I-4. Bandpass Filters with Steep Skirt Selectivity

Eugene N. Torgow and Peter D. Lubell

Dorne and Margolin, Inc., Westbury, N. Y.

Low-pass constant-k filters and exact insertion-loss filters of the Butterworth or Tchebycheff types have long been used as prototype sections for bandpass filters in the microwave region. Such filters having LC ladder structures can be readily transformed into coupled-cavity bandpass microwave filters. Such basic low-pass prototypes having monotonically increasing rejection characteristics will contain many circuit elements when sharp cutoff characteristics are required. The introduction of m-derived sections, or the synthesis of prototype filters exhibiting Tchebycheff ripple characteristics in the stop band, reduces the number of elements. These filters are no longer simple ladder networks and, when transformed to yield bandpass or band-reject characteristics, contain complex arrangements of circuit elements which cannot be readily realized as a microwave structure.

In a manner analogous to the design of image parameter filters, a technique is described in this paper for realizing bandpass filter characteristics at microwave frequencies exhibiting extremely sharp cutoff characteristics. This performance is achieved by the use of band-reject filter sections which augment the cutoff characteristics of conventional bandpass filters. Image parameter filters, having different attenuation characteristics but the same image impedance characteristics, can be connected directly to yield a composite filter whose attenuation characteristic is the logarithmic sum of the attenuations of the component elements. In the technique described below, filter sections obtained by conventional synthesis procedures to yield Butterworth or Tchebycheff passband response are combined to yield the desired composite performance. It is demonstrated that the composite filter performance is the sum of the performances of the individual sections to a high degree of approximation. It is further shown that no spurious transmissions will result due to mutual reactive interactions between component parts of the filter when these parts are interconnected through properly phased lengths of line.

Composite Filter Properties. Narrowband, bandpass filters with extremely sharp rejections generally exhibit high passband insertion loss with available cavity Q's. A filter with fewer sections and a wider passband will exhibit more gradual rejection characteristics, with less insertion loss. Highly selective high and low-frequency rejection slopes can then be independently achieved by placing at least two separate band-reject filters in tandem with the bandpass filter. If a band-reject characteristic is placed within the edges of a bandpass characteristic, the resulting composite curve can be made to approximate the sum of the two rejection characteristics. The resulting performance is closely related to that exhibited by composite image filters or insertion-loss filters exhibiting Tchebycheff characteristics in the rejection region.

The advantages of this technique result from the fact that the Q of the band-reject cavities limits only the maximum rejection which can be realized. Not only is the insertion loss of a band-reject cavity in the passband independent of Q, but also, since the cavities are loosely coupled to the main transmission line, no significant reflection is produced in the pass region.

Figure 1 illustrates the manner in which a composite characteristic is achieved by the superposition of individual response functions.

Figure 2 compares the values of Q and the number of cavities required to realize composite and Butterworth filters exhibiting equivalent response characteristics.

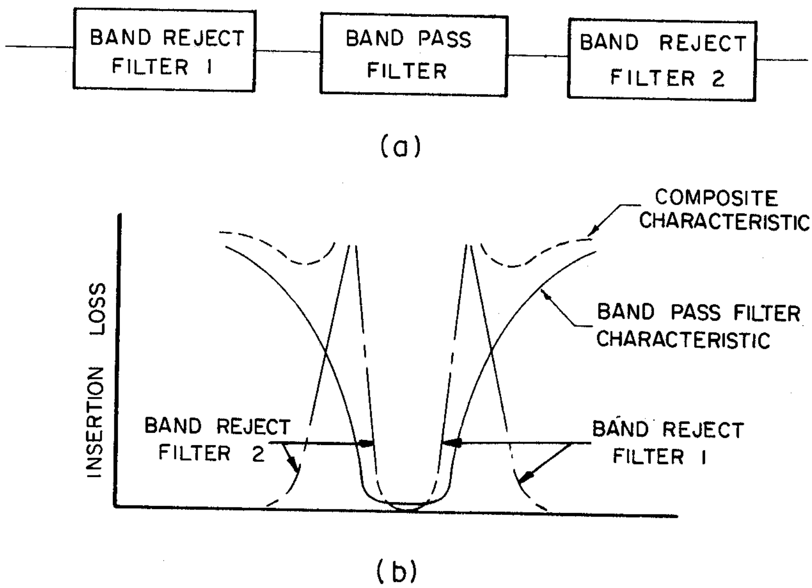


Fig. 1 Composite bandpass filter. (a) Filter. (b) Performance characteristics.

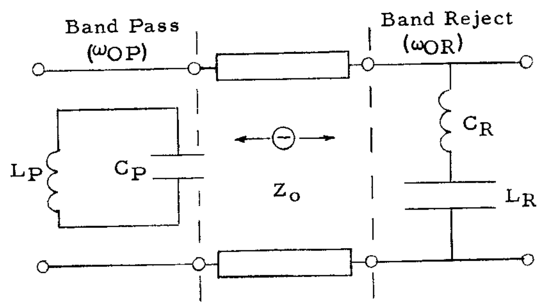
3db Bandwidth = 0.43% f_o; Insertion Loss = 1.5 db; 3 db to 50 db Skirt Width = .033%

	Butterworth	Composite*
Number of Cavities	40	27
Unloaded Cavity Q	10,275	5 at 7600 10 at 3300 10 at 1600

*The composite filter utilizes a band-pass filter and two pairs of band-reject filters.

