PRACTICAL REALIZATION OF BROADBAND MICROWAVE DIPLEXERS

By

A. J. Anselmo and A. F. Hinte

AIL, a division of Cutler-Hammer

Melville, New York

Abstract

The computer-aided design and practical realization of 20- to 50-percent bandwidth complementary-filter diplexers is described. Each diplexer consists of an interdigital band-pass filter and a hybrid (direct-coupled resonator/parallel-coupled resonator) band-stop filter. Measured and computed performance data of a typical diplexer is presented.

Introduction

Advances in multioctave antenna technology have created a need for broadband microwave multiplexers to direct signals to several suboctave-bandwidth receivers. To exploit the low-noise capabilities of modern microwave receivers, the multiplexer must provide both low loss and low VSWR. The theoretical capability to accomplish this exists with a microwave multiplexer configured of several cascaded complementary filter diplexers, however, the realization of well-matched, low-loss microwave diplexers having wide-channel bandwidths is a formidable problem. The solution to this problem--the practical realization of the diplexer building-block for use in multiplexers of 20- to 50-percent channel bandwidth, at frequencies up to 12 GHz--is the subject of this paper and its achievement is substantiated by measured data presented herein.

Technical Discussion

A complementary-filter diplexer is a diplexer formed by the series or parallel connection of two filters designed to have conjugate-matched input impedances. These diplexers are theoretically matched at all frequencies, thereby allowing them to be cascaded to form a well-matched multiplexer.

In the microwave frequency range, the best complementary diplexer described to date is the band-pass/band-stop diplexer described by Matthaei and Cristal(1). Consisting of an interdigital band-pass filter and a parallel-coupled, band-stop filter, this diplexer is physically realizable for channel bandwidths up to about 15 to 20 percent. The limitation is the band-stop filter. For bandwidths above 15 to 20 percent, the gaps between the main-line and the band-stop resonators become too small to control.

This limitation is overcome by replacing the parallel-coupled resonator filter with a hybrid filter which combines direct- and parallel-coupled resonators, as shown in Fig. 1. Since the direct-coupled to parallel-coupled stub equivalence is exact, either physical configuration may be used without altering the filter's input impedance. The input impedance of this hybrid filter is also conjugate-matched to that of the interdigital band-pass filter so that the complementary property of the diplexer is maintained.

The combination of direct- and parallel-coupled resonators is needed because of the large variation in stub impedances which result from the band-stop filter design. For example, a 40-percent bandwidth diplexer will typically require about a 50-ohm stub for the input resonator, and a 500-ohm stub for the output resonator. This large asymmetry is a result of applying Kuroda's Identity from only one side of the band-stop filter. In the hybrid filter, direct-coupled resonators are used for stub impedances up to about 125 ohms, and parallel-coupled resonators are used for higher impedances. With the addition of this hybrid band-stop filter, band-pass/band-stop diplexers can now be realized for channel bandwidths ranging from a few percent (using an all parallel-coupled, band-stop filter), up to approximately 50 percent (where the realizability of the interdigital filter is the limiting factor).

Truly complementary filters must be derived from single-ended Butterworth prototypes and therefore, result in diplexers which have a Butterworth amplitude versus frequency characteristic. Since an equal-ripple response is often required, it is necessary to be able to design diplexers from Tchebycheff prototypes. Although Tchebycheff filters can never be truly complementary, it has been found that by adjusting the design center frequencies and design bandwidths of the band-pass and the band-stop filters such that the real part of the normalized input admittance of each equals 0.5 at the desired cross-over frequencies, diplexers having excellent characteristics can be realized.

This design optimization is accomplished with the aid of a digital computer and three programs. Each program has the specific function listed below:

Program One: Design and analyze the band-stop filter

Program Two: Design and analyze the band-pass filter

Program Three: Analyze the diplexer

A three-program approach is used because it allows greater flexibility in combining different filters to form diplexers.

In Program One, the band-stop filter is designed using the algorithm proposed by Cristal[2] and modified by Matthaei and Cristal[1] to account for the single-ended application of Kuroda's Identity. The analysis segment utilizes ABCD matrices applied to a direct-coupled stub, band-stop filter. Using this program, the design parameters, center frequency and bandwidth, are adjusted such that the real part of the normalized input admittance of the band-stop filter equals 0.5 at the desired crossover frequencies.

In Program Two, the interdigital filter is designed using the equations of Matthaei[3], and the analysis is performed utilizing ABCD matrices applied to the open-wire equivalent circuit. Here, again, the design parameters, center frequency and bandwidth, are adjusted such that the real part of the normalized input admittance equals 0.5 at the desired crossover frequencies.

In addition to the design and analysis described above, Programs One and Two store the ABCD values of each filter, at each frequency, in binary data files. Program Three reads both files, and computes the performance of the overall diplexer.

All three programs are fully conversational and calculate performance parameters such as insertion loss (including the effects of dissipation), return loss, group delay, and phase over any specified frequency range.

With the aid of the computer programs just described, it is a relatively simple matter to determine the design parameters of the band-pass and band-stop filters and calculate total diplexer performance. The major problem is in converting these design parameters to physical dimensions which will provide the desired bandwidths. Very close matching of the bandwidths of the band-pass and band-stop filters is critical to achieving good diplexer performance; for example, bandwidths mismatched by more than 2 percent will increase the input VSWR over a significant portion of the passband.

The band-pass filter is a conventional interdigital filter and its physical dimensions are determined by calculating the self and mutual capacitances of the resonators using the equations in [3], and converting these to resonator widths and gaps using Getsinger's curves[4]. Little or no bandwidth shrinkage occurs with this procedure if a ratio of $t/b = 0.2$ is used.

