Building Practical Double-tuned Circuits with EMRFD Procedures

12, 13 Feb 2013, w7zoi

Recent Internet posts (EMRFD Yahoo Group, starting with post #8174) emphasized a difficulty in the presentation of Table 3A in EMRFD, page 3.14. The table should have included a statement to indicate that the schematic is the **simplified ideal circuit** that resulted from the design process. The actual circuit we build may or may not be more complicated. The need for additional discussion is the reason for this report.

Note that there is a typographic error for this particular entry in EMRFD Table 3A on page 3.14. A bandwidth of 0.2 MHz is shown for the design with 14.2 MHz center frequency. The bandwidth is actually a wider 0.4 MHz.

Analysis

The filter schematic from the table is shown below.

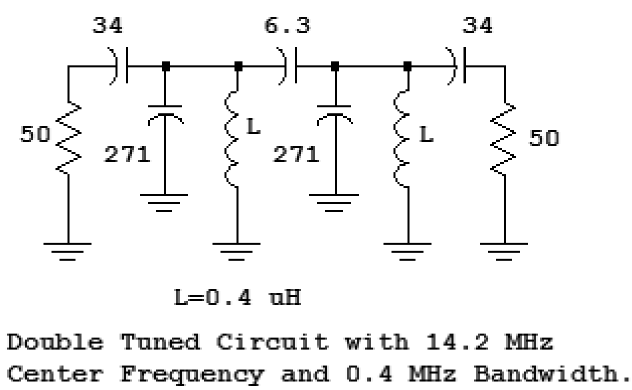


Fig. 1.

This is the design that comes from the design procedure outlined in EMRFD, which is also embedded in the computer program distributed with the book. The latest version of this is DTC08.exe. Circuit analysis will confirm the design of Fig 1.

Any number of computer programs can be used to confirm that the circuit from Table 3A is indeed a valid filter. We used two. One was Ladpac, the package that is distributed with EMRFD. The other is LT SPICE. The results were identical. No need to present them here.

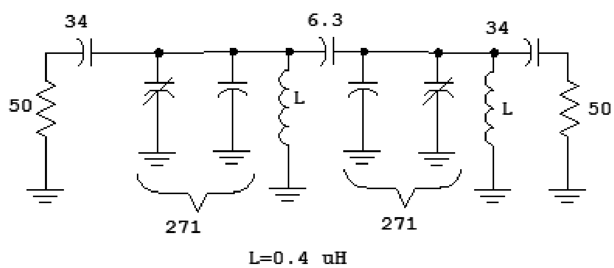
Construction: No-Tune versus a Design with Trimmers

Having examined the filter design and generally feeling comfortable with the values, we can now build an actual filter. But how? The first thing we might do is to build the filter exactly as shown in the ideal schematic of Fig 1. This can be demonstrated by Bob Kopski, K3NHI, in http://groups.yahoo.com/group/emrfd/files/K3NHI-DTC/

and related text (post #8183, 8210, 8226.) Bob managed to build filters that had the general shape of a double tuned filter. Swept instruments were used to align his filter. Bob has built his own swept signal source to drive LC filters in the RF range from near DC to 100 MHz. He uses this with a homebrew AD8307 based power meter.

Bob's approach was to build what we might call a ***No-Tune*** filter. The *no-tune* LC filter is a circuit that includes no adjustments. Most of the crystal filters we build are tweak-free *no-tune* circuits. Rick Campbell, KK7B, has spent a large chunk of his life with the exploitation of *no-tune* circuits. Contrast his *no-tune* microwave transverters and the direct conversion receivers with *no-tune* LC audio filters. Rick's microwave *no-tune* filters, usually of order 3, have a typical bandwidth of 10 to 20%. The *no-tune* audio filters are even wider, from perhaps 30% to 100% width.

The filter example of this study in Fig 1 is much narrower, about 3%. While Bob has demonstrated that a *no-tune* design is possible, it may not be the most practical solution. The traditional approach is to include variable trimmer capacitors as part of the elements that tune each mesh, as illustrated below.

