Microwave Multiplexer Design Based on Triplexer Filters

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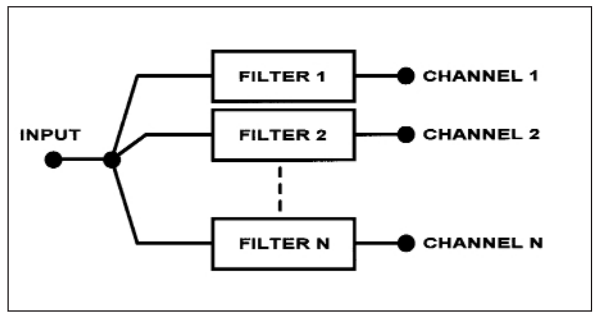
This article describes the design procedure for a multiplexer using the complementary triplexer filter method. This technique allows the designer to accomplish matched structures with a large range of frequencies. The required network conditions that can be realized with complementary filters are shown. The design procedure is developed for the bandpass and bandstop complementary filters connected at a common junction for narrow band applications. A stripline structure is employed to realize one triplexer. Good agreement between the experimental and theoretical results is achieved.

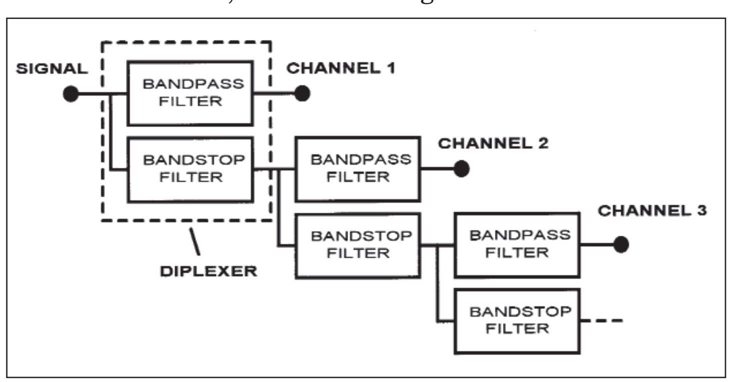


▲ **Figure 1. Diagram of a multiplexer using bandpass filters combined at a common input.**

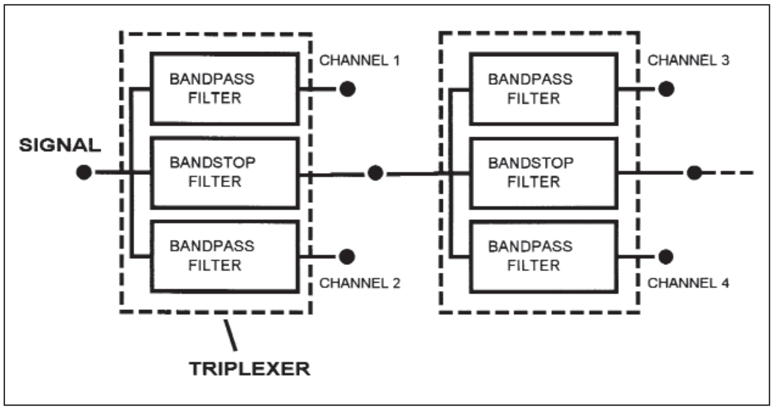
Introduction

Multiplexers split a wide frequency band into a number of signals of different frequency ranges. The separation of the desired frequency bands can be achieved by using bandpass filters combined at a common input, as shown in Figure 1. The main problem with this topology is that because filters are reflective devices, performance depends on a good impedance match between source and load inside the passband and a strong mismatch outside. If filters are carelessly connected together, undesirable mutual interaction effects appear, because the input impedance of each individual filter may be destructive outside its own passband. These effects may degrade the overall performance of the system.

One way of accomplishing a match over a wide frequency range is by using complementary filters. The sum of the input impedances will be real and constant for all frequencies. However, only minimum reactance and minimum susceptance networks can be made complementary [1]. When bandpass and bandstop complementary filters are connected in parallel or series, they present a constant-resistance input impedance. This combination constitutes a diplexer, which is the basic building block of a multiplexer. For each channel to be separated, one diplexer is needed, as shown in Figure 2.



