Band pass filter design
Part 3 - Using Norton's Transform

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1. Introduction

Part 1 gave the procedure for design a third order filter from first principles. Sometimes it is necessary to change the filter impedance part way through the filter, perhaps so that standard values of inductors can be used or to give an insertion gain. One method is Norton's Transform and Part 3 of this series demonstrates its use.

The filter developed in Part 1 Fig. 14 had the following specification:

- Chebychev with 1dB pass band ripple (so that the ripple is visible on simulations)
- Third order, capacitor input
- Centre frequency (Fo) of 10MHz
- Bandwidth (F_{BW}) of 500kHz

The terminating resistance at the input and output was 2,540 Ohms – if another terminating resistance is required then a matching section must be used, and this will be discussed in Part 7 of this series.

The circuit diagram is shown in Fig 1.

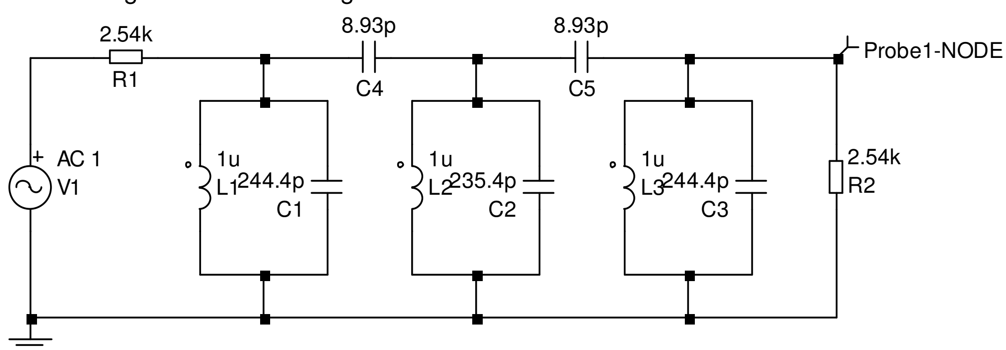

Fig. .1. Filter circuit

The insertion loss, as predicted by the SPICE simulator (Ref. 1), is shown in Fig. 2.

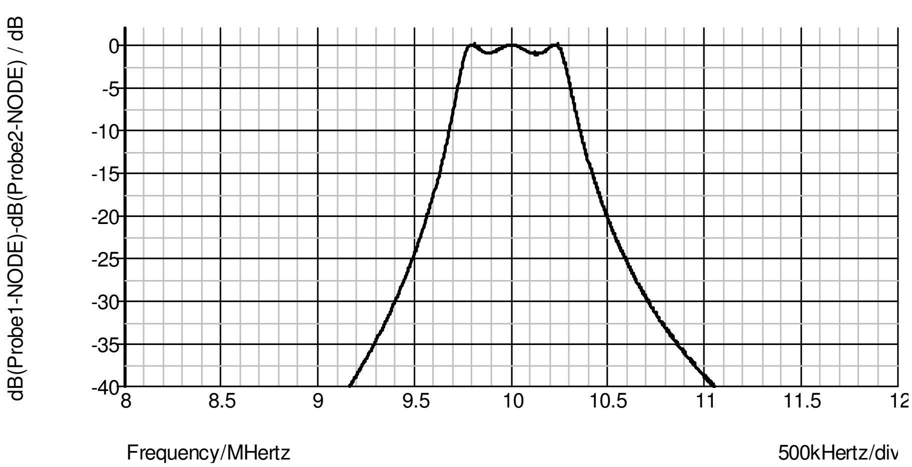

Fig. 2. Insertion loss

2. Norton's Transform

Norton's Transform (Refs. 2 & 3) is a useful technique for changing the impedance within a filter. This might be necessary to equalise inductor values, or to change a non-standard inductor value to a standard value or to ensure impedance matching with a load, such as the input to an amplifier. The purpose of Part 3 of this series is to demonstrate this Transform. Part 4 will describe an alternative method.

On the left hand side of Fig. 9 is a capacitor connected in series with the primary winding of an N-to-1 transformer. This combination can be replaced by three capacitors, as shown on the right hand side. Of course the circuit on the right doesn't give the same isolation as that on the left but that is not what we are trying to achieve.