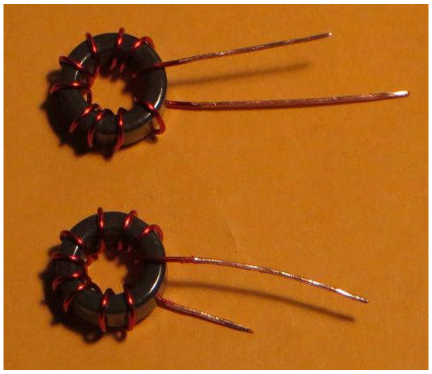


Double Tuned Circuit with 14.2 MHz
Center Frequency and 0.4 MHz Bandwidth,
modified to be easily tuned.

Fig 2.

As a complement to the *no-tune* filters that Bob built, I decided to fabricate and measure a filter with the added trimmer approach of Fig 2. An additional constraint was applied: **No special equipment, including swept tools, would be used in the construction and tuning of the filter**. After all, we managed to build double tuned circuits long before we had swept instrumentation. I would use traditional methods instead of RF techniques. The filter would be tuned with drive from a homebrew signal source and the output would be observed on an oscilloscope. However, once the filter is built and operational, a spectrum analyzer and tracking generator would be used for evaluation.

As a first step, two coils were wound. New T50-6 cores and a spool of #22 wire were pulled from the parts bin, resulting in the coils shown below.

 Fig 3.

The two inductance values were measured with an AADE L/C meter. The results were 415 and 429 nH. The coils were NOT changed after these measurements.

The trimmer drawer was pulled and a couple of old variable capacitors were extracted and measured. Both had a maximum of about 65 pF, with a minimum of about 5 pF. I also found some 200 pF fixed capacitors. A look at Fig 2 shows that this value is not high enough. Some 24 pF capacitors were pulled to parallel with the 200 pF parts. 33 pF capacitors were substituted for the end matching elements, and a 6.8 pF capacitor was used for inter-element coupling. The final circuit that was built is shown below.

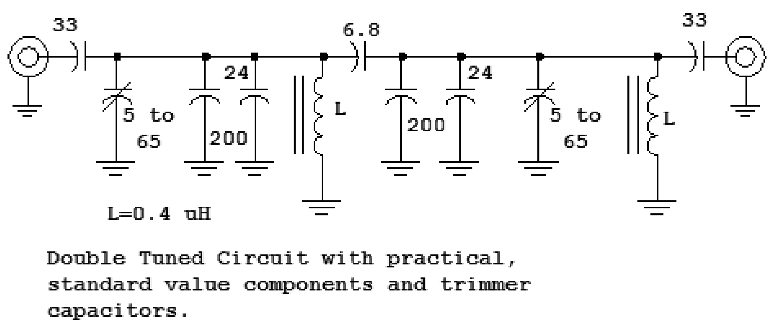


Fig 4.

The signal source is that from EMRFD, page 7.15, Fig 7.27, shown below.

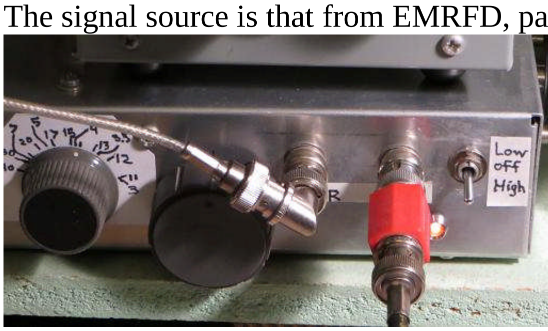


Fig 5. The red “blob” is a 6 dB pad that is added to the generator to help establish a clean 50 Ohm output impedance. The silver braid coax leads to a frequency counter.

