Band pass filter design
Part 7. Impedance matching

1. Introduction

We have little control over the input and output terminating resistances of filters because choosing the values of the inductors is usually more important. On the other hand, applications generally will require certain terminating resistances, for example 50 Ohms input for a receiver input and perhaps 1,000 Ohms to connect to a mixer, such as an SA612.

Impedance matching is familiar to most Amateurs because antennas have to be matched to transmitters. Some of the circuit configurations used for ATUs can be used to change the termination resistances of filters. However, in many applications, a simple capacitor matching network can be used.

2. Matching a lower resistance to a higher resistance

1 Often is it possible to match a lower terminating resistance to a filter that requires a higher terminating resistance by the use of capacitors.

Fig.1 show a parallel and series combination of a resistor and a capacitor.

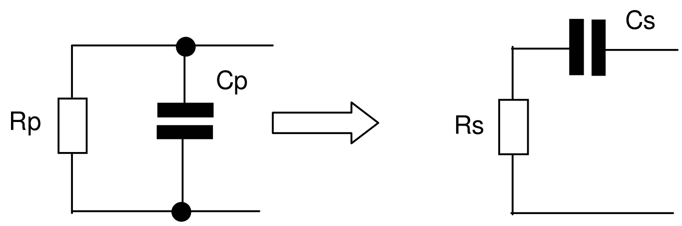

Fig. 1 Parallel and series RC combination

At a single frequency, Fo, there is an exact conversion between these two forms. In practice the conversion is sufficiently accurate over a small range of frequencies typical of band pass filters for amateur use. The resistors and the frequency are defined and so we need to calculate the values for Cp and Cs.

$$Cp = \frac{\sqrt{\left\{ \frac{Rp}{Rs} - 1 \right\}}}{2 \pi \, Fo \, Rp}$$

$$Cs = \frac{1}{2 \pi \, Fo \, Rs \sqrt{\left\{ \frac{Rp}{Rs} - 1 \right\}}}$$

To change the input terminating resistance, we must calculate Cp and reduce C1 by this amount. We then need to calculate Cs and add it in series with Rs, so paying back the value of Cp that we “borrowed” from C1.

The filters can be simulated using SPICE – Ref. 1. is an excellent fully functional SPICE simulator. Consider the filter in Fig. 2 below (from Part 2 Fig. 3). This is a 10MHz filter with 500kHz bandwidth, with a Chebychev 0.1dB response. The calculated input and output terminating resistance to achieve the required frequency response is 2,058 Ohms. We will now match the input to 50 Ohms and the output to 1,000 Ohms using a simple capacitive matching circuit.

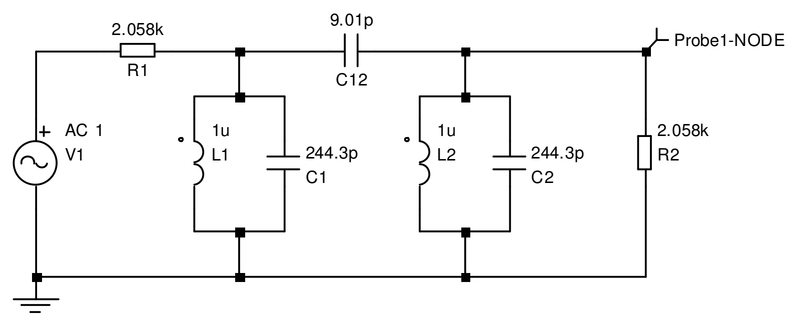

Fig. 2. Filter circuit from Part 2

Putting Rp = 2058 Ohms and Rs = 50 Ohms into the above equations, we get Cp = 49.0pF and Cs = 50.2pF, as shown in Fig.3.

