DESIGN FORMULAS FOR BANDPASS CHANNEL DIPLEXERS

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Design Formulas are given for the element values in symmetry bandpass channel diplexers in terms of the known realization of the doubly terminated single channel filter prototype. Experimental results on a 5 cavity per channel, waveguide diplexer are given and show close agreement with theory.

Summary

Direct design formulas are given for all classes of symmetrical bandpass channel microwave diplexers of relatively narrow bandwidth. Starting from the doubly terminated filter prototype with characteristics corresponding to the requirements of one channel of the diplexer, the interaction effects are taken into account analytically in an exact manner. Knowing that if the channels are well separated the element values will tend to those in the single filter case apart from a frequency shift. The actual required values are expressed in terms of a power series in a well-defined bandwidth separation factor from which the leading coefficients correspond to the single filter case. In this paper exact formulas are given for the higher ordered coefficients up to a fourth ordered error term. These formulas, even in the limiting contiguous channel case, give rise to an acceptably low level of deterioration.

As an example of the application of the results a direct coupled cavity bandpass channel filter operating in waveguide WR137 has been designed to exhibit a Chebyshev response characteristic and shows excellent agreement with theory.

Design Formulas for the Symmetrical Bandpass Channel Diplexers

The basic doubly terminated low-pass prototype in normalized form is shown in Fig 1 from which the diplexer is to be designed. Operating from a 1Ω generator the first two elements are shunt capacitors separated by an impedance inverter of characteristic admittance K_{12}. This combination if followed by a lossless two-port network described by its transfer matrix $[N(p)]$ and terminated in a 1Ω load resistance. Shifting zero frequency to $+\alpha$ for one channel and $-\alpha$ for the other, the symmetrical bandpass channel diplexer will be of the form shown in Fig 2 with

$$C_1' = C_1 \qquad C_2' = C_2 \tag{1}$$

$$R = 1 + \varepsilon(\alpha^{-4}) \tag{2}$$

$$K_{12}' = K_{12}\left(1 - \frac{\alpha^{-2}}{8C_1^2}\right) + \varepsilon(\alpha^{-4}) \tag{3}$$

where $\varepsilon(\alpha^{-4})$ indicates an error term ofthe order α^{-4} and the frequency invariant reactances are given by

$$\frac{B_1'}{C_1} = -\left(\alpha + \frac{\alpha^{-1}}{2C_1^2} + \left(\frac{K_{12}^2}{C_2} - \frac{1}{C_1}\right)\frac{\alpha^{-3}}{8C_1^3}\right) + \varepsilon(\alpha^{-5}) \tag{4}$$

and

$$\frac{B_2'}{C_2} = -\left(\alpha + \frac{K_{12}^2\alpha^{-3}}{8C_2C_1^3}\right) + \varepsilon(\alpha^{-5}) \tag{5}$$

whilst,

$$[N'(p)] = [N(p-j\alpha)] + [\varepsilon(\alpha^{-4})] \tag{6}$$

and

$$[N''(p)] = [N(p+j\alpha)] + [\varepsilon(\alpha^{-4})] \tag{7}$$

Also, there is an increase in the insertion loss over the passband of the opposite channel given by

$$\Delta L(db) = 6 + 10\log\left(1 + \frac{\alpha^{-2}}{4C_1^2}\right) \tag{8}$$

The remarkable feature about these results is that the undefined part of the network characterized by the transfer matrix $[N(p)]$ only suffers a shift in freqency up to the fourth ordered correction term. For fourth ordered and above, the change in $[N(p)]$ is very complicated but for most applications is sufficiently small to neglect.

The complete proof of the above results has been given in a full paper [1]. However, the key elements will be given here.

The basic approach is to maintain the correct distribution of the zeros of the reflection coefficients at the individual channel ports and also at the common port where both sets corresponding to each of the channels are obtained. Expanding the modified element values in terms of α^{-1} where 2α is the frequency difference between the centres of the two channels, then the correct design is achieved when the coefficients of these expansions are of the values required to maintain the correct zero distribution of all three reflection coefficients.

The first ordered terms which arise when $\alpha \to \infty$ and the channels become well separated resulting in the recovery of the doubly terminated single filter case. Applying a first ordered correction to all n elements

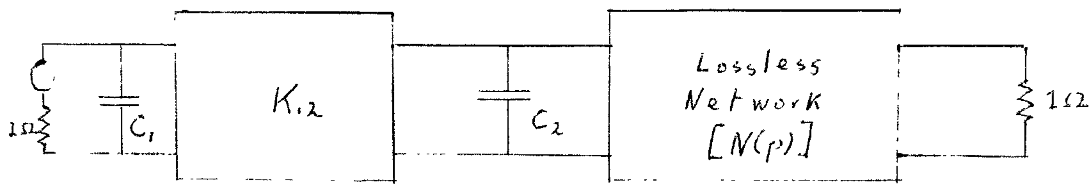
1Ω
C_1
K_{12}
C_2
Lossless
Network
[N(p)]
1Ω

