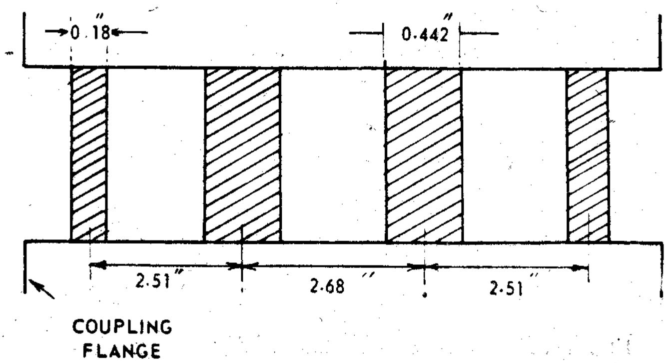


Fig. 9. Section of a three cavity Direct Coupled Filter.

Both these filters were finally fabricated in the local workshop from entirely indigenous materials.

For studying the characteristics of these filters the experimental arrangement shown in Fig. '10' is needed. The sweep generator should be capable of giving sweep broad enough to cover the entire pass band of the filter. However, due to the nonavailability of the sweep generator, the transmission pattern of the filter was obtained by point to point frequency tuning of the oscillator, keeping the input power level constant at each frequency and plotting these results. The method was not found convenient due to the following reasons.

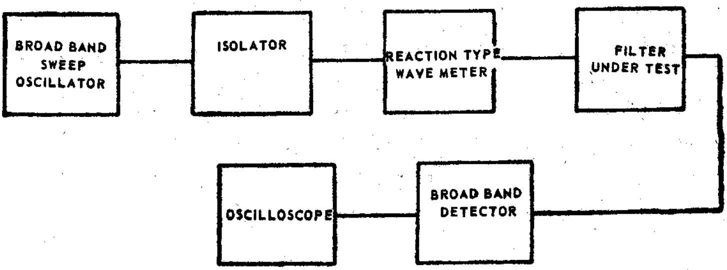


Fig. 10. Block diagram of the Experimental set-up required to Study Microwave Filters.

Because of the approximations in the theory, inaccuracies associated with the machining of the components, the required pattern is never obtained from the filter having the calculated value of the post diameters. It is a standard practice in the tuning of the microwave filters, to do a fair amount of development work before the desired pattern is obtained. This is done by varying the diameters of the posts by a few thousands of an inch. Also, capacitive screws have to be provided at the centre of the broad face of the individual cavities and their penetrations have a marked effect on the characteristic of the filter. Considering the variables *i.e.*, the post diameters and the screw penetration, it is easy to see the large number of combinations that are to be tried. It is because of the need of this development work that posts are preferred to irises for providing the required characteristics, as it is easier to have fabricated posts of diameters varying by only a few thousandths of an inch from the design values than is the case with use of irises.

The characteristics obtained with the two filters *i.e.*, the quarter wave coupled and the direct coupled are shown in figs (11) & (12) respectively. It is seen that the mid frequency

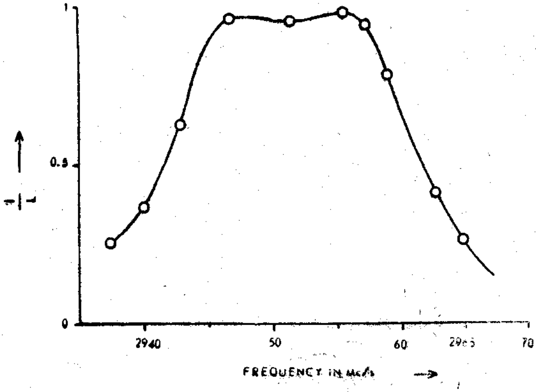


Fig. 11. Experimental Characteristics of Quarter-Wave Coupled Filter.

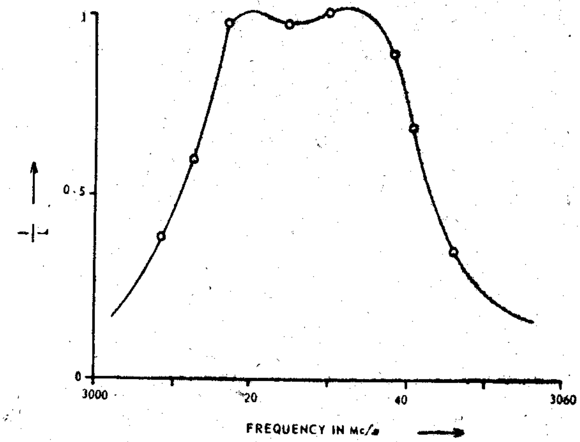


Fig. 12. Experimental Characteristic of the Equivalent Direct Coupled Filter.

in case of both the filters is not exactly 3KMC and also the bandwidth is not 30 Mc/s. The reason for this deviation from the expected values has already been given. These characteristics could definitely be made to approach nearer the wanted characteristics by further adjusting the screw penetrations and post diameter by very small amounts. Because of the experimental difficulties due to the lack of proper apparatus, further improvements in these characteristics were not done. In order to appreciate the pronounced effects of the screw penetrations and post diameters on the filter characteristics, two characteristics of the filters corresponding to the screw penetrations and the post diameters only slightly different from those of figs. (11) and (12) are shown in figs. (13) and (14), respectively. Hence it is quite reasonable to expect that by further development work the filter characteristics of figs (11) and (12) could be considerably improved and made to approach the desired values.

