WIDE-BANDWIDTH COMBLINE FILTERS WITH HIGH SELECTIVITY

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ABSTRACT

The selectivity of wide-bandwidth combline filters can be greatly enhanced with the addition of a relatively small number of finite transmission zeros. Techniques for introducing them are described and examples are given.

Introduction

Combline bandpass filters are used in many applications, primarily with moderate to wide bandwidths. They are popular because of their compact size and wide stop bands, combined with simplicity of construction and ease of tuning. They are commonly built with octave bandwidths and occasionally with bandwidths up to 100% (3:1 band-edge ratio). At these wide bandwidths, however, the selectivity leaves much to be desired. Although the attenuation on the high-frequency side of the pass band is quite strong, the attenuation on the low-frequency side is correspondingly weak, and the ratio of the slopes can be as great as four to one. An example of this effect is the attenuation characteristic of a 15-rod combline filter of 79% bandwidth, shown as the dashed curve in Figure 1. The unequal slope behavior comes from the locations of the transmission zeros of the response. A conventional combline filter with N sections has 2N-1 transmission zeros above the pass band, but only one below it -- at d-c.

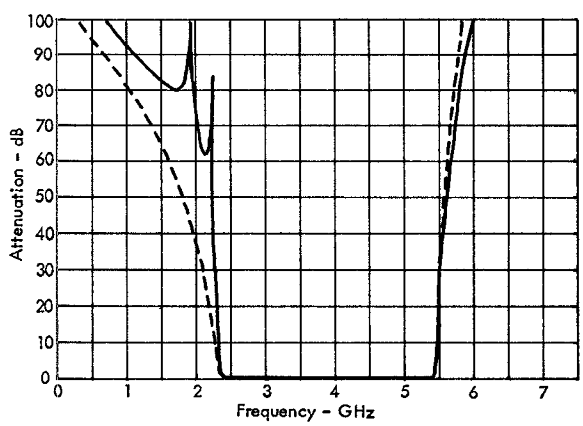

Figure 1. Responses of 15-rod combline filters

This characteristic allows combline filters to be used very effectively in band-limited low-pass filter applications and in broad-bandwidth frequency-multiplier filtering, in which the spurious signals above the band are closer than those below it. For applications in which the selectivity requirements are arithmetically symmetrical, however, the use of a combline filter may require some compromise. The normal solution is to add as many sections as necessary to meet the low-side rejection specification. Adding sections increases insertion loss, but much more at the high end of the band than at the low end. Consequently, the high corner of the filter is usually placed significantly above the high corner of the specified pass band, and, since the high-side attenuation rises rapidly, the high-side rejection specification can still be met. This technique works well enough in many applications, but not when it is required that the attenuation increase immediately above the pass band.

Low-Side Finite Transmission Zeros

A method for correcting the attenuation slope assymmetry is the introduction of finite transmission zeros below the pass band. Normally, only one or two are required to obtain approximate symmetry. The solid curve in Figure 1 is the response of another 15-rod combline filter, with the same ripple value and band-edge frequencies as the first, but with two low-side transmission zeros. It can be seen that the attenuation slope on the high side has become slightly less sharp, while that on the low side has been greatly enhanced. In fact, the low-side attenuation is now even sharper than that on the high side. Although the degree of the filter is unchanged, two pairs of transmission zeros have been moved from above the band to below it (each of the two zeros shown is paired with one at a negative frequency). Examination of this case indicates that it should not be necessary to have more than two transmission zeros below the pass band in any practical situation with symmetrical attenuation requirements.