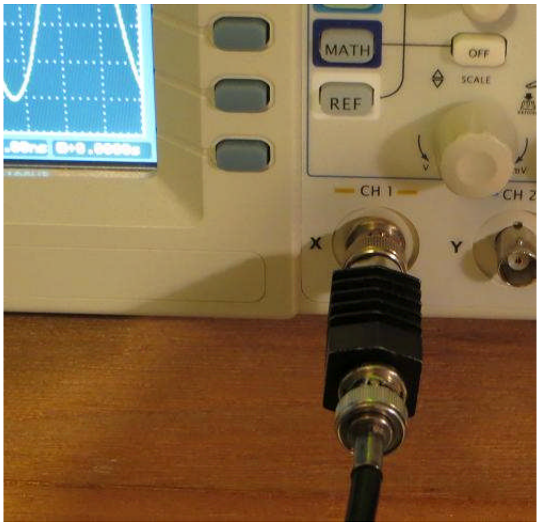


Fig 6. The detector end is a digital storage sampling oscilloscope (1 Meg input Z) with a 50 Ohm terminator **at the 'scope**.   Virtually any oscilloscope can be used so long as it has a bandwidth approaching the filter frequency.

Two pieces of 50 Ohm coax were attached to a barrel, forming a single line between the RF generator and the 'scope, are shown below.

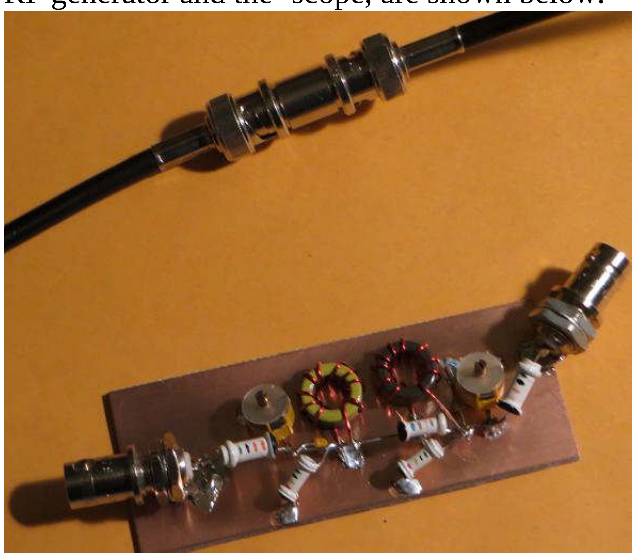


Fig 7. The response is measured first with the BNC barrel "through" connection. The barrel is then removed and replaced by the filter.   The filter trimmer capacitors are tuned for maximum response at the filter center frequency.   No sweeping is necessary.   The response is then measured, allowing calculation of insertion loss.

Results with the Trimmer-Based Filter

The filter was aligned by setting the generator to 14.2 MHz, and then leaving it fixed while the trimmers were adjusted.   This fixed frequency alignment is generally possible with any coupled resonator filter.   That is, sweeping is not necessary so long as the end loading and coupling elements are right.   After the circuit was tweaked, the insertion loss was determined. The response with the barrel through connection was 816 mV pk-pk. This dropped to 568 mV pk-pk with the aligned filter connected, indicating an IL of 3.2 dB. This is a bit more than the simulated 1.9 dB, suggesting a resonator Q less than the specified 250 value. A casual manual sweep was done with the generator, confirming that the filter was behaving with the right bandwidth and center frequency.

Having done our "due diligence" with the simple test gear, it was time to bring on the more refined equipment. The filter was examined with a spectrum analyzer with a tracking generator with the result below.

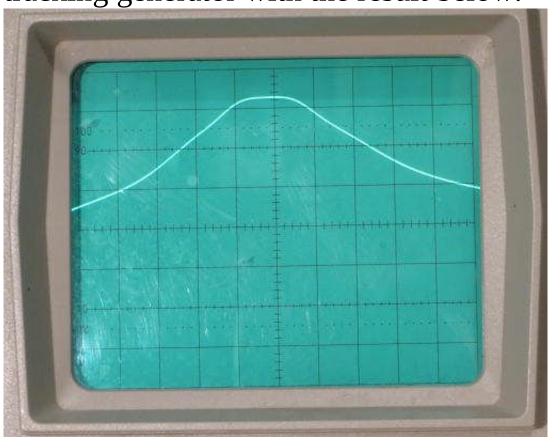


Fig 8. Spectrum Analyzer with Tracking Generator response for the filter. The sweep is centered at 14.2 MHz with a span of 0.2 MHz per division. The vertical scale is 10 dB/div. The TG amplitude was set to put the center peak 3 dB above a major division, allowing easy observation of the 3 dB bandwidth.