▲ **Figure 2. Diagram of a multiplexer using cascaded complementary diplexers.**



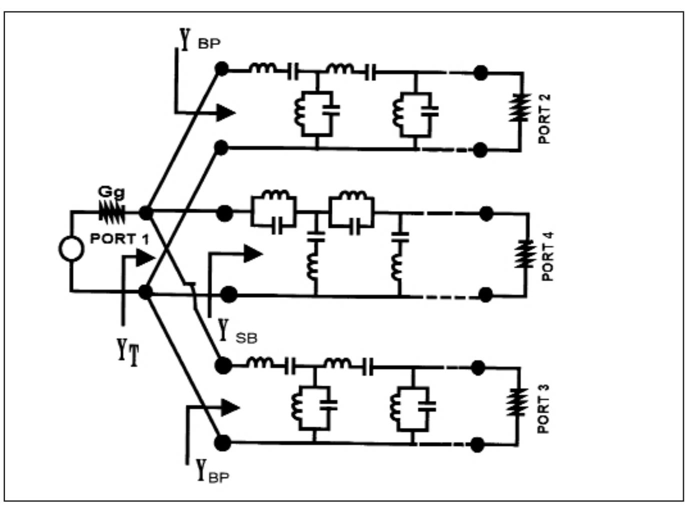
▲ **Figure 3. Diagram of a multiplexer using cascaded complementary triplexers.**

Another way to design the multiplexer is by using narrowband complementary triplexer filters [2]. The triplexer is a four-port device with a constant-resistance input impedance at the all frequencies, that separates out two contiguous channels. It consists of two contiguous bandpass filters and one complementary bandstop filter connected in parallel. It can be cascaded to obtain a multichannel system without interaction between the filter channels, as shown in Figure 3.

Complementary multiplexers

The design of complementary multiplexers is based on the construction and connection of triplexers in cascade. The triplexer consists of two bandpass filters and a bandstop filter arranged in a way that the sum of the bandwidth of the two bandpass filters is equal of the bandwidth bandstop filter. The cutoff frequencies of the stopband filter cross over at 3 dB points of the inferior cutoff frequency of one bandpass filter and the superior cutoff frequency of the other.

The filters are interconnected to produce a constant resistance input impedance at all frequencies. Figure 4 shows a schematic representation of a triplexer using bandpass and bandstop complementary filters connected in parallel [4].

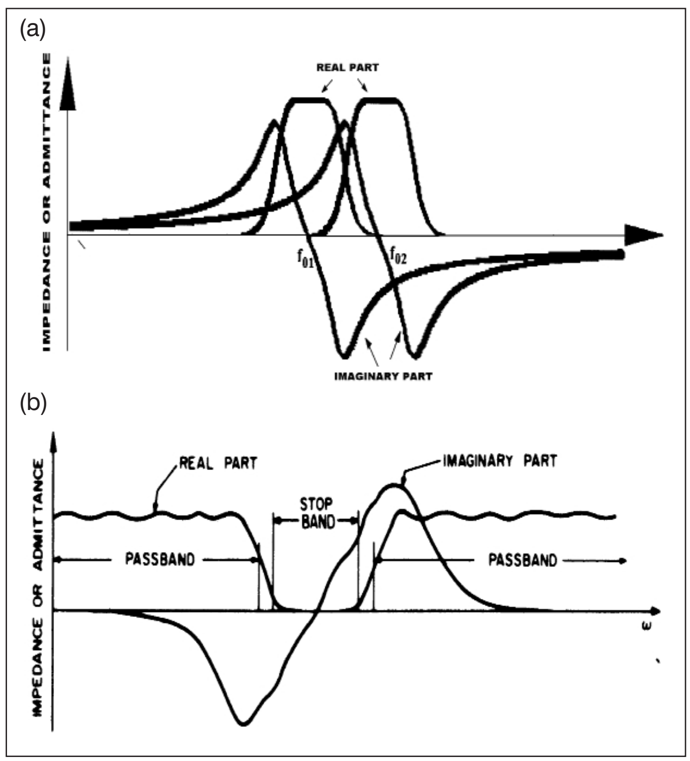


▲ **Figure 4. Diagram of parallel-connected triplexers using complementary filters.**

