MULTI-OCTAVE COMBLINE-FILTER MULTIPLEXERS

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Abstract

Common-junction combline-filter multiplexers covering multi-octave frequency ranges have successfully been built. They offer significant cost and performance advantages over previous approaches to broadband microwave frequency multiplexing.

Introduction

The combline filter has become the mainstay of microwave band-pass filters for moderate to octave bandwidths. It was introduced with narrow-band design equations by Matthaei in 1963[1], and design approaches for broad-bandwidth units were later presented by Pregla[2] and Wenzel[3]. The popularity of the combline compared to other types of filters can be attributed to small size, broad stop band, and ease of manufacture. This last is true because the filter consists primarily of a highly redundant inductive array of rods, all mounted on a common surface, which not only can be fabricated with a good degree of accuracy, but also can have all significant parameters conveniently varied by tuning screws. This combination allows filters with large numbers of resonators to be tuned nearly to theoretical performance without excessive cost.

Multi-octave frequency multiplexers have in the past not enjoyed such manufacturing advantages. They have typically been constructed as cascades of diplexers, the diplexers often consisting of difficult elliptic-function high-pass and low-pass filters. Since ripple and VSWR increase significantly as each additional diplexer is added to the cascade, the user has usually been faced with the choice of either marginal performance at reasonable cost or good performance at excessive cost; i.e., more than twice the cost per channel of a comparable single-channel filter. If the cascade-type multiplexers could be replaced by single-junction devices, and if the filters involved could be comblines, one should be able to obtain good performance for a reasonable manufacturing cost. This paper describes how such combline multiplexers have been successfully designed and built.

Background

A design method for combline-filter multiplexers (along with much excellent material on microwave multiplexers in general) was presented several years ago by Matthaei and Cristal[4]. Their design equations are based upon narrow-band approximations and the junction design, consisting of high-impedance lines connected between the junction and the input resonators of the separate channel filters, is limited to total frequency ranges of the order of one octave. In the intervening years many combline multiplexers have been built using either this approach or other similar ones. These have generally shown satisfactory performance for band-edge ratios up to 2.5:1, but no greater. The reason for this limitation can be seen in the admittance plot of Figure 1. This is for a singly-terminated combline channel filter with a series-inductance input, comparable to the junction connection described above. Note that the susceptance becomes increasingly negative below the pass band, because the input is directly connected to ground at d-c. This means that in a multiplexer consisting of channel filters of this type, the highest frequency filter will tend to short out the lowest frequency filter, an effect which becomes more pronounced with increasing frequency range.

For a parallel-connected multiplexer to operate satisfactorily over a broad bandwidth, the channel filters should be minimum-susceptance. A combline filter is not minimum-susceptance, however, and it cannot be made so by foreshortening or designing from a singly-terminated prototype. There is necessarily excess shunt inductive susceptance because of the direct connection to ground at d-c. It is only through the judicious choice of input line lengths and impedances that band-edge ratios as great as 2.5:1 can be achieved at all.

Design Approach

A minimum-susceptance band-pass filter suitable for parallel-connection multiplexing is shown in Figure 2. This type of filter is easily designed from a reactance transformation of a low-pass prototype. The series-resonant series branch at the input presents a low impedance within the pass band and a high impedance elsewhere; therefore it does not short out any of the other channels, and filters of this form can be connected in parallel at will. Unfortunately, this circuit is awkward to realize at microwave frequencies.

A more practical microwave circuit, however, can be realized by combining the series-resonant series input branch with a remaining structure identical to a combline filter. This forms a truly minimum-susceptance combline filter suitable for broad-bandwidth multiplexing. The lumped-constant prototype form of this filter is shown in Figure 3, while the admittance plot of a typical channel filter, in its distributed form, is shown in Figure 4. Note that the susceptance below the pass band is well behaved, dropping to zero at d-c. This type of filter can be used to build multi-octave band-pass multiplexers. There is no danger of the high frequency filters shorting out the low frequency filters. Instead, the frequency range is limited by the spurious resonances of the lowest frequency filter interfering with the highest. This imposes a requirement for short electrical length for the resonators of the lowest frequency filter.

The design procedure for this type of filter so closely parallels that of Wenzel[3] for the combline filter, that it will not be repeated here. The major difference is that there are two transmission zeros at d-c instead of only one. Also, since the filter is used in broad-bandwidth multiplexing, it will almost always be designed for the singly-terminated case.

