Band pass filter design
Part 4 – Improving the HF-side response of a band pass filter

Richard Harris G3OTK

1. Introduction

In this article we will look at using the star-to-delta transformation to either improve the frequency response of a band pass filter above the pass band, or to eliminate small coupling capacitors. For this exercise, we will look at a band pass filter with two parallel tuned circuits that could be designed using the techniques outlines in Part 1, or by the "q and k" method (Ref. 1, 2 & 3) described in Part 2. Rather than specify a terminating resistor, an inductor value can be selected and the terminating resistor value calculated. The specification that we will use is as follows:-

- Chebychev with 0.25dB pass band ripple (so that the ripple is visible on simulations)
- Two parallel tuned circuits
- Centre frequency of 10MHz
- Bandwidth of 500kHz (to 0.25dB attenuation)
- Inductors of 1uH

The design is shown in Fig 1.

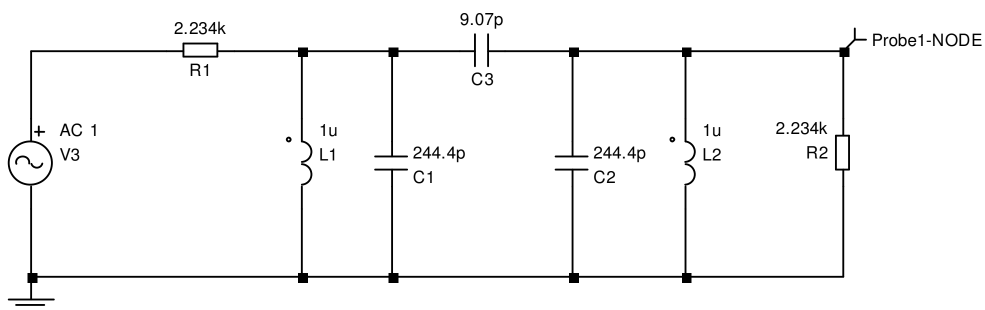


Fig. .1. Filter circuit

The insertion loss, as predicted by the SPICE simulator, is shown in Fig. 2. This simulator is available as a free down load (Ref. 4).

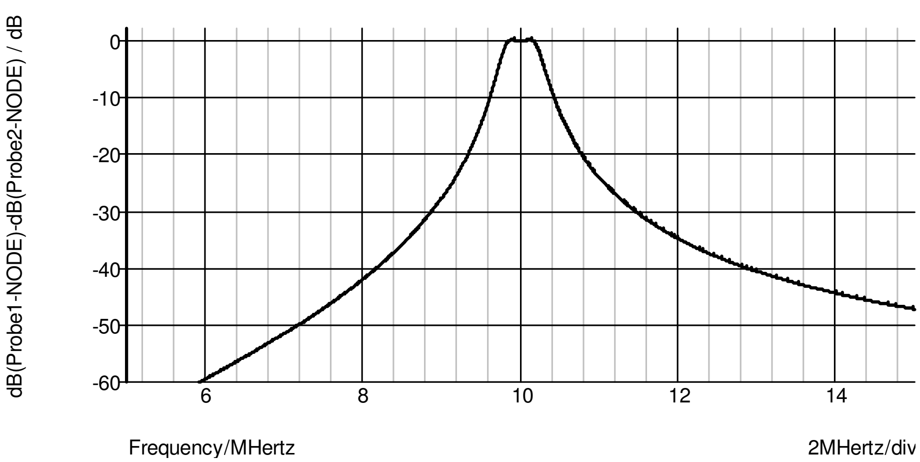


Fig. 2. Insertion loss

Notice that the attenuation falls off more rapidly on the low frequency side than on the high frequency side. The reason is quite straightforward. At very high frequencies, the inductors can be thought of as open circuits and so the filter becomes a series of capacitors, which, with the termination resistors, give a much slower roll off.

2. Improving the HF-side attenuation

The rate of increase in insertion loss on the high frequency side can be improved if there is at least one series inductor since the series impedance will keep increasing with frequency. To show how this can be done, we can redraw the circuit in Fig 1.