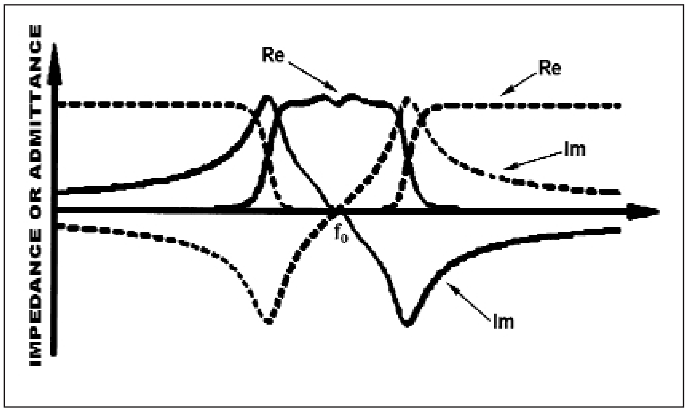
Since the networks are minimum susceptance, the input admittances of the bandpass filters and the bandstop filters have the general form illustrated in Figure 5. The input admittance of the triplexer is approximately the superposition of the input admittances of the individual filters. The design of the triplexer requires that the cutoff frequencies of each filter be such that the real part of the input admittance is approximately 0.5 mhos (normalized) for each filter. The normalized input admittance of the triplexer is shown in Figure 6. The imaginary components of the input admittances of the filters are conjugates of each other and provide a constant resistance input impedance for all frequencies [1, 4].

Design of complementary multiplexers

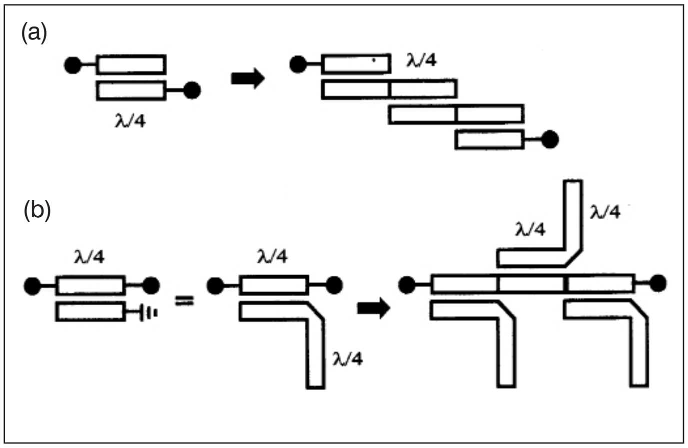
The triplexer may be used as the basic building block of multiplexers. Each triplexer separates two contiguous channels. Since each triplexer provides a constant resistance input impedance, it's possible to replace the load resistance of the bandstop filter by another triplexer, without affecting the performance of the system. Thus, several triplexers may be cascaded to separate the desired number of channels.



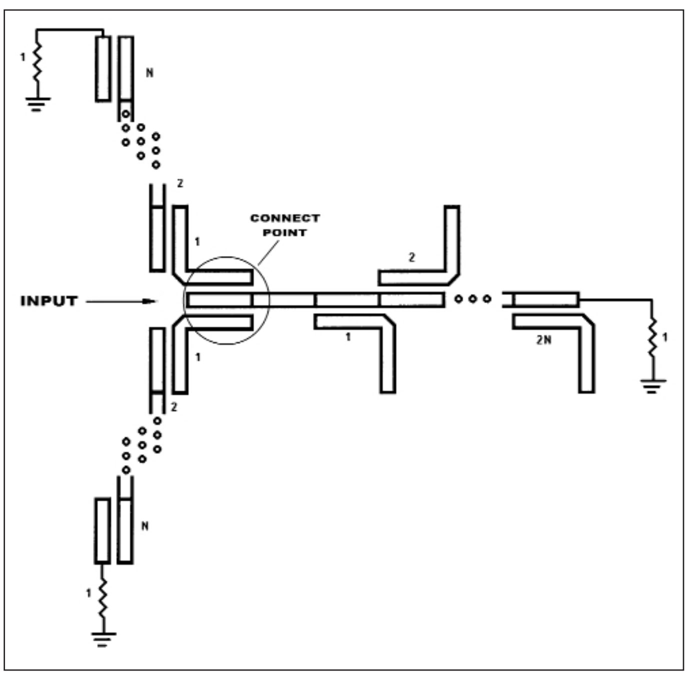
▲ **Figure 5. Input admittance of minimum-susceptance networks: (a) bandpass network characteristics; (b) bandstop network characteristics.**