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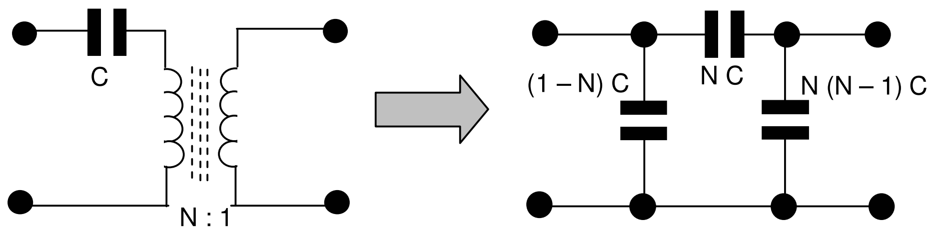

Fig 3. Norton's Transform

So how is it possible to replace a capacitor and a transformer with just three capacitors, and, perhaps more to the point, what if the transformer is a step-up transformer? How can you get a higher voltage out of a combination of just three capacitors? The answer is quite simply that one of the capacitors, either one on the left or the one on the right, will have a negative value. We met negative capacitors in Part 1 and, whilst they are not physically realisable, the concept can still be used, providing that there is a parallel capacitor that has a larger value so that the combination is still positive. At a single frequency a negative capacitor can be replaced by an inductor and this explains why it is possible to get a voltage step-up.

To demonstrate Norton's Transform, we will increase the impedance of the filter by a factor of 2.2 so that L3 is increased from 1uH to 2.2uH whilst keeping L1 and L2 at 1uH. The terminating resistance R2 must be increased and C3 must be reduced by the same factor.

Recall that transformers change impedance levels by the square of the number of turns, so the turns ratio, N, of our notional transformer in Fig. 9 will be the square root of the ratio of L1 to L3, which is 0.674.

Taking the right-hand side of the circuit diagram, as shown in Fig. 4.

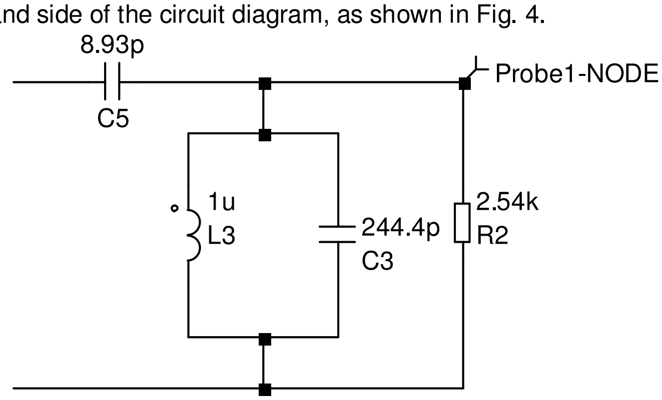

Fig 4. Right hand side of filter

Next add a transformer with a ratio of 0.674:1 between C5 and L3/C3/R2, whilst increasing the value of L3 and R2 by a factor of 2.2 and reducing C3 by the same factor.

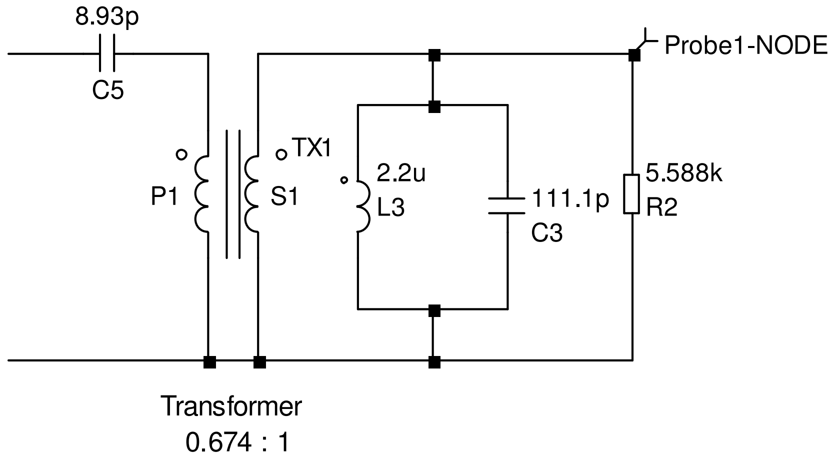

Fig. 5. Transformer added to increase impedance

Norton's Theorem enables us to replace C5 and TX1 by three capacitors.

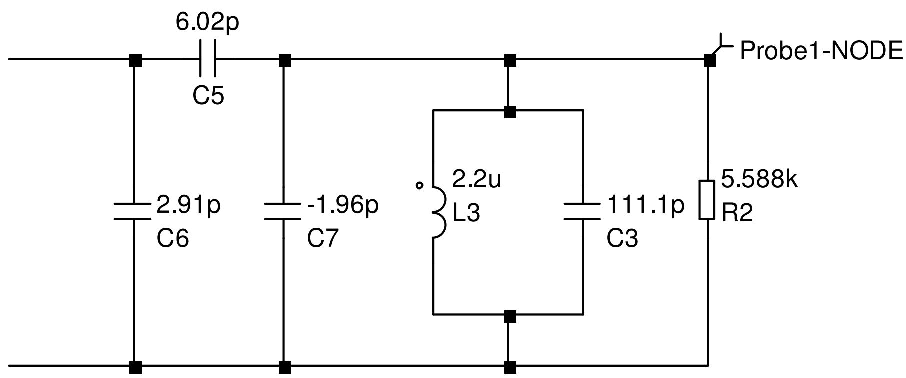

Fig. 6. Replacing C5 and transformer with Norton's Transform capacitors

Now, although C7 is a negative value capacitor, it can be absorbed into C3, reducing it slightly. C6 can be absorbed into C2 (see Fig. 1), increasing it slightly. So we have the final circuit diagram for this filter