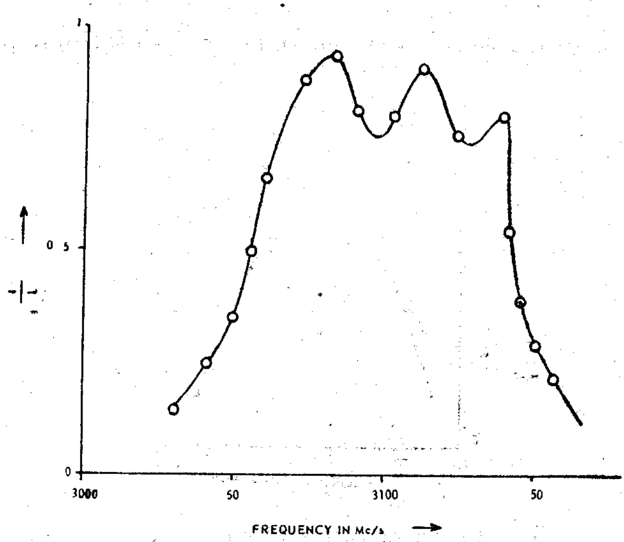


Fig. 13. One of the Characteristics obtained for Direct Coupled Filter while tuning.

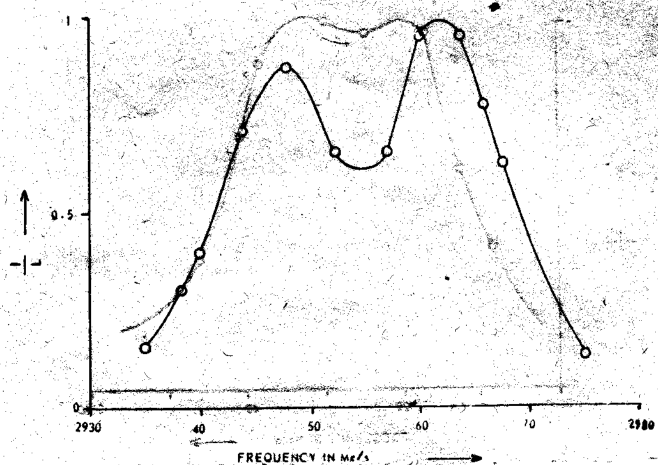


Fig. 14. One of the Characteristics obtained for Quarter Wave Coupled Filter while tuning.

Finally, the theoretical curves of $\frac{1}{L}$ *Vs* frequency and $\sigma\, V_s$ frequency for the three-cavity quarter wave coupled filter are shown in figs. (15) & (16) respectively.

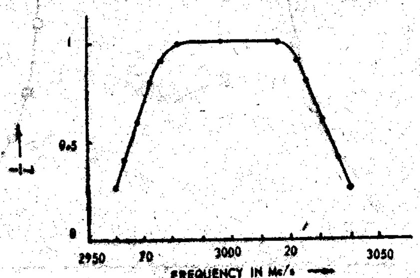


Fig. 15. Theoretical Curve of $\frac{1}{L} V_s$ Frequency.

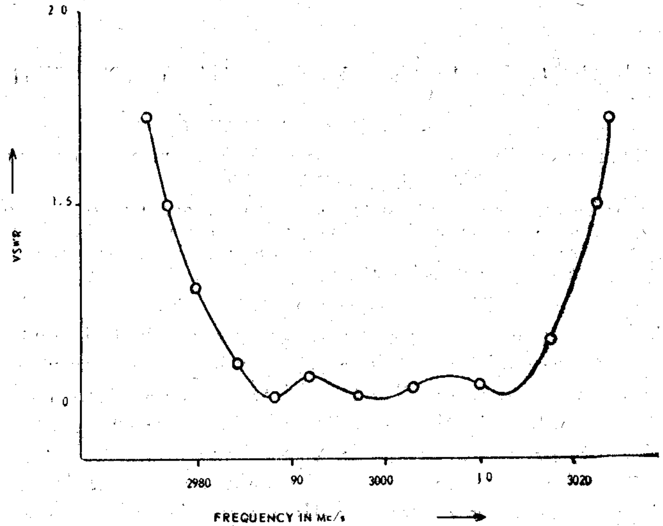


Fig. 16. Theoretical Curve of VSWR Vs Frequency.

## CONCLUSIONS

It may be concluded that by following the design procedure mentioned before the wide-band microwave filters required for various applications may be obtained indigenously, although considerable amount of development work would be required.

Even so, it will certainly be or economical and quicker to develop these filters indigenously than to import them from abroad.

It may also be mentioned that the direct coupled filters are preferable to the quarter wave or three quarter wave coupled ones due to their compactness and higher off-band attenuations. It may be noted that by tolerating a little higher insertion loss in the pass band, the off-band attenuation can be considerably increased. Also, comparing the expressions for insertion loss of a three-cavity and a four-cavity coupled filter as given by eqns. (37) and (41) respectively, the off band attenuation in the later case is much higher. In general, the off-band attenuation goes up with the increase in the number of cavities used. However, the design of filters employing more than four cavities becomes very complicated and also the fluctuations of the insertion loss in the pass band become too much to be tolerated in most communication applications.

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