Transformer Coupled LC Bandpass Filters

w7zoi, 10June08, 19April09

Most of the LC bandpass filters that I design and build tend to use capacitors for matching at the ends. Using capacitors produces a non-ambiguous topology that is easily duplicated. The alternative is to use transformer coupling. This usually takes the form of a link wound on the inductors. As such, it is a minimum component circuit.

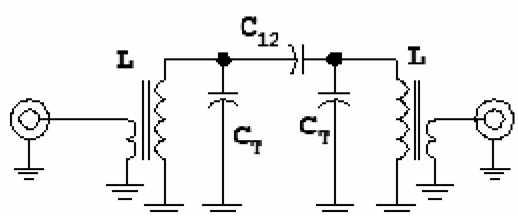
There is a design problem related to this approach. This relates to the less than ideal nature of the magnetic coupling that we see with links wound over inductors. This difficulty appears with powder iron toroids, and is even worse when using air core coils.

This note describes an experiment I did today with a simple double tuned circuit where I used link coupling. While not a universal “answer” to the problem, a simple method is presented that will allow experimental adjustments.

This double tuned circuit is about as simple as a multiple resonator filter can get. The design equations are summarized in this figure where F is the center frequency of the filter.

Double Tuned Circuits with Link Coupling

$$\omega = 2\cdot\pi\cdot F$$



$$C_0 = \frac{1}{\omega^2\cdot L}$$ Nodal Capacitance

Butterworth Shape:

$$k = \frac{1}{\sqrt{2}} \qquad q = \sqrt{2}$$

$$C_{12} = \frac{C_0\cdot k\cdot B}{F}$$ where B is the Bandwidth.

$$C_T = C_0 - C_{12}$$

$$Q_{end} = \frac{q\cdot F\cdot Q_u}{B\cdot Q_u - q\cdot F} \qquad R_p = Q_{end}\cdot\omega\cdot L$$

Design equations for a general double tuned circuit. The k and q values can be changed for shapes other than Butterworth.

The experimental filter I considered used inductors consisting of 19 turn of #26 enamel wire on T44-6 toroids. I wound the coils and then measured them with an AADE LC meter, finding an inductance of 1.55 µH. The inductors have an unloaded Q of about 200. The tuning capacitors in the filter, C_T, are 325 pF while the coupling capacitor is 8.33 pF.

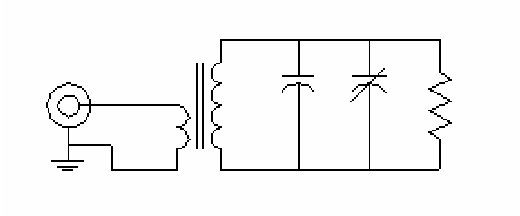
The underlying concept for a coupled resonator filter is that the filter shape is established by establishing the coupling between resonators, the loaded Q of the end sections, and the resonant frequency of all resonators. The expression for Q_{end} above provides a value of about 49. This is the Q related to the external loading, in this case by the 50 Ohm terminations attached to the links. A parallel resistance, R_P, with the value shown will establish this Q. Or the link coupling to 50 Ohms will do the job.

But how many turns should be on the link? This is the critical question.

The value for R_P in my filter was 3.37 K. If the inductor was wound on a high permeability ferrite, we could validly assume that impedances would transform in proportion to the square of the turns. Hence, we would take the square root of 3370/50 to obtain a turns ratio of 8.2. The basic inductor uses 19 turns. So that would suggest that we use a 2 turn link, for 19/8.2=2.3.

Transformers, ideal or not, transform with the same ratio for both directions. Here we want a 50 Ohm load attached to the link to appear as 3.37 K Ohms to the other side. So, if we attach a 3.37K resistor to the 19 turn winding, we should see 50 Ohms when looking into the link.

Accordingly, I attached a 3.3K resistor to the 19 turn winding and measured the impedance looking into the link. This is shown below:



A circuit for adjusting the turns on a link for loading a tuned circuit.

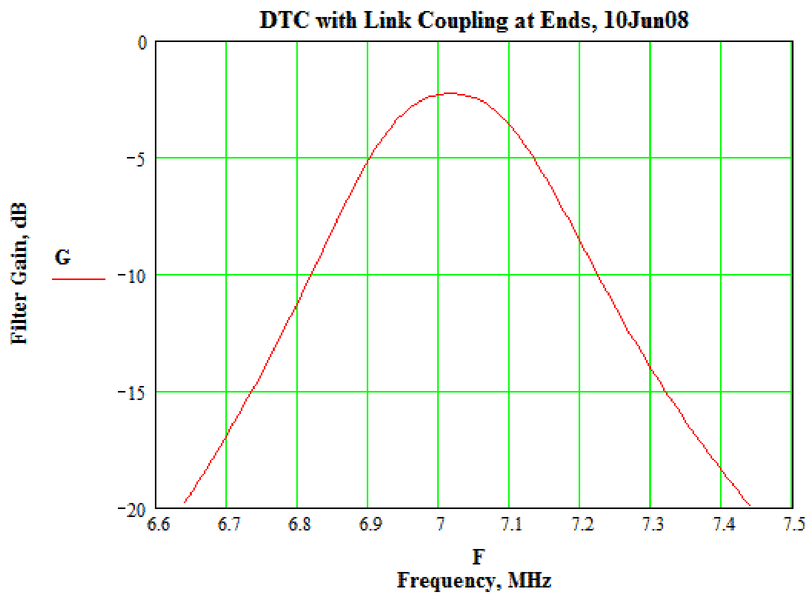
The procedure is simple enough. Load the high impedance winding with a suitable resistor. Then look into the link with a return loss bridge driven at the frequency of interest. Adjust the circuit for resonance, indicated by the highest (best) return loss. Then adjust the number of turns in the link and perhaps the position of the link to obtain the best match. The resistor is then removed. The transformer is inserted into the filter and final alignment is done.

The simplistic calculations above suggested a 2 turn link as close to optimum. But that would have described the tight coupling between the link and the coil related to ferrite. This was a powder iron core with permeability of 8, so we would not expect ideal coupling. Accordingly, I measured the input impedance with 2, 3, and 4 turn links. The measurements were:

N	Reflection coefficient	Impedance
2	0.291 at 171 degrees	28+j3
3	.0855 at -10	59+j2
4	0.3396 at -17 degrees	95-j20

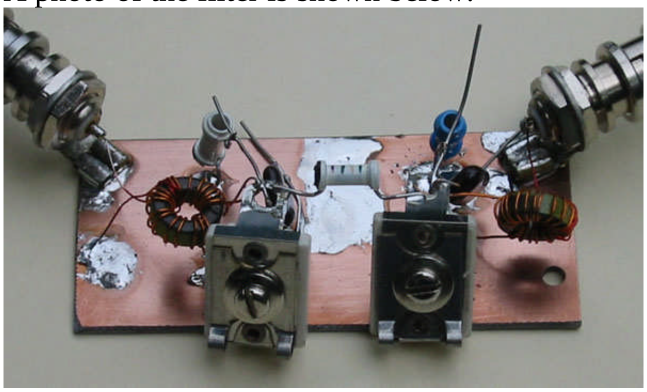
The 3 turn winding offers the better match.

The filter was assembled after the end measurements with the transfer function result shown below:



Measured Filter

A photo of the filter is shown below.



Experimental link coupled filter.