▲ **Figure 6. Input admittance of the complementary triplexer.**



▲ **Figure 7. (a) Interdigital bandpass filter; (b) Parallel-coupled-resonator bandstop filter.**



▲ **Figure 8. Layout of the complementary triplexer.**

One topology of filters that is attractive for narrow channel triplexers are filters using quarter-wavelength parallel coupled sections. These filters can be designed with good accuracy, a compact structure and easy realization. The design of the filters is based on a cascade combination of quarter wavelength parallel coupled sections, as shown in Figure 7. For the bandpass filter, the input and output ports for each section are diagonally located, and the remaining terminals are open circuits. In the case of the bandstop filter, the input and output ports of each section are located on the same line, while the terminals of the other line are open and short circuits. Because of the narrow bandwidth, it is possible to replace the short circuits by open circuit quarter wavelength stubs, without disrupting the performance of the filter. Figure 8 shows the layout of the multiplexer composed by two bandpass filters and a parallel-coupled-resonator bandstop filter.

The interconnection problem

In a triplexer, adequate performance is obtained when the filters' input admittance characteristics are unaltered. This does not happen if a redundant element is introduced at the filters input ports. However, the narrow passband filter synthesis requires the introduction of at least one redundant element in the input port to achieve realizable impedance levels. Thus, the parallel connection of the filters that compose the triplexer cannot be used to obtain a complementary structure.

The interconnection problem for a narrowband triplexer can be solved by using the parallel-coupled line configuration shown in Figure 9. The center line section constitutes the redundant unit element, while the transformers (1:n) and capacitors *C* are parts of the bandpass filters. These four-port configurations allow for the interconnection of the three filters in complementary form. The appropriate choice of the transform ratio *n* allows the use of adequate impedance levels for the passband filter inner sections.

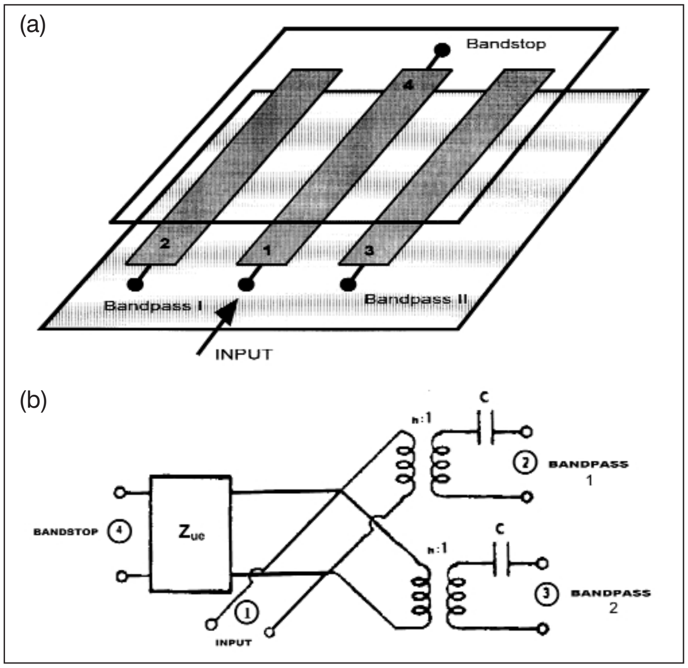
The design procedure starts by the direct synthesis in distributed parameters (exact synthesis) of the simply terminated resistive bandpass filters. The realizable impedance levels are achieved adding unitary elements of impedance Z_0 at the input and output ports of the filters. Using the Kuroda transformations, the equivalent circuit is obtained.