Practical Considerations

The series-resonant input circuit is the only real departure from a typical combline filter, and it can cause problems in some situations. The series capacitor can be realized in either distributed or lumped form, and its realization is straightforward except, perhaps, for the difficulty of adjusting it. The series inductor is most conveniently realized as a high impedance transmission line -- a poor approximation in most cases. The approximation can be avoided by transforming a redundant unit element all the way through the filter from the output end, through the series inductor (changing it to a shunt capacitor), and leaving the series capacitor at the junction. This procedure, however, has the disadvantage common to all procedures involving redundant unit elements -- all the impedances become more difficult to realize, because it is more difficult to keep a unit element from contributing to a filter's response that it is to let it contribute. The ideal solution seems to be to synthesize the prototype filter with a contributing unit element included, although this has not yet been attempted.

Regardless of the approximations used, however, the series inductor in this circuit represents an element which is conveniently realizable only for filters with wide bandwidths, as the impedance level increases with decreasing bandwidth. For bandwidths less than 30%, the impedance becomes too high, and the filter is usually better realized without the series-resonant input branch.

For contiguous-channel multiplexing, requirements in addition to those already mentioned are that the normalized real parts of the input admittances of adjacent channels pass through the value 0.5 at the crossover frequency and that the attenuation slopes of the two channels be equal and opposite in the crossover region. This latter criterion is not easily met with the circuit of Figure 3, because, like all combline filters, it has a very assymmetric response for wide bandwidths. The symmetry of the response (and, therefore, the ease of equalizing slopes in the crossover region) can be improved by using alternative forms of the circuit with more of the transmission zeros below the passband. These, however, require additional series capacitors. Because series capacitors are usually difficult to adjust, the tuning advantage typical of combline filters disappears rapidly as they are introduced. In practice it has been found that the equal-slope requirement can be compromised -- filters with design slopes as different as 2:1 have been successfully tuned for a well-matched crossover.

Parallel-connected band-pass multiplexers necessarily require some degree of susceptance annulling, as explained by Matthaei and Cristal[4]. This can be provided by a parallel-resonant circuit connected between the junction and ground, with zero-crossing and slope adjusted to best cancel out the net susceptance of all the channel filters. A convenient alternative, however, is to forego the series-resonant coupling for the lowest channel of the multiplexer, and simply couple it through a series inductor. This is permissable because there are no lower frequency channels which could be shorted out. Then no separate annulling circuit is required, because the inductive part is provided by the input to the low frequency channel, and the capacitive part can be provided by a tuning screw over the junction area. The susceptance plots in Figures 1 and 4 are an example of this approach. They are actually for the two channel filters of a contiguous diplexer.

Results

Several combline filter multiplexers have been built using the techniques described. Their performance has been very good, including low VSWR and insertion loss, high selectivity, and negligible crossover-frequency drift over temperature. In addition, there have been advantages in physical size and configuration, and in simplicity and reliability when compared with alternative forms of multiplexing. The frequency range of the widest design built so far is in excess of 5:1, and typical performance data for this design are shown in Figure 5. It is believed that the same technique can be used successfully for frequency ranges as great as 9:1 (e.g., a 2-18 GHz quadruplexer).

Summary

A technique for building multi-octave combline-filter multiplexers has been described. The individual channel filters are very similar to standard comblines, and they exhibit many of the advantages typically associated with single-channel filters. Performance of designs built to date has been excellent. It is anticipated that this type of multiplexer will assume an important role in multi-octave microwave systems.

Acknowledgements

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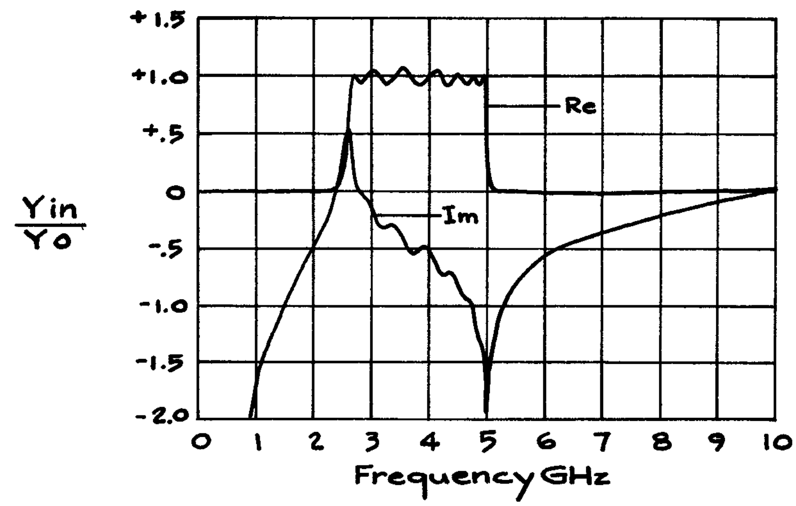