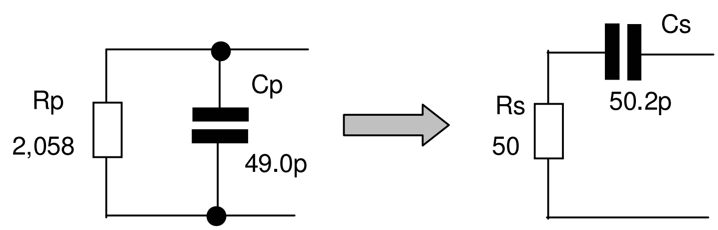

Fig. 3. Changing input terminating resistance

The 49.0pF of Cp can be "borrowed" from the filter capacitor C1 in Fig 2, reducing it to 195.3pF and is "paid back" by means of a series 50.2pF capacitor.

We can also do the same to change the output terminating resistance to 1,000 Ohms. This is shown in Fig. 4.

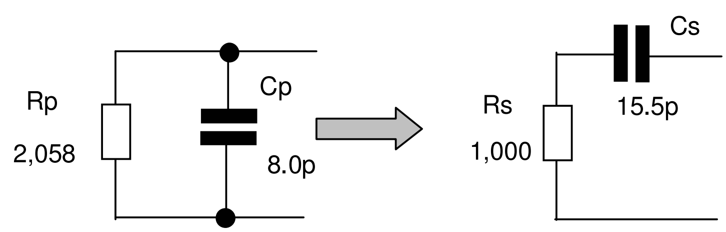

Fig. 4. Changing output terminating resistance

We can now modify the circuit diagram in Fig. 2 to give the final filter design with a 50 Ohm input resistance and a 1,000 Ohm output resistance.

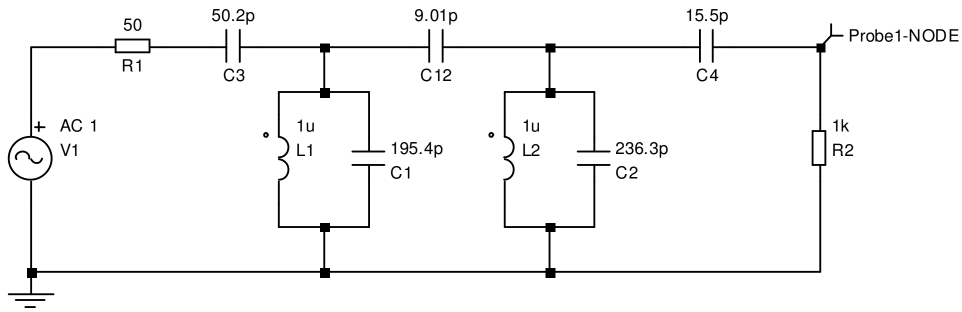

Fig. 5. Filter for use with a 50Ohm source and 1,000 Ohms terminating resistance

There will be a voltage gain equal to the square root of the ratio of the input and output terminating resistances, namely 13dB. Using this technique, the overall shape of the response is unchanged – it is just raised by 13dB.