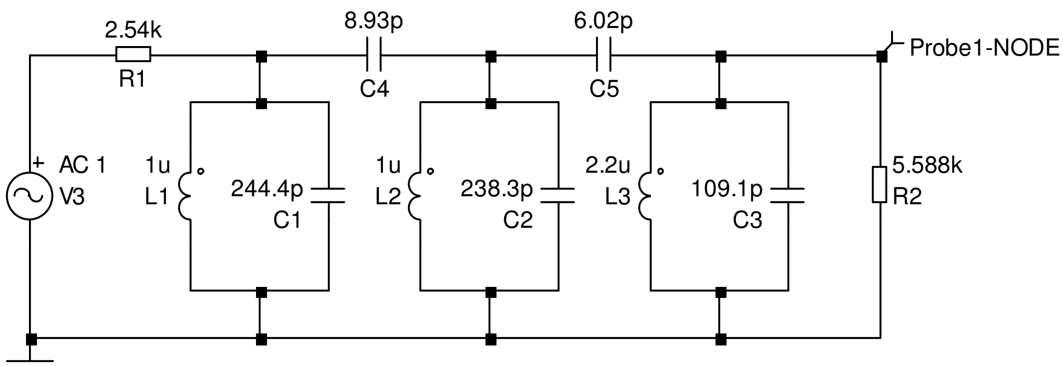

Fig 7. Filter final circuit diagram

The insertion losses of the original filter in Fig. 1 and the modified filter in Fig. 7 can be simulated and are shown in Fig. 8. The red curve is the response of the filter of Fig. 7. The modified filter has an insertion gain because of the unequal terminating resistances. This gain is the square root of the ratio of the output and input terminating resistances, 3.42 dB.

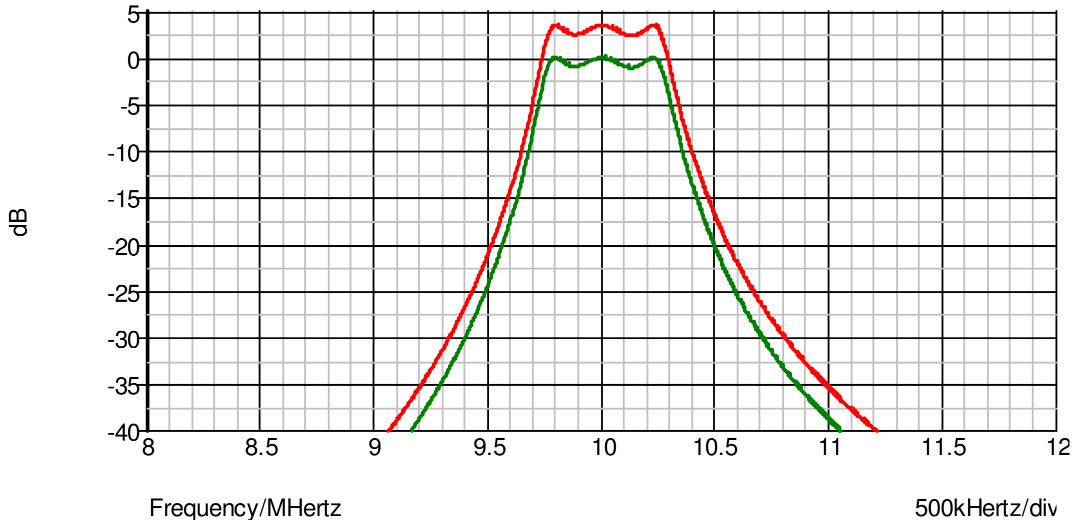

Fig 8. Insertion losses of Fig. 1 and Fig. 7.

3. Conclusion

Norton's Transform can be used to increase the impedance within a filter so that standard value, or specific value inductors can be used. The terminating resistances cannot be chosen independently and the calculated values have to be used. However, matching sections can be used to convert to some other terminating resistance as will be discussed in a later part to this series.

4. References

1. www.simetrix.co.uk An excellent free fully functioning evaluation version of SPICE. The limitation of this evaluation version is the number of components – in the region of 100. This is rarely a problem.

2. Anatol I. Zverev, "Handbook of Filter Synthesis", Wiley Interscience. This book was first published in 1967 and is regarded as a classic and is quoted as a reference in a great many articles on filter design. It is now available new in paperback form.

3. Arthur B. Williams and Fred J, Taylor, "Electronic Filter Design Handbook", McGraw-Hill. This is a very good book, much more readable and usable than Zverev, at least for amateur radio projects.

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