Fig. 1 - Admittance plot for singly-terminated combline filter with series-inductance input

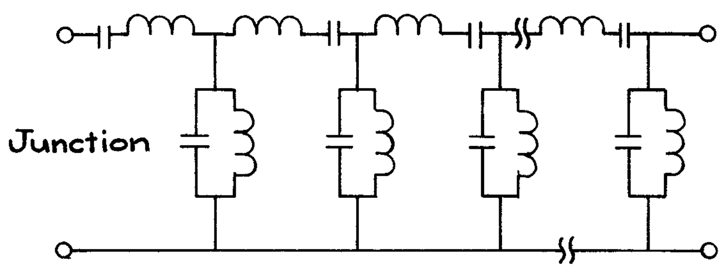

Fig. 2 - Minimum-susceptance band-pass filter suitable for parallel connection

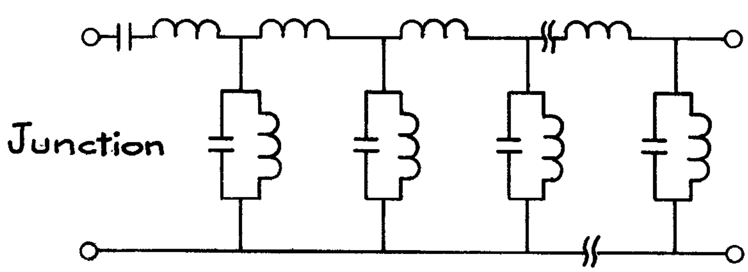

Fig. 3 - Prototype form of minimum-susceptance combline filter suitable for broad-bandwidth multiplexing

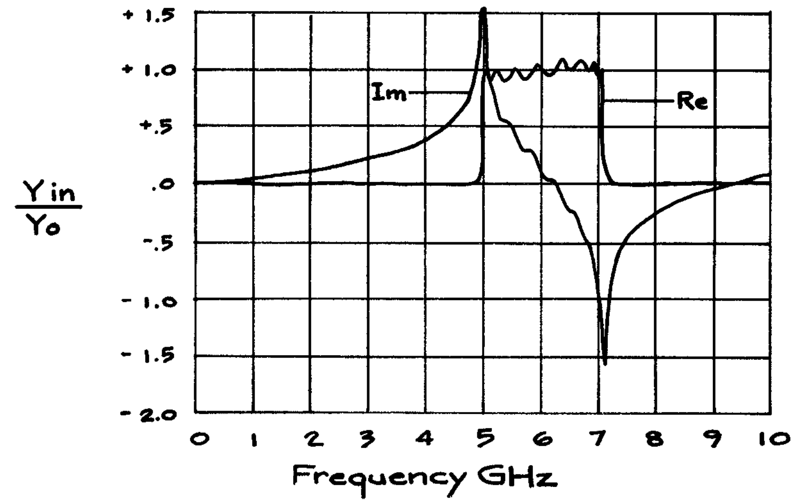

Fig. 4 - Admittance plot for minimum-susceptance singly-terminated combline filter based on prototype of Fig. 3

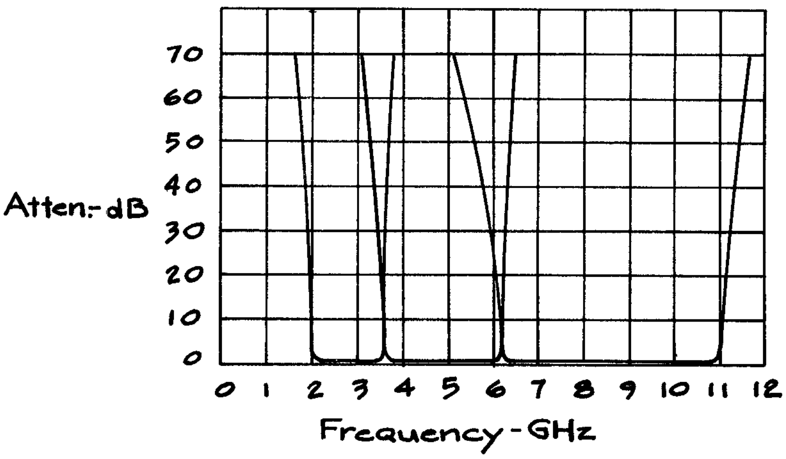

Fig. 5 - Typical performance data for broad-bandwidth combline triplexer