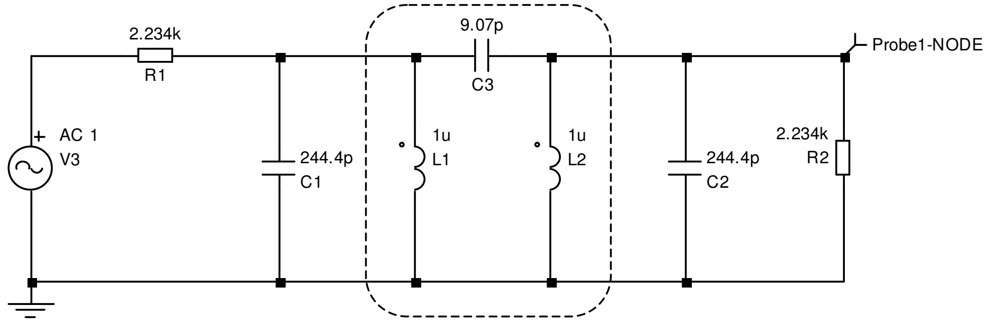


Fig. 3. Redrawn Circuit

The termination resistance is the result of calculation – it cannot be arbitrarily chosen without using an impedance matching section. L1, C3 and L2 have been deliberately grouped together because we are going to undertake a "Delta-to-Star" transformation.

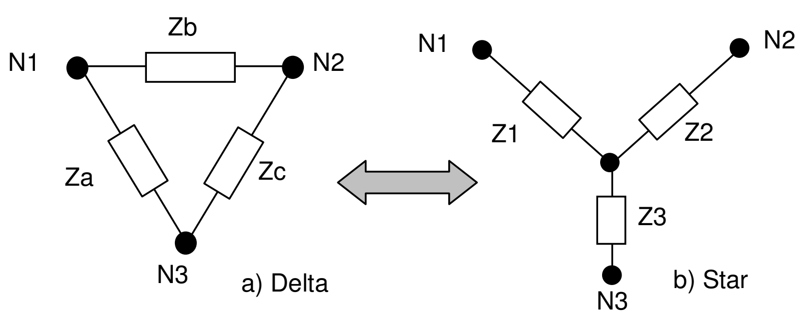


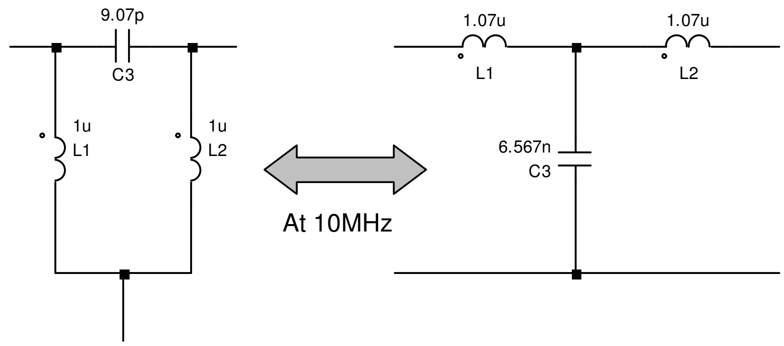
Fig. 4. Delta and Star Transformations

Standard formulae to convert a Delta configuration to a Star configuration and vice-versa can be found in many text books or on the Internet. Converting from Delta to Star:-

$$Z1 = \frac{Za\ Zb}{Za + Zb + Zc}$$

$$Z2 = \frac{Zb\ Zc}{Za + Zb + Zc}$$

$$Z3 = \frac{Za\ Zc}{Za + Zb + Zc}$$



a) Delta **b) Star**

Fig. 5. Transformation of L1, L2 and C3 from a Delta to a Star configuration at 10MHz

These are only equivalent at one frequency. However, within the pass band of a narrow band filter the response will be substantially the same. Notice that the small top-coupling capacitor in Fig. 5a has been replaced by a large bottom coupling capacitor in Fig. 5b. Care must be taken in selecting a suitable dielectric for a bottom coupling capacitor – ceramic capacitors will use a high-K dielectric and so have poor temperature characteristics. Many other capacitors types will have excessive inductance. Silver mica would probably be a suitable type, perhaps with NPO ceramic used to trim the value. Polystyrene capacitors may also be suitable although your writer hasn't tried either of these types.

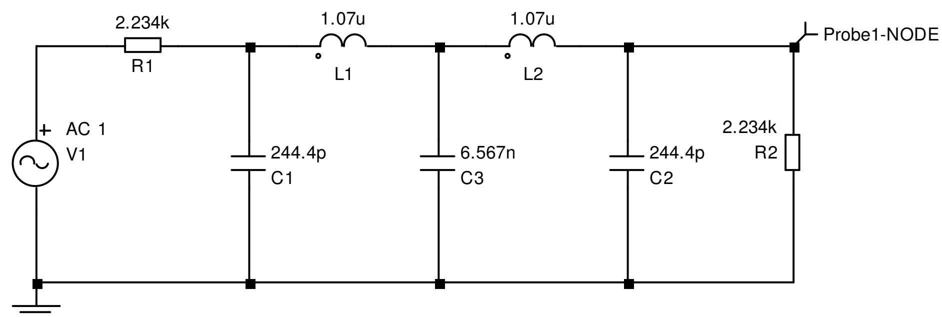


Fig. 6. Filter after delta-to-star transformation of L1, L2 and C4

The insertion loss frequency responses of Fig 3 and Fig 6 can be compared using SPICE

Fig. 7. Insertion loss of filters in Fig 3 and Fig 6

As can be seen, the attenuation on the high frequency side of the insertion loss frequency response graph is better in the version of the filters with series inductors (Fig. 6) compared with the conventional top coupled filter as shown in Fig 3. At higher frequencies the difference is even more marked.