Fig 1

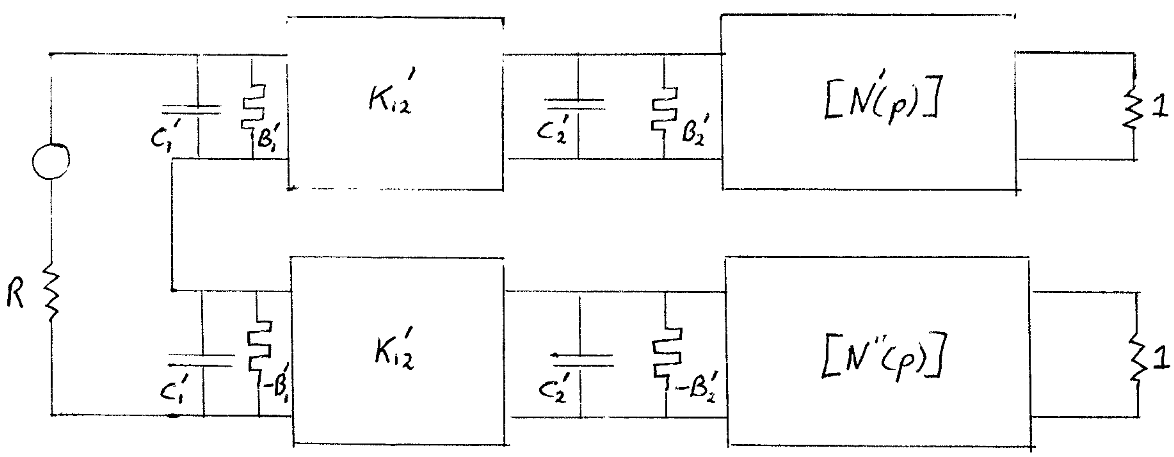
R
C_1'
B_1'
K_{12}'
C_2'
B_2'
[N'(p)]
1
C_1'
$-B_1'$
K_{12}'
C_2'
$-B_2'$
[N''(p)]
1

Fig 2

in each channel to satisfy the zero distribution at all n frequency points, results in a set of n simultaneous equations with n unknowns. However, the solution to these equations may be shown to be that all corrections are identically zero apart from a change in resonant frequency of the first element expressed by the frequency invariant reactance B_1'. For second and third ordered corrections similar degeneracies occur resulting in the design equations as expressed in equations $1 \to 7$. However for fourth order and above, all elements require a finite and very complicated modification but in most applications this is sufficiently small to neglect even when the channels move so close as to be contiguous.

Example of a Waveguide Symmetrical Diplexer

The following specification was given for a diplexer to be constructed in WR137.

Channel 1

Passband 6396.5 $\pm$ 13MHz, V.S.W.R. $<1.1:1$

Stopband f>6425.5, Ins. Loss >35db
f>6325.5, Ins. Loss >45db

Channel 2

Passband 6438.5 $\pm$ 13MHz, V.S.W.R. 1.1:1

Stopband 6409.5, Ins. Loss >35db
6509.5, Ins. Loss >45db

Converting to an equivalent prototype network, α = 1.61 and the first stopband specification becomes the limiting one. Taking into account the advantage given by equation (8) and using a Chebyshev prototype, 5 cavities per channel are required (6 cavities per filter would have been necessary to meet the individual channel requirements if the diplexer were to be constructed using a circulator).

Using a similar technique to the design of direct-coupled waveguide filters but taking into account the modifications described in equation $1 \to 6$, a diplexer was obtained for a physical realization in the form shown in Fig 3. The major change in each channel, as compared to the individual doubly terminated filter case, apart from relative shifts is resonant frequencies of the first two cavities which is readily obtained by the normal cavity tuning screws, was the increase of 10% in the susceptance of the second iris whilst the first and all others remained virtually unchanged. This effectively also provides the extra attenuation across the opposite passband.

The experimental results are shown in Fig 4 and show very close agreement with theory with the diplexer being tuned on reflection at the common port.

Conclusions

A very simple design process has been given for symmetrical bandpass channel diplexers from which all forms of relatively narrow bandwidth microwave diplexers can be designed. An example on a waveguide direct coupled cavity diplexer was given to illustrate the close agreement which can be achieved with theory.

Reference

1 J D Rhodes, 'Direct Design of Symmetrical, interacting Bandpass Channel Diplexers' submitted for publication, IEE Journal on Microwaves, Optics and Acoustics.