Determining the physical dimensions of the band-stop filter, however, only appears to be a simple matter. The computer has already determined the characteristic impedances of the stubs and interconnecting lines, and converting these to physical dimensions is not difficult. The problem is that these impedances are for an idealized circuit having no parasitics or discontinuities. The fact is that the T-junction discontinuities (at the junction of each stub resonator to the mainline), increase the effective impedance of the resonators and, therefore, significantly narrow the bandwidth of the filter. To account for these discontinuities, an accurate model of the stripline T-junction is needed.

The equivalent circuit for a stripline T-junction is shown in Fig. 2. It has four variable parameters; d_1, d_2, jB and N^2. In a band-stop filter, the first parameter d_1 (the foreshorting between resonators) is not critical, and d_2 and jB affect resonator tuning, which is adjustable. Available data[5] on these parameters is sufficiently accurate to obtain good diplexer performance.

However, this is not the case for the turns ratio, N^2, which directly affects the filter bandwidth. Available data[5] on this parameter is in error by up to 10 percent, depending on the frequency and the t/b ratio of the stripline. If this data is used to design a band-stop filter with a t/b greater than 0.12, the filter will not have the desired bandwidth and the diplexer performance will be severly degraded.

For the diplexer described in this paper, this error has been corrected by measuring the effective impedance of various stubs connected to a 50-ohm mainline, calculating N^2, then comparing these values to the values given by[5]. This comparison gives a correction factor which is assumed to be constant for this ground plane spacing, t/b ratio, and frequency, for all values of mainline impedance. Fig. 3 is a family of curves of N^2 versus Z_{02} with Z_{01} as a parameter; for $b = 0.25$ inch, $t/b = 0.2$, and $f = 5.5$ GHz. This family was generated by multiplying the values given by[5] by the correction factor described above.

These curves are used as follows. Enter the graph at Z_{02} equal to the desired resonator impedance (Z_R) assuming no discontinuity effect. Rise vertically to the curve for Z_{01} equal to the average of the mainline impedance to the left and right of this resonator. Read the value N^2. The actual resonator impedance is $Z_R' = N^2 Z_R$.

Using the design procedure and computer programs described above, a 40-percent bandwidth band-pass/band-stop diplexer was designed and built. The filters were designed from $N = 7$, 0.05 dB-ripple Tchebycheff prototypes. The diplexer, shown in Fig. 4, was constructed in 1/4-inch ground plane spacing strip transmission line having a ratio of $t/b = 0.2$. Figs. 5 and 6 show a comparison of the measured and computed performances and demonstrate the validity and accuracy of this design and analysis procedure.

Conclusion

Complementary band-pass/band-stop diplexers having channel bandwidths up to 50 percent can now be realized. These diplexers are matched over very wide frequency ranges and can be cascaded to form well-matched, high-performance multicouplers.

Acknowledgements

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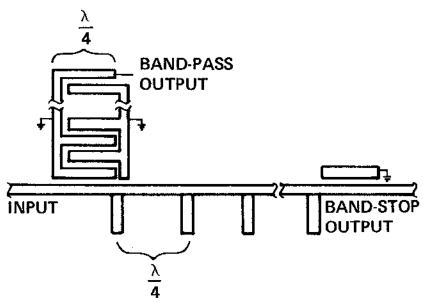

Fig. 1. Broadband Band-Pass/Band-Stop Diplexers Configuration

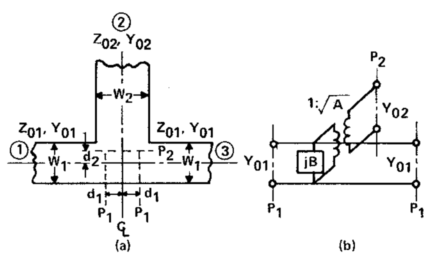

Fig. 2. Equivalent Circuit of a Stripline T-Junction

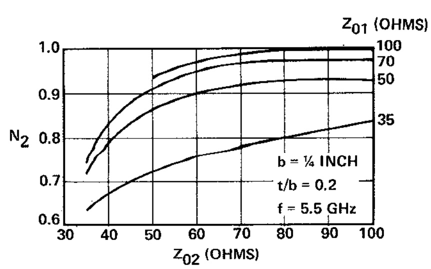

Fig. 3. N^2 Versus Z_{02}

References

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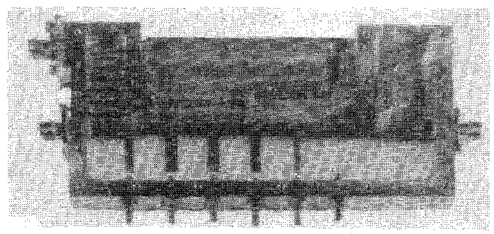

Fig. 4. Band-Pass/Band-Stop Diplexer

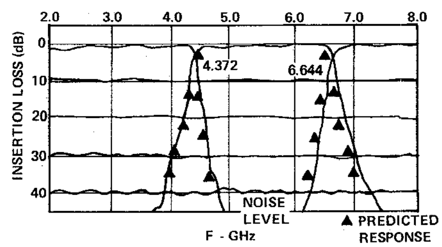

Fig. 5. Plot of Diplexer Response

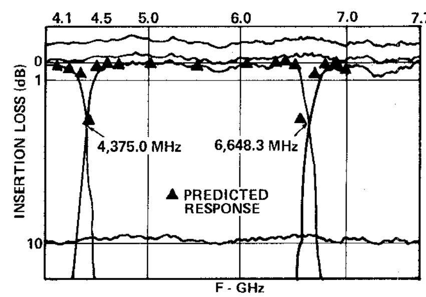

Fig. 6. Expanded Plot of Passband and Crossover Regions of Diplexer