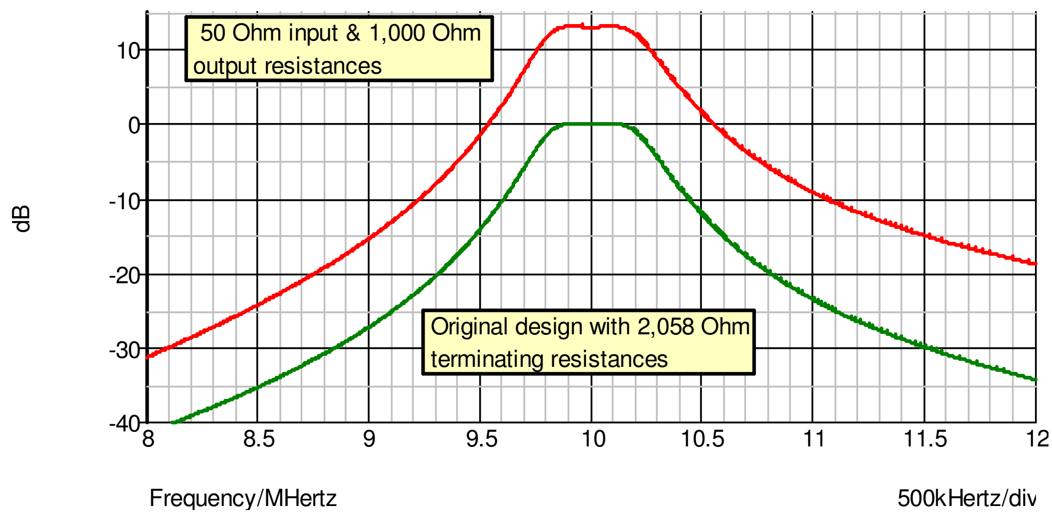

Fig 6. Insertion loss of final filter

3. Using an L-match

Many ATUs use an L-match. An L-match can be used to match a lower or higher terminating resistance to a filter. An L-match will consist of an inductor and a capacitor and the presence of the inductor will modify the frequency response, possibly in a beneficial way.

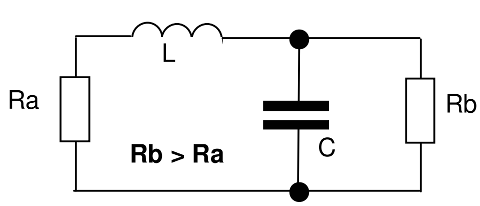

Fig. 7. L-match

If Rb is equal to, ot greater than, Ra then

$$L = \frac{Ra \sqrt{\left\{ \frac{Rb}{Ra} - 1 \right\}}}{2 \pi Fo}$$

$$C = \frac{\sqrt{\left\{ \frac{Rb}{Ra} - 1 \right\}}}{2 \pi Fo\ Rb}$$

Taking the earlier example where we matched an input terminating resistance of 50 Ohms to the filter input terminating resistance of 2 058 Ohms we find that

L = 5.03 uH

C = 49.0 pF

Finding a 5.03uH inductor is a problem but a 4.7 uH inductor may work satisfactorily. The capacitor must be absorbed into C1 by increasing the value of C1 by 49 pF

So how about matching the terminating resistance of the filter to 1,000 Ohms as we did with the capacitive matching. The component values are starting to become unrealistic with L = 16.4uH and C = 8 pF.

Using an L-match at the input has the advantage of improving the filter high frequency side roll-off. In some applications this may be the preferred matching solution for this reason. The final circuit is shown in Fig. 8 and uses an L-match at the input and a capacitive match from Section 2) at the output.

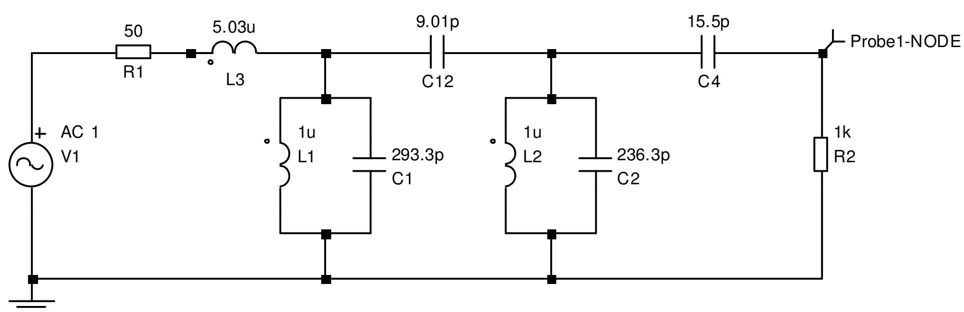

Fig. 8. Filter with input matched by an L-match

The insertion loss of this filter is compared with the capacitive input match version in Fig. 9.

Fig. 9. Comparison of L-match and capacitive match

As can be seen, the high-side attenuation is improved at the expense of the low side attenuation. By 15MHz there is an additional 10dB of attenuation.

Fig. 10. Comparison of L-match and capacitive match – pass band response

Fig 10 shows the simulated pass band response. The L-match causes the pass band to widen a little. Fitting an off the shelf 4.7uH inductor shifts the response a little but would be an acceptable solution.

3. Conclusion

A simple method of matching lower terminating resistances to filters requiring higher terminating resistors has been described. The shape of the frequency response of the filter is unchanged.

4. References

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

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