A convenient way to introduce the low-side zeros, while maintaining the basic coupled-rod structure of the combline filter, is the use of series capacitors between the ungrounded ends of the coupled rods, as reported by Pregla[1] and Levy and Rhodes.[2] Equivalences for inter-rod coupling are shown in Figure 2. A hybrid notation is used here, in which

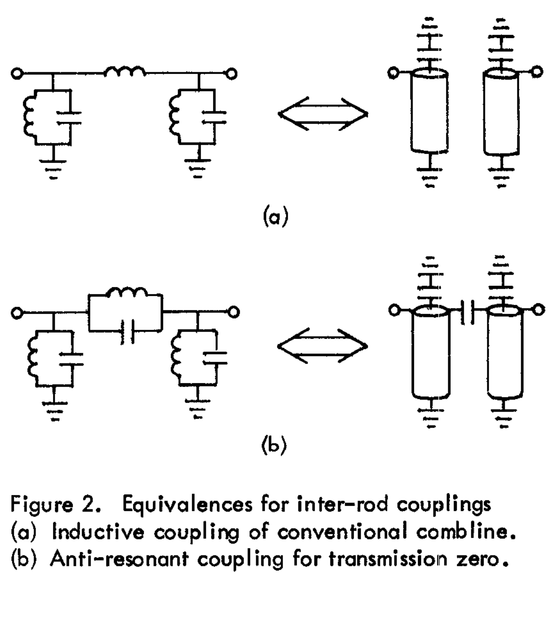

Figure 2. Equivalences for inter-rod couplings
(a) Inductive coupling of conventional combline.
(b) Anti-resonant coupling for transmission zero.

the inductor symbol represents a transmission-line inductor and the capacitor symbol represents a lumped-element capacitor. Part (a) of the figure shows a conventional combline coupling and (b) a coupling with the series capacitor added. It is apparent that the addition of the capacitor changes an inductive coupling to one which has an anti-resonant frequency. In the situation discussed here the anti-resonant frequency is below the pass band, making the coupling predominantly capacitive within the band.

Design Method

In order to design a combline filter with low-side transmission zeros, the approaches of either Pregla[1] or Wenzel[3] may be followed. In either case the specifications are first converted, by use of the appropriate transformation, from the actual RF frequencies to S-plane frequencies; a lumped-element S-plane prototype filter is synthesized to meet those specifications; and the prototype filter is converted to an RF filter through simple substitutions. The only differences between designing this type of filter and the conventional combline are in specifying the locations of the transmission zeros in the approximation phase and then implementing the finite zero pairs in the actual synthesis. Referring again to Figure 1, for the prototype for the first filter there would be one zero at d-c and twenty-nine zeros at infinity. For the second there would be one at d-c, two pairs at finite frequencies, and twenty-five at infinity. In either case the degree of the filter is thirty.

In the synthesis the finite zeros are extracted as parallel-resonant circuits connected in series, as described above. There are a number of possible locations for these circuits - between any two adjacent shunt resonators. It has been found advantageous to place them at the ends of the filter, between the first and second resonators. Broadband combline filters typically have end coupling gaps which are inconveniently narrow. When the filter is synthesized with the transmission-zero couplings in these locations, however, the gaps become larger, and yet they are still generally small enough for a series capacitor to fit in with minimum parasitic inductance.

The implementation of the series capacitors can be troublesome. In the case of broad-bandwidth filters, the capacitance required for a low-side transmission zero is invariably too high to be realized with simply a parallel-plate air gap. At low frequencies a commercial discrete capacitor can be used. At high frequencies it is generally necessary to make a capacitor from thin dielectric material which has been clad on both sides. If a "soft" material is used the capacitor can be soldered directly to the resonators, as shown in Figure 3. If ceramic or porcelain is used, however, it is necessary to provide some kind of flexible bonding for thermal stress relief. The greatest problem with a series capacitor is that the finite size of its attachment points to the rods and the volume it occupies between the rods effectively decrease the inductance of the coupling gap, particularly at higher frequencies. This means that the gap must be made larger to begin with in order to compensate for the effect.

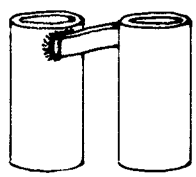

Figure 3. Capacitor made from copper-clad "soft" dielectric soldered between two rods

High-Side Zeros

Occasionally there is a need for high-side transmission zeros. This is not generally the case, because combline filters generally have very strong high-side attenuation slopes. If there is a potentially interfering signal immediately above the high end of the pass band, however, and it must be attenuated by 10 to 20 dB, it may be desirable to notch it out with a transmission zero.