The bandstop filter is designed based in the composition of a redundant element and the complementary load presented by the filters.

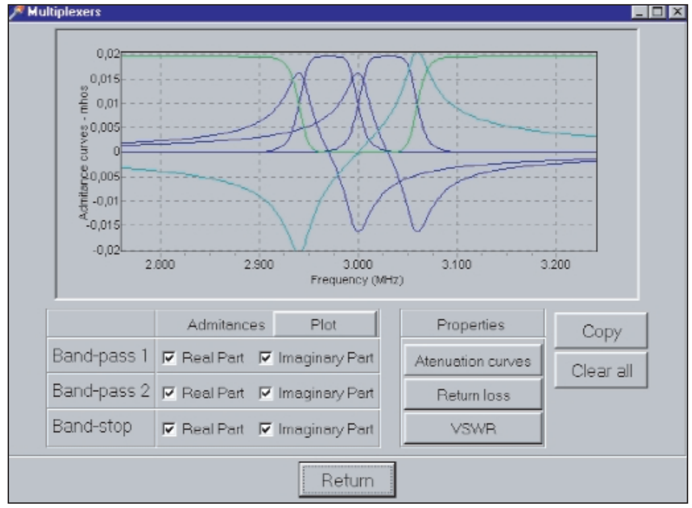
$$Y_{in_{BS}} = 1 - Y_{in_{BP1}} - Y_{in_{BP2}} \tag{1}$$

where

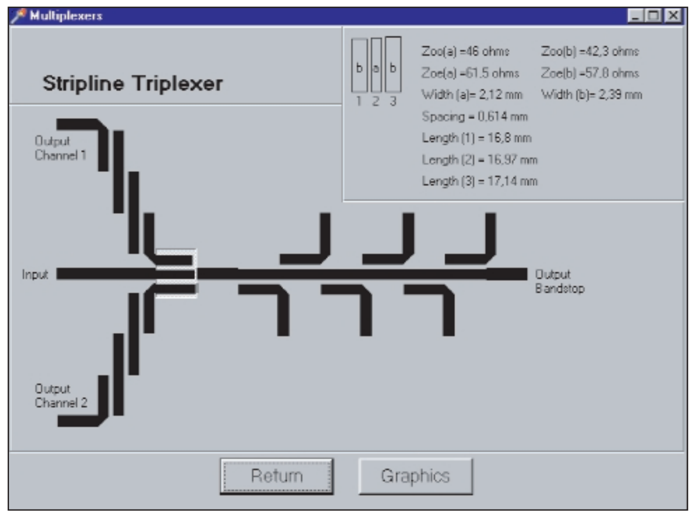
$Y_{in_{BS}}$



▲ **Figure 9. (a) Interconnection network for narrowband complementary filters; (b) equivalent circuit.**



▲ **Figure 10. Frequency responses and admittance curves of the filters.**



▲ **Figure 11. Stripline triplexer design.**

equals bandstop filter input admittance and

$$Y_{in_{BP}}$$

equals bandpass filter input admittance.

Design procedure

A design software program was developed for the complementary triplexer. The software contains three independent modules that execute these functions:

- Construction module of the transfer function filters. This module contains a dedicated graphic interface that permits the visualization of the frequency response and input admittances of each filter.
- Graphics visualization and analysis module of the poles and zeros of filters in the "S" Plane (complex variable plane).
- Synthesis module of the filter in lumped parameters and distributed parameters. This module provides the layout of the filter, including all calculated dimensions, taking into account the fabrication technology.

