SYNTHESIS OF NON-CONTIGUOUS DIPLEXERS USING BROADBAND MATCHING THEORY

Ralph Levy

R. Levy Associates
1897 Caminito Velasco, La Jolla, CA 92037

ABSTRACT

An approximate but highly accurate simple closed form solution for the element values of non-contiguous lowpass/highpass diplexers has been obtained using broadband matching theory. Excellent results are demonstrated by analysis of several diplexers of degree 10 having return loss of 26 dB. Suggestions are made for extending the method to other types of non-contiguous multiplexers.

INTRODUCTION

Closed-form formulas for the design of contiguous diplexers are well known, but no such formulas have been available for lowpass/highpass non-contiguous diplexers having Chebyshev characteristics. This paper presents an analytical derivation of a set of formulas in closed form which are approximate in the sense of giving a non-exactly equi-ripple result for the common port VSWR, but one that is acceptable by normal standards. One may note that even the existing contiguous diplexer theory based on singly-terminated prototypes is also an accurate approximation.

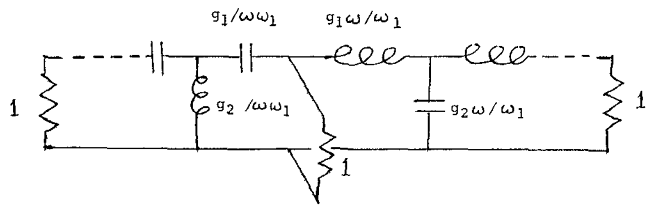

Fig. 1 Diplexer circuit

The non-contiguous diplexer consists of lowpass and highpass filters connected at a common junction, as shown in Fig. 1, which illustrates a shunt connection. The two filters are assumed to have Chebyshev response characteristics with all transmission zeros at the extreme frequencies , although more general cases with finite frequency attenuation poles are amenable to somewhat different treatment.

Synthesis of non-contiguous multiplexers having several narrow bandwidth channels has been described [1]. This is based on a perturbation theory where the the input admittance of each channel is expressed as a series expansion of terms dependent on the inter-channel spacings. The method is suitable for total bandwidths up to one octave, and is not applicable to the lowpass/highpass case considered here.

This paper describes an approximate but very accurate analytical method based on the theory of broadband matching. Each filter is designed as a broadband matching network over its respective low or high passband, with the immittance of the other filter representing the load network to be matched. It is found that excellent results are obtained when only the first element of the "other" filter is taken into account in the load network. Good results almost to fully contiguous operation are obtained for high-degree Chebyshev lowpass/highpass diplexers.

THEORY

Fig. 2 illustrates the diplexer characteristics for low and high pass filters designed using the same prototype, leading to the reciprocal relationship

$$\omega \rightarrow 1/\omega \qquad (1)$$

where the equi-ripple pass band edges are ω_1 and $1/\omega_1$.

CH2870-4/91/0000-0543$01.00 © 1991 IEEE

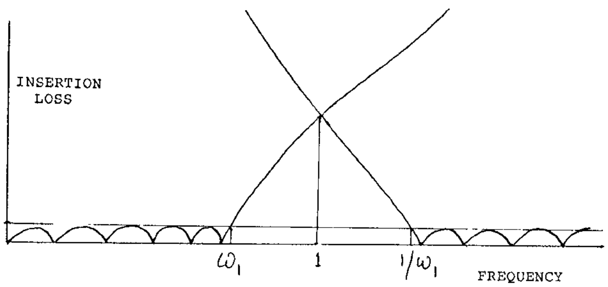

Fig. 2 Diplexer response characteristics

When ω_1 is sufficiently small the problem may be solved with marginally acceptable results by designing independent doubly-terminated filters. The ripple closest to cut-off is usually quite bad, and recourse to optimization is generally required.

At the other extreme we have the contiguous situation which effectively defines an upper limit to ω_1 lying typically in the range .6 - .9, depending on degree n and ripple level.

Here we are interested in the solution for intermediate cases.

As stated above the method is to design each filter as a matching network, with the first element of the other filter in shunt across the common port representing the load network to be matched. There are two sets of conditions to be simultaneously satisfied, one for each filter.