Anti-resonant couplings could again be used. In fact, the elliptic combline filter[2] has this kind of coupling in every gap. Because of the difficulties with series capacitors, however, it seems desirable to use the minimum number necessary, particularly at the higher frequencies. In the case of the high-side zeros an alternative method is available in the addition of inductive coupling between alternate rods. The design sequence for this configuration begins with a shunt-connected series-resonant circuit in the S-plane prototype filter, and is shown in Figure 4. Interestingly, this configuration bears a strong resemblance to the "reject resonator" which is often empirically added to a combline filter to sharpen the attenuation slope. It is now seen that in the case of a high-side transmission zero the reject resonator can be exactly designed as part of the filter and add a reflection zero to the response.

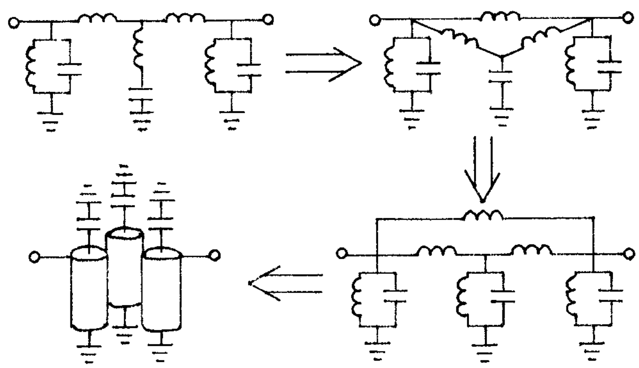

Figure 4. Sequence for designing inductive coupling between alternate rods for high-end transmission zero

An eight-rod combline filter was designed with 81% bandwidth and two finite transmission zeros, synchronously tuned, on each side of the pass band. The equivalent circuit is shown in Figure 5 and the computed response in Figure 6.

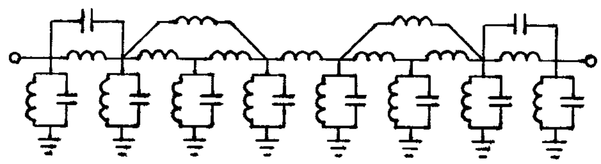

Figure 5. Equivalent circuit of combline filter with two transmission zeros on each side of the pass band

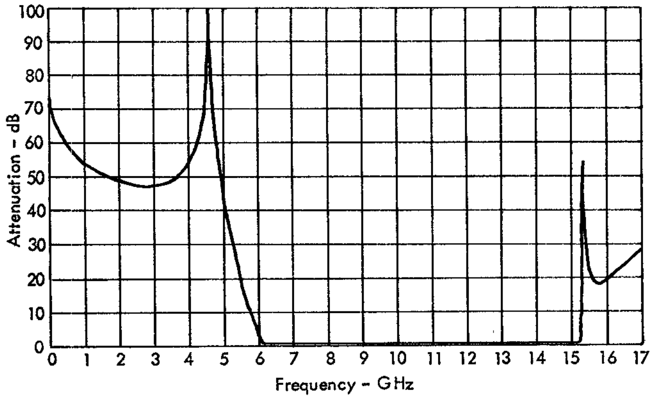

Figure 6. Response of eight-rod combline filter with two (synchronous) transmission zeros on each side of the pass band

Conclusion

The addition of a small number of finite transmission zeros can greatly enhance the selectivity of broad-bandwidth combline filters. These new filters can be exactly designed by following the same sequence as for conventional combline filters. There are difficulties in their implementation which require further investigation, but it is not believed that they will prevent eventual widespread use of the techniques.

References

1. R. Pregla, "Microwave filters of coupled lines and lumped capacitances," IEEE Trans. Microwave Theory Tech., vol. MTT-18, May 1970, pp. 278-280.

2. R. Levy and J. D. Rhodes, "A comb-line elliptic filter," IEEE Trans. Microwave Theory Tech., vol. MTT-19, Jan. 1971, pp. 26-29.

3. R. J. Wenzel, "Synthesis of combline and capacitively loaded interdigital bandpass filters of arbitrary bandwidth," IEEE Trans. Microwave Theory Tech., vol. MTT-19, Aug. 1971, pp. 678-686.