Mixed Form N=3 LC Bandpass Filter

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Abstract

The traditional LC bandpass filter uses parallel resonators with coupling in the form of small capacitors between high impedance nodes. End section loading is realized with either inductive coupling to an end inductor or with a series capacitor connected to a low impedance termination. This traditional form degenerates into a high pass filter in the stopband. An alternative form is sometimes used where all end loading and resonator-to-resonator coupling is realized with shunt capacitors. This circuit degenerates into a low pass filter within the stopband. This study considers a mixed form. The resonators still look generally like parallel tuned circuits, allowing small capacitors between high impedance nodes to couple between elements. However, the end section loading is realized with the pseudo low pass methods. The result is a filter with a symmetric frequency domain shape and better than normal attenuation within the VHF stopband.

Introduction

The underlying concept central to the design of most bandpass filters is the Dishal Method (See Zverev, Chapter 9.) What Dishal tells us is that we can design our filters of any polynomial (Butterworth, Chebyshev, etc.) by controlling the loaded Q of the resonators at the filter ends and the coupling between resonators. This sentence is important; it is essentially a complete summary of most of our filter design work. In this study, we will change the format of the end resonators to be the one we would use with a filter using series resonators. But we will still couple out of that resonator with small series capacitor to the next element, just as if we had a parallel tuned circuit. The basic concept is illustrated in Fig 1.

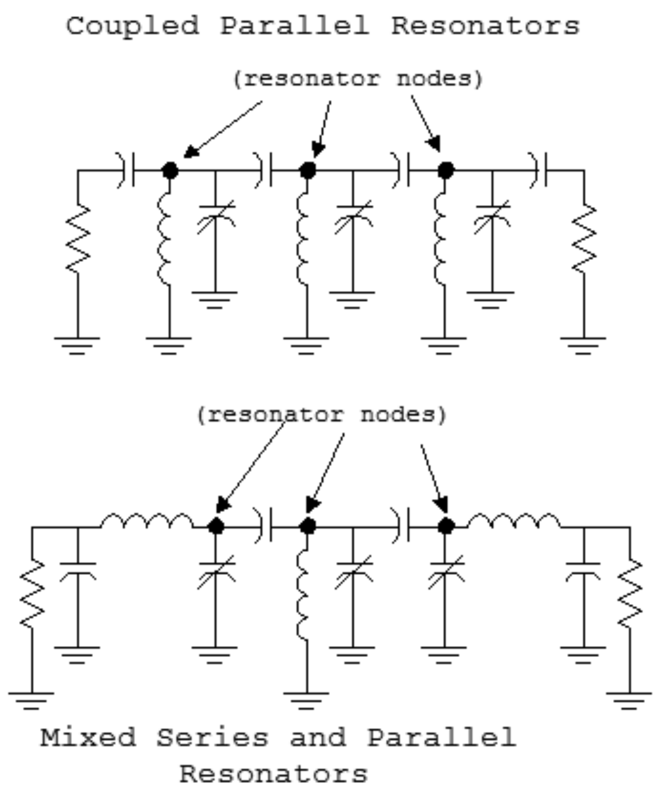


Fig 1. The top figure uses parallel resonators while the bottom one uses series resonators at the ends, but a parallel tuned circuit in the middle. The end transformations are summarized in Fig 2.