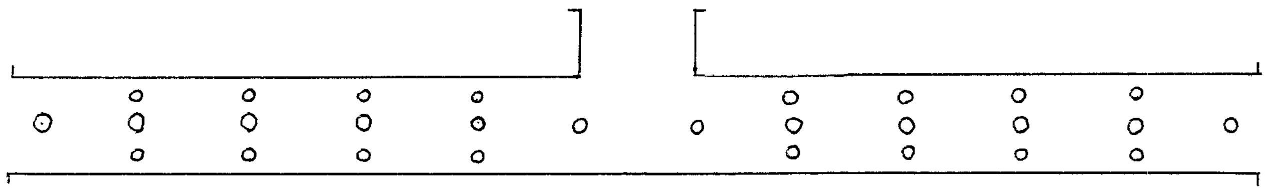

Fig 3

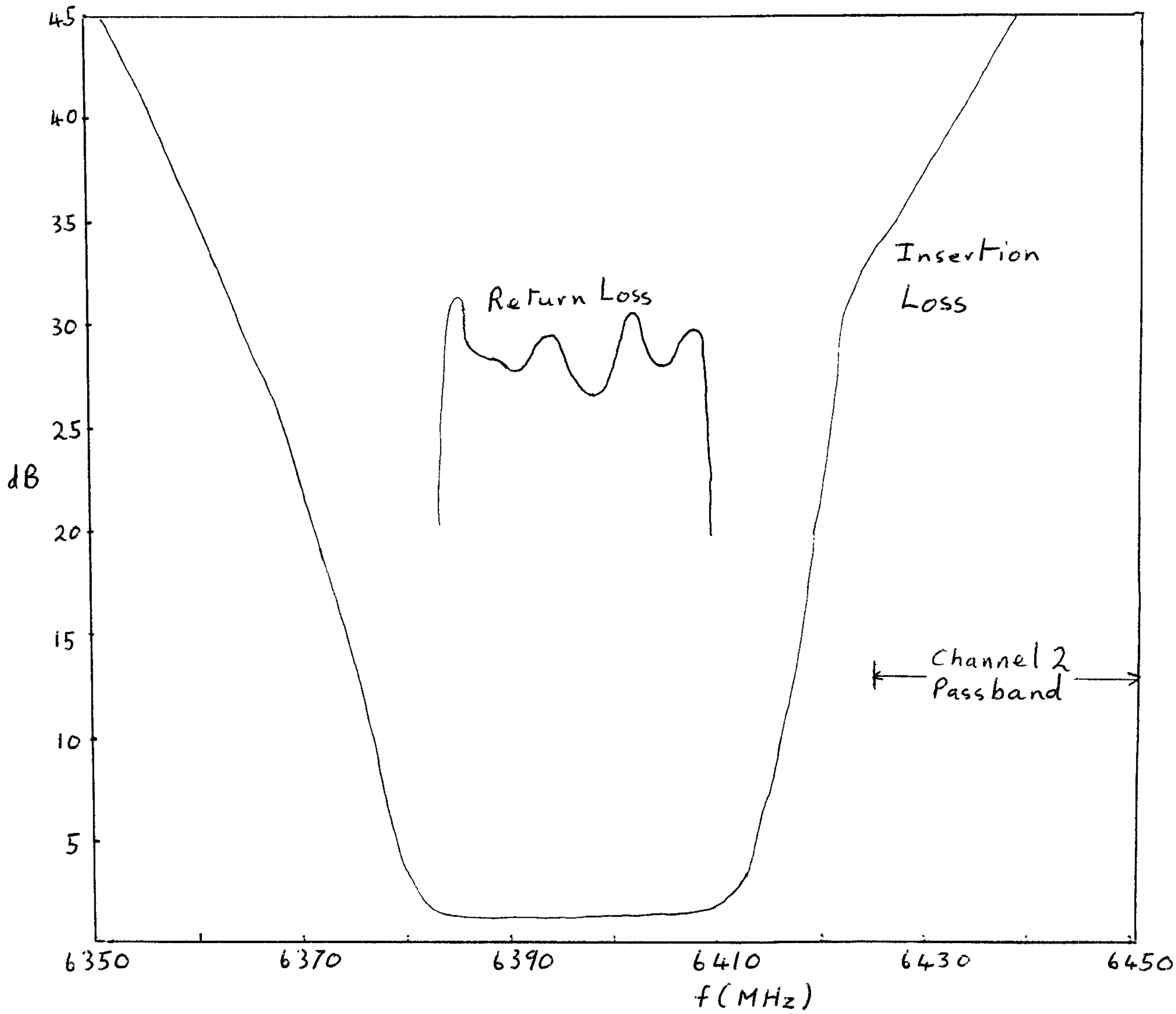
45
40
35
30
25
20
15
10
5
dB
Return Loss
Insertion Loss
Channel 2 Passband
6350
6370
6390
6410
6430
6450
f (MHz)

Fig 4