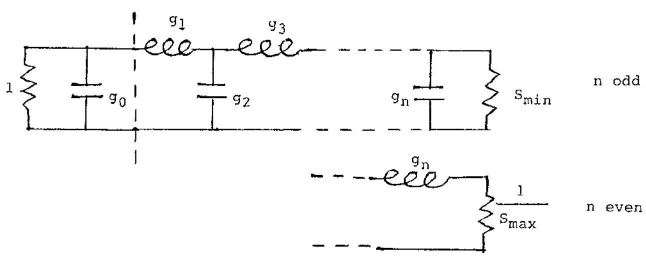

Fig. 3 Lowpass matching nework

Consider the matching problem of Fig 3. having the closed form solution given previously [2]. Since the network has n+1 reactive elements, n for the filter and 1 for the load element due to the other channel, it is logical to modify the notation given in [3] so that the load element is g_0 and the filter elements have indices from 1 to n, leading to the formulas

$$g_0 = \frac{2\sin(\pi/2N)}{x - y} \tag{2}$$

$$g_r g_{r+1} = \frac{4\sin(2r-1)\pi/2N \, \sin(2r+1)\pi/2N}{x^2 + y^2 + \sin^2 r\pi/N - 2xy\cos r\pi/N} \tag{3}$$

for

$$r = 0,1,2,\ldots n, \quad \text{with} \quad N = n+1 \tag{4}$$

and

$$S = (g_n/g_0).(x+y)/(x-y) \tag{5}$$

The matching network possesses an equi-ripple response with the reflection coefficient varying between

$$\rho_{max} = \frac{\cosh N\sinh^{-1} y}{\cosh N\sinh^{-1} x} \tag{6}$$

and

$$\rho_{min} = \frac{\sinh N\sinh^{-1} y}{\sinh N\sinh^{-1} x} \tag{7}$$

The value of the terminating resistance is equal to the VSWR

$$S_{max} = (1+\rho)/(1-\rho) \tag{8}$$

calculated from (6) when N is even and is equal to $1/S_{min}$ calculated from (7) when N is odd.

In matching theory the value of the maximum pass band reflection coefficient (6) is minimized under the constraint imposed by the load network, but here we have a different set of conditions to be satisfied, namely that the reactive part of the load network is equal to that of the first element of the other channel. Referring to Fig 1, this gives the condition

$$\frac{g_0\omega}{\omega_1} = \frac{\omega\omega_1}{g_1}$$

i.e.

$$g_0 g_1 = \omega_1^2 \qquad (9)$$

When the similar set of conditions is written down for the matching of the highpass filter it is found that the identical equation (9) results, as expected from the reciprocal relationship (1).

Hence the desired set of g values for a given VSWR is obtained by solving for the known maximum reflection coefficient (6) under the constraint imposed by (9), i.e. there are two equations to solve for the two unknowns x and y.

Actually it is necessary to modify the theory to allow for the value of the terminating resistances (S_{max} for N even or $1/S_{min}$ for N odd), noting that when we replace these by unity, the actual VSWR will increase to S_{max}^2 for N even and to $S_{max}S_{min}$ for N odd. Thus in the case of N even we must design for a VSWR of $\sqrt{S_{max}}$, and since in practice it turns out that there is little difference between S_{max} and S_{min}, we use the same value for N odd.

In the more general case when the low and high pass filters have different degrees, we will have 4 equations with 4 unknowns, readily solvable by iteration.

RESULTS

To illustrate the validity of the method it was decided to investigate high-degree cases having very good return losses, thus insuring a severe test of the theory.

Typical results for 10 section non-contiguous diplexers are shown in Fig. 4 for a return loss of 26 dB with normalized band edge parameters ω_1 of .4, .7 and .81, the latter representing 98% of the contiguous case.

The return loss is practically identical to the design level almost everywhere, the only notable deterioration being to 20 dB for the almost-contiguous case. As ω_1 decreases the actual bandwidth increases, which may be corrected by compensation, (i.e. design for a slightly smaller ω_1). Also one or two of the return loss poles become suppressed compared with the prototype.