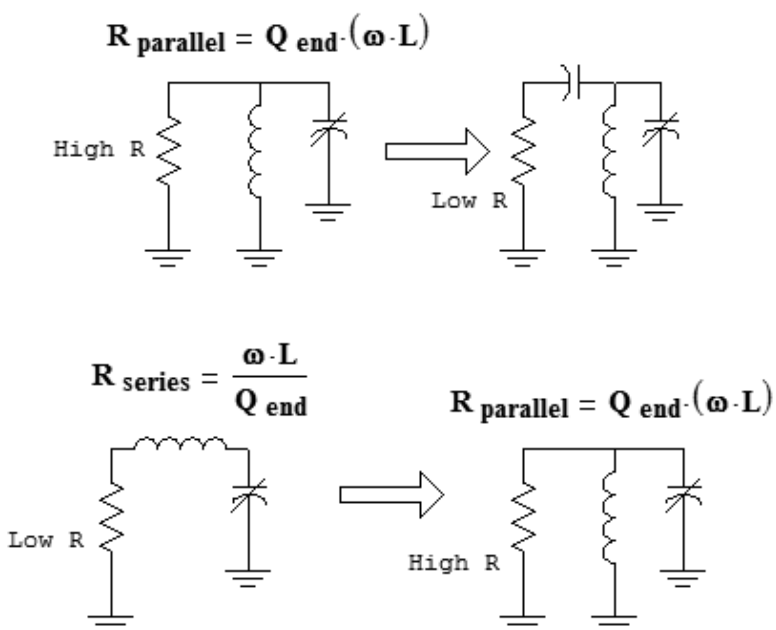
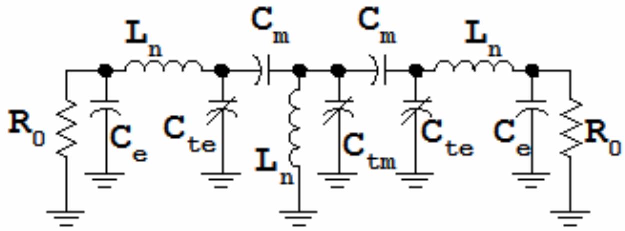


Fig 2. End transformations.

The design is summarized with the following equations for a triple tuned circuit:

Triple Tuned Circuits with Mixed Resonators.

End resonators have series L with one end going to termination and other to a grounded tuning cap. Middle resonator is just a classic parallel tuned circuit with small coupling caps.



Independent Variables: **f** (in MHz), $\mathbf{L_n}$ (in nanohenry), $\mathbf{Q_u}$, **B** (in MHz), $\mathbf{R_0}$.

$$\omega := 2\cdot\pi\cdot f\cdot 10^{6} \qquad L := L_n\cdot 10^{-9} \qquad Q_f := \frac{f}{B} \qquad q_0 := \frac{Q_u}{Q_f}$$

$$C_0 := \frac{1}{\left(\omega^2\cdot L\right)}$$

N=3 Butterworth k=0.7071 and q=1.0.

$$Q_e := \frac{1}{\left(\frac{1}{q\cdot Q_f} - \frac{1}{Q_u}\right)}$$

(This is Q of end section, denormalized.)

$$K := \frac{k}{Q_f}$$

(And this is the denormalized coupling coef.)

$$R_s := \omega\cdot\frac{L}{Q_e} \qquad C_e := \sqrt{\frac{R_0 - R_s}{R_s\cdot\omega^2\cdot R_0^2}} \qquad C_m := C_0\cdot K$$

But, this is the wrong Cm. See refined form below.

c, cc, and ccc are intemdiate variables.

$$c := \frac{C_e^{\,2} \cdot \omega^2 \cdot R_0^{\,2} + 1}{C_e \cdot \omega^2 \cdot R_0^{\,2}}$$

(c is the series equivelent capacitance at the termination.)

$$Z := R_s + j \cdot \left(\omega \cdot L - \frac{1}{\omega \cdot c} \right)$$

$$cc := \frac{\frac{1}{\omega} \cdot \left(\omega \cdot L - \frac{1}{\omega \cdot c} \right)}{R_s^{\,2} + \left(\omega \cdot L - \frac{1}{\omega \cdot c} \right)^2}$$

Doing the math produces cc, which is the capacitance we will use for the end for coupling calculation. Actually, we must use the geometric average of cc and C0 for this, ccc, because the middle resonator is a classic parallel circuit.

$$ccc := \sqrt{cc \cdot C_0}$$

$$C_m := ccc \cdot K$$

(coupling cap)

$$C_{te} := \left(\frac{1}{C_0} - \frac{1}{c} \right)^{-1} - C_m$$

(end tuning cap)

$$C_{tm} := C_0 - 2 \cdot C_m$$

(middle tuning cap)

A Design Example

A 10% wide Triple Tuned Circuit at 10 MHz was examined. BW=1. I did simulations of this filter (red) and a classic one with coupled parallel resonators. The comparison is shown below.   Butterworth k and q values were used.