Fig. 2 Comparison between Butterworth and composite bandpass filters.

Analysis of Filter Performance. Any filter or filter section can be regarded as a length of transmission line having a phase length equal to its image phase and a characteristic impedance equal to its image impedance (both quantities being functions of frequency). Since the band-reject filter section outside of the immediate vicinity of resonance presents an image impedance close to the characteristic impedance of the line, two band-reject filters having different rejection frequencies can be used to establish the cutoff characteristics of a filter without mutual interference. The analysis also demonstrates that a band-reject filter, whose rejection frequency lies



(a)

Manner of Connection	Evaluation of Calculations
Direct - coupled	Only two cases of possible spurious transmission: 1. when $\omega \simeq \omega_{O\bar{R}} < \omega_{OP}$, and 2. when $\omega \approx \omega_{O\overset{+}{R}} > \omega_{OP}$* Analysis of these responses shows that the spurious response bandwidth is extremely narrow. Thus, the spurious transmission is highly attenuated by the small residual shunt resistances which remain after the reactances cancel out.
Spaced $\lambda/4$ of ω_{OR}	No spurious transmissions possible. Only cancellation exists in passband of composite filter. This is a desirable effect since it reduces passband insertion loss.

*ω_{OP} = Band-pass center frequency (radians/second)
ω_{OR} = Band-reject center frequency (radians/second)
ω = Operating frequency (radians/second)
$\omega_{O\bar{R}}$ = Frequency slightly below ω_{OR}.
$\omega_{O\overset{+}{R}}$ = Frequency slightly above ω_{OR}.

(b)

Fig. 3 (a) Simplified equivalent circuit for composite filter section. (b) Summary of possible spurious responses between tandem-connected bandpass and band-reject filters.

within the band edges of the passband of a bandpass filter, will establish a new cutoff frequency with little effect in the passband. Interaction between the two filters beyond cutoff, where the bandpass loss is rising while the band-reject loss is decreasing, can be controlled by appropriate lengths of interconnecting line to result in an insertion loss equal to or greater than the sum of the two rejections.

The possible interactions between a bandpass filter and a band-reject filter have been considered. The results of this analysis, using the equivalent circuits of Fig. 3(a) are summarized in Fig. 3(b).

Within the approximations involved, the analysis indicates that control of phase length between sections will insure the desired summation of responses.

Experimental Results. A UHF model of a composite bandpass filter was constructed. Figure 4 is an oscillogram of the response of this filter. Curve A is the response of the bandpass filter sections alone. In curve B, a single band-reject filter section has been used to increase the steepness of the upper cutoff skirt. Improper phase lengths between the bandpass and band-reject filter elements result in a partial cancellation of rejection (shaded area). This was eliminated when the proper line length between filter elements was used. Curve C shows the composite response when a second band-reject cavity was stagger-tuned with the original band-reject filter section. Similar results were obtained when band-reject filter sections were used to increase the rejection skirts on both sides of the passband. Note that the midband loss is virtually unaffected by the addition of the band-reject sections.

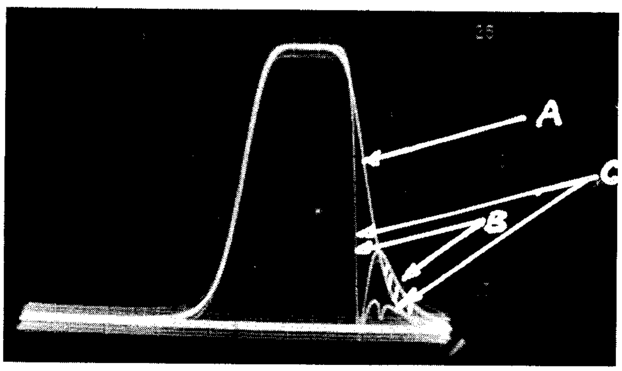


Fig. 4 Oscillogram of filter response.

A pair of band-reject sections were used to increase the rejection characteristics and narrow the passband of a 400 Mc bandpass filter. A decrease in the 3 db bandwidth of the composite filter to one-half that of the bandpass filter alone increased insertion loss by only 0.2 db–0.6 db. Not only were the rejection skirts steeper, but a bandpass filter using the same cavity Q's would have an insertion loss of at least 0.95 db for this bandwidth.

Conclusions. It can be seen that two band-reject filters closely spaced in frequency provide a narrow passband with low insertion loss and steep rejection skirts. The rejection characteristics can then be maintained over a wider band by the use of a supplementary bandpass filter. Supplementary band-reject filters having wider rejection bands and less steep skirts can also be used to supplement the rejection filters which establish the rejection characteristics.

In the design of a conventional bandpass filter, the complete performance is generally specified and the designer is left with the structure he must build to realize the required performance. In the case of composite bandpass filters, however, the designer has a freer choice in the design of the bandpass portion of the filter. He can select a bandpass filter design which requires more moderate values of resonator Q. The specifications for the band-reject filters then result from the difference between the desired rejection characteristics and the characteristics obtained from this bandpass filter. An additional degree of flexibility can also be realized by the use of stagger-tuned band-reject filter sections.

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