3. Bottom coupled band pass filters

Band pass filters, such as shown in Fig 1, may have inconveniently small value capacitors for top coupling. We can use an alternative star-to-delta transform to replace the small top-coupling capacitor with a much larger bottom-coupling capacitor.

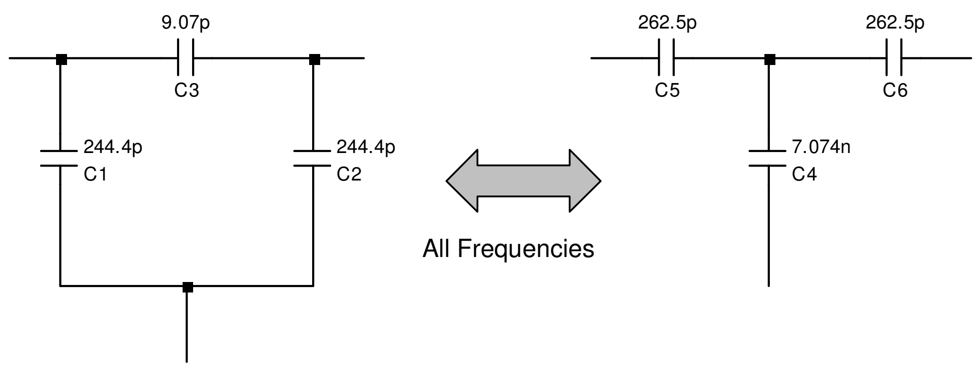


Fig. 8. Delta to Star Transform of C1, C2 and C3

This transform is independent of frequency because it consists of just capacitors. We can now modify Fig. 1 to change it from top coupling to bottom coupling.

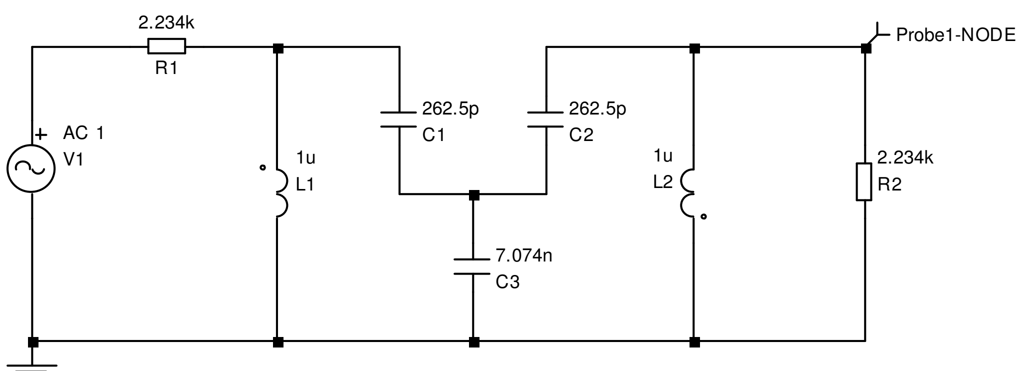


Fig 9. Bottom coupled version of the filter in Fig 1.

The response of the filter in Fig 9 is identical to that in Fig 1, so it is not necessary to show a comparison.

4. Conclusion

The Delta-to-Star Transform is a useful tool for increasing the attenuation above the pass band and may well result in a simpler filter. This transform also allows top coupling of a pair of tuned circuits, which inevitably use a small value capacitor, to be replaced by bottom coupling using a relatively large value capacitor. However, care must be taken to ensure that this capacitor uses a stable dielectric and is low inductance.

5. References

1. Wes Hayward W7ZOI, "Radio Frequency Design" published by the ARRL and available from the RSGB bookshop.

2. Hayward, Campbell and Larkin, "Experimental Methods in RF Design". Published by the ARRL, this is a first-class book for the experimenter and may be purchased from the RSGB bookshop.

3. William E Sabin W0IYH, "Narrow Band-pass Filters for HF", QEX Sep/Oct 2000 pp13 – 17.

4. www.simetrix.co.uk An excellent free evaluation version of SPICE.

Other useful references are given in Part 1.

Richard Harris G3OTK
June 2010
rjharris@iee.org