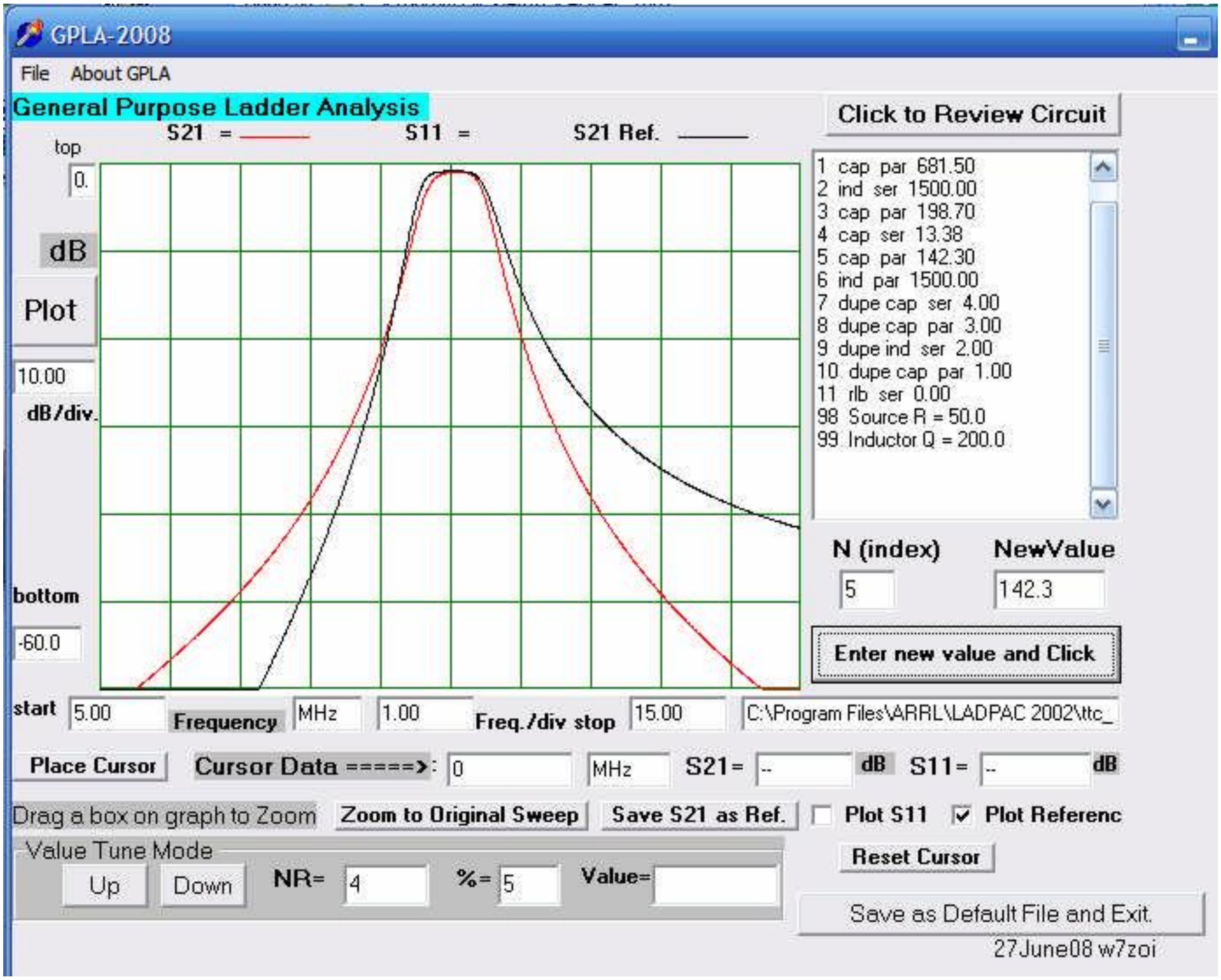


Fig 3. Comparison of a mixed form bandpass filter (red) and one with parallel tuned circuits (black). Note the improved symmetry. These filters have a 1 MHz bandwidth at 10 MHz.