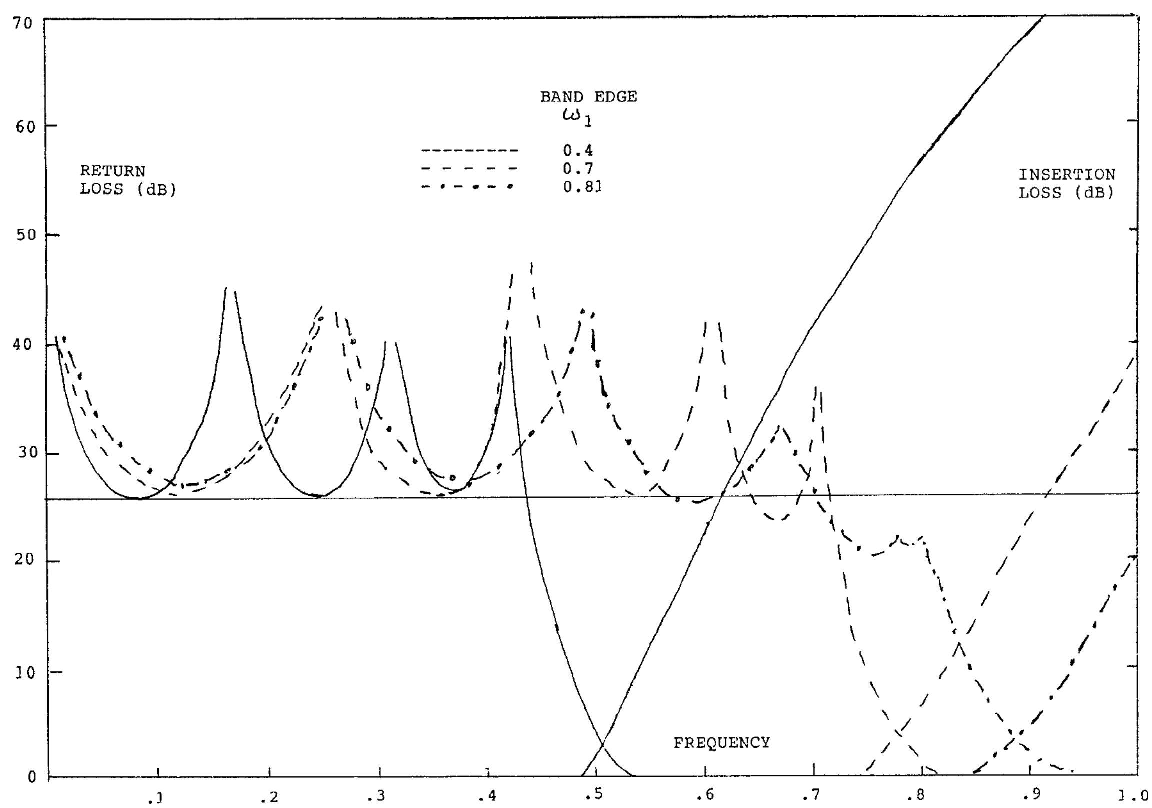

Fig. 4 Example diplexer characteristics

Element values for a number of cases, including those plotted in Fig. 4, are given in Table 1, together with the doubly- and singly-terminated (contiguous) values for purposes of comparison. The non-contiguous designs may be considered reasonably asymptotic to the singly-terminated values at the high ω_1 end, but not to the doubly-terminated values at the low end. This is not surprising since analysis shows that return loss of the latter is only 12.8 dB when applied to the case $\omega_1 = .5$ and 15 dB for $\omega_1 = .4$, indicating the necessity for the new equations.

We note that in this theory the g values all change compared with the doubly-terminated values, as in the case of the g values for contiguous diplexers.

CONCLUSIONS

Closed-form formulas for the design of non-contiguous lowpass/highpass diplexers have been presented, giving an almost perfect equi-ripple common port VSWR response. The theory is based on broadband matching with the out-of-band channel representing the load network for the in-band channel.

It would be interesting to extend the theory to situations other than the simple lowpass/highpass case, e.g. to several broadband bandpass channels. Here it is unlikely that closed-form equations would result, but the principle of applying broadband matching theory still holds, and numerical synthesis techniques might be applied.

Another extension would be to take into account the first two or more elements of the out-of-band filter, giving a more complicated matching problem which possibly could be tackled using general broadband matching theory [3].

REFERENCES

[1]. J. D. Rhodes and R. Levy, "A generalized multiplexer theory", IEEE Trans. on Microwave Theory and Techniques, vol. MTT-27, pp. 99-111, Feb. 1979.

[2]. R. Levy, "Explicit formulas for Chebyshev impedance-matching networks, filters and interstages", Proc. IEE, vol. 111, pp. 1099-1106, June 1964.

[3]. D. C. Youla, "A new theory of broad-band matching", IEEE Trans. on Circuit Theory, vol. CT-11, pp. 30-50, March 1964.

TABLE 1

Element values for diplexers, n=10

g	1	2	3	4	5	6	7	8	9	10
Doubly-term.	0.8299	1.4406	1.8280	1.7306	1.9435	1.7580	1.9132	1.6535	1.5926	0.7507
0.4	0.6379	1.0558	1.1752	1.4615	1.4130	1.6192	1.4755	1.5484	1.2596	0.7299
0.5	0.7842	1.2447	1.3369	1.6193	1.5370	1.7387	1.5707	1.6765	1.3285	0.7685
0.6	0.9228	1.3990	1.4595	1.7271	1.6209	1.8129	1.6317	1.7300	1.3695	0.7870
0.7	1.0520	1.5235	1.5525	1.8017	1.6796	1.8603	1.6726	1.7618	1.3949	0.7950
0.81	1.1841	1.6287	1.6325	1.8542	1.7278	1.8887	1.7047	1.7753	1.4092	0.7880
Contig. (0.8277)	1.2326	1.6551	1.5358	1.7060	1.5387	1.6846	1.4917	1.5706	1.2355	0.7112