Transmission Zeros in Filter Design

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More economic and effective bandpass filters can be designed by controlling the location of transmission zeros. What do we mean by transmission zeros? Consider the fifth-order lowpass filter in Figure 1(a). There is little attenuation at low frequencies and increasing attenuation above the cutoff. Only at infinite frequency is there no transmission. In fact, at infinite frequency, each inductor becomes an open and each capacitor becomes a short. This filter has five transmission zeros (TZs) at infinite frequency. The fifth order highpass filter in Figure 1(b) has five TZs at DC.

It is essential that the inductors and capacitors alternate. If we were to attempt to build a fifth-order lowpass with five series inductors, we would essentially have only one inductor whose inductance is the total of the five series inductors: this is only a first order filter. A similar effect occurs if all elements are shunt capacitors. The discovery by Cambell in the U.S. and Wegner in Germany in 1915, that elements or resonators must alternate, was the beginning of filter theory.

Recognizing the number of TZs is more interesting with bandpass filters. Consider the conventional third-order bandpass in Figure 2(a). At DC (B), the series inductors and the shunt capacitor have no effect — they vanish. There are three TZs at DC. At infinity (C), the series capacitors and the shunt inductor vanish, and there are three TZs.

In lowpass filters, the quantity of TZs at infinity determines the selectivity. In bandpass filters, the quantity of TZs at DC determines the selectivity below the passband, and the quantity of TZs at infinity determines the selectivity above the passband. If the number of TZs at DC and infinity is equal, the transmission response...
plotted on a logarithmic frequency scale has equal slope above and below the passband. The quantity of TZs at DC and infinity are not required to be equal. In fact, if more attenuation is required above the passband, then the bandpass may be designed with more of the TZs at infinity. Consider the third order bandpass shown in Figure 3. This filter has three resonators with top coupling inductors. It also has a total of six TZs but one is at DC and five are at infinity.

Compare the responses of the conventional bandpass and the top-L coupled bandpass shown in Figure 4. The red trace with circular markers is the amplitude response of the conventional bandpass. Plotted on a linear frequency scale, it has more selectivity below the passband. The blue trace with square markers is the amplitude of the top-L coupled bandpass. Notice the similar passbands and the increase selectivity of the top-L above the passband.

Selecting the quantity of TZs at DC and infinity provides independent control of the selectivity above and below the passband. How can we achieve a symmetrical response? Carassa [1] proved that if the quantity of TZs at infinity is three times the quantity at DC, then the bandpass is symmetric when plotted on a linear frequency scale. This can be true even if TZs are added at finite frequency.

Consider the bandpass shown in Figure 5. Unlike the previous filters, this bandpass has TZs at finite frequencies, that is, frequencies other than DC or infinity. For example, C3 and L2 resonate at 103 MHz which causes a notch (TZ) above the passband. Likewise, L3 and C5 resonate at 40 MHz, which causes a TZ below the passband.

This filter has three TZs at infinity and one at DC, which satisfies Carassa’s rule, and thus provides a symmetric response, as shown in Figure 6. Notice that it has similar selectivity above and below the passband and the group-delay response is symmetric.

The design of the conventional bandpass and capaci-
tor or inductor coupled resonator filters is accomplished using predefined lowpass to bandpass transforms [3]. These filters are restricted to specific ratios of DC and infinite TZs. The design of filters with arbitrary placement of finite, DC and infinite TZs, such as the symmetric filter shown in Figure 5, requires direct synthesis techniques [2].

References

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