Clearly, this filter has a bandwidth that is very close to the 400 kHz design value. The skirt response is just what we would expect from simulations.

Again, we emphasize that the swept instruments were used for evaluation, but only after the filter had been built and aligned with routine equipment. The equipment used, even though homebrew and simple, was designed for a 50 Ohm environment. High impedance vacuum tube era service instruments are generally not suitable.

Stopband Results

Things now become interesting. I thought it would be useful to see what the filter did at VHF and beyond. I expected that the filter might be less than optimum, for there were some moderately long lead lengths in the *ugly* construction. The results of a sweep from a 0 to 500 MHz sweep are shown below in Fig 9.

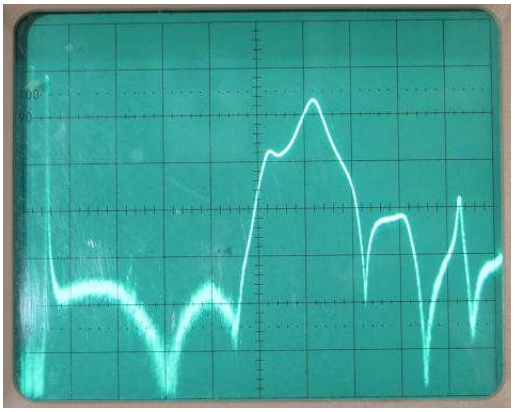
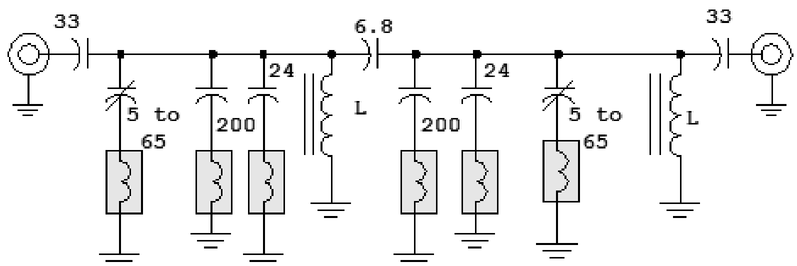


Fig 9. The 14 MHz bandpass filter response at VHF.   The SA/TG now sweeps to 500 MHz.   The peak near 300 MHz is only 10 dB below the response at 14 MHz.

The horrible response shown in Fig 9 could easily produce severe spurious responses if the filter was the only filter in a receiver front end.   A cascaded low pass filter, carefully built with suitable VHF components (e.g., SMT) would eliminate these problems.

What could lead to this horrid VHF stopband response?   The observations make more sense if we redraw the schematic to include some of the spurious inductors, shown below.



Schematic including parasitic inductors
related to capacitor lead lengths.

Fig 10.   The parasitic inductor in series with the grounded capacitors have values of a few nH.   The individual parasitic inductor values are commensurate with the length of the capacitor body and the attached wire leads.   These inductors resonate with the attached capacitors to create resonances at VHF and above.

The observed behavior is not really an anomaly, although it can certainly be a surprise when not expected.   The effect is often seen when unequal capacitors are paralleled.   This is discussed in detail in Section 2.8 of EMRFD.   As always, careful measurements rather than lore will reveal what will and what will not work.

Conclusions and Comments

The filters in Table 3A work.   Really. We have built many of them, and all were simulated when designed.   Some may be suitable for construction in a *no-tune* form, especially if they are of wide bandwidth. Most will be more easily realized in a classic topology where the net capacitance of a parallel resonator is split into segments of fixed and variable. This is especially recommended for bandwidths of less than a few percent.

The filter design programs are preferred over the tables. One can even design his/her own filters without any computer crutches. Programs or back-to-basics design allow one to optimize the filters for other characteristics beyond the original ones. For example, redesigning the filter considered here with slightly larger inductors (480 nH instead of 400) would have eliminated the 24 pF capacitors, probably eliminating some of the VHF resonances.

The degraded VHF stopband performance of many HF bandpass filters is an interesting challenge. Cascaded low pass filters will often eliminate the problems. Alternative topologies for the bandpass filters may also help to suppress VHF spurs.