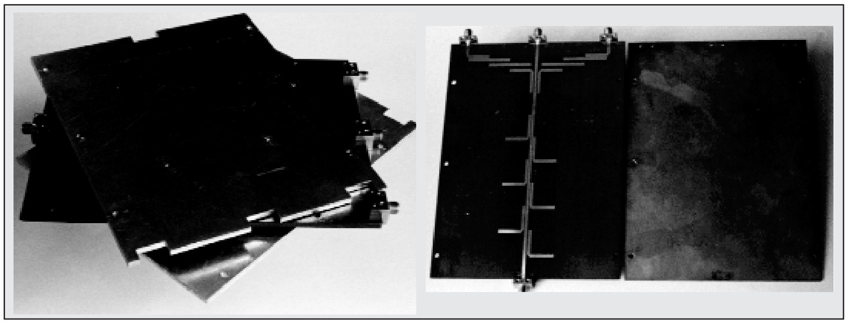
From the filter specifications and the basic parameters of the transmission structure, it is possible to access the analysis and synthesis modules of the computer program. These modules allow the realization of the circuit using all necessary data. Figure 10 shows a typical output of the frequency response module, including the admittances curves, attenuation and the return losses for each filter. The synthesis module derives the lumped and distributed parameters. The program derives the isolated filters and then the interconnection network. A screen displaying the layout of a stripline triplexer is shown in Figure 11.

Experimental results

A triplexer with central frequency of 3.0 GHz and fractional bandwith of each channel of 2 percent was designed and tested. The design of the filters was realized by applying the exact synthesis theory followed by numerical techniques. The tuning was done using a computer-aided optimization process.

The triplexer was constructed using dielectric sheets with ε_r = 2.17, with ground planes having 3.048 mm spacing. A photograph of the device is shown in Figure 12; its performance is shown in Figure 13.

The insertion loss in the bandpass was approximate-



▲ **Figure 12. Photographs of the complementary triplexer.**

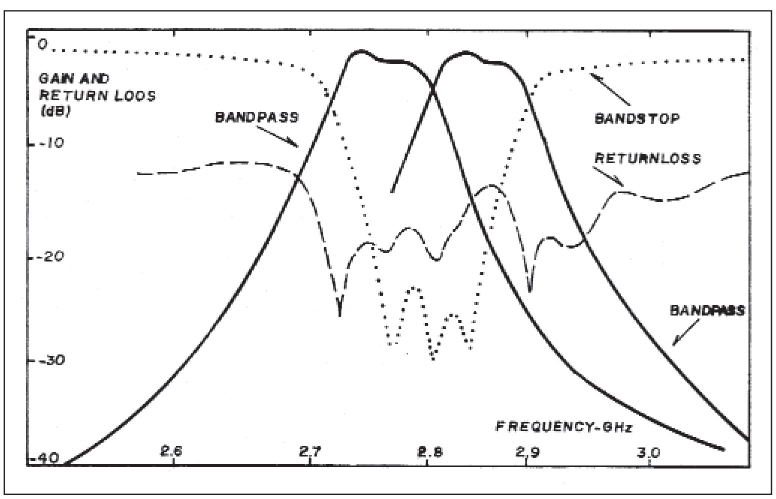
ly 1.5 dB and the crossovers occurred at 4.5 dB down. Stopband attenuation of more than 20 dB around 80 percent of the bandwidth was achieved. The measurements indicate a displacement of 7 percent at the center frequency. The return loss at frequencies outside the crossover region was worse due to the incomplete compensation of the interconnections and the loose coupling of the bandstop filter resonators.

Conclusion

A design procedure for multiplexers with contiguous channels was presented. A triplexer using filters connected in parallel was analyzed. The same approach can be used for triplexers with the filters connected in series.

A software which provides all the elements needed to the triplexer conception was implemented. The tool can be used as a starting point for optimization.

A stripline triplexer was realized and good agreement between the theoretical and experimental results was shown, which proved the efficiency of the complementary filters for the isolation of each channel. The triplexer solution compared to a diplexer has a reduced number of separating units and is therefore more compact. ■



▲ **Figure 13. Insertion and return loss for the triplexer.**

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