

Design spreadsheet for a tapped LF antenna loading coil

©Jim Moritz, M0BMU 26/7/2006

The tapped loading coil of Figure 1 is physically the simplest way of matching an LF transmitter to a vertical antenna. Electrically, using the loading coil as an “auto transformer” to match the transmitter output impedance to R_{ANT} looks intuitively simple. But the theoretical design is actually much more complicated, because the impedance transformation depends on the mutual inductance between the two sections of the coil, which in turn depends on the geometry of the coil windings as well as the tapping point on the coil. It also is significantly affected by the Q of the loading coil, and the stray capacitance, C_0 , of the coil and wiring. As a result, these loading coils are usually designed by trial and error.

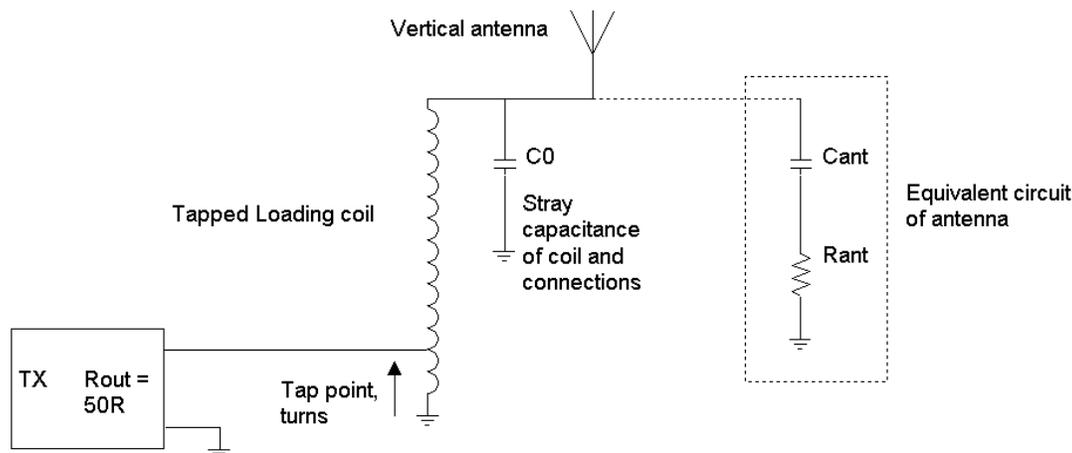


Figure 1 – LF antenna matching with tapped loading coil

The Excel spreadsheet “tap_coil.xls” is the result of an attempt to produce a reasonably accurate numerical design procedure for the tapped loading coil. Expecting high precision is unrealistic, because most of the variables in the system are only approximately known, but practical experiment suggests that the matched antenna resistance can be predicted within around 10%, and the tap point within a turn or two. This is accurate enough to take much of the guesswork out of loading coil construction. Also, it gives useful insights; for example, there is a definite upper limit on the resistance that can be matched by a particular loading coil, which depends on the coil diameter and winding pitch. The calculations involved are tedious, but checking the design using the spreadsheet only takes a moment after some basic coil and antenna data has been entered. Some measurement of real loading coils were made to prove that the method works!

The spreadsheet calculates the matched value of R_{ANT} for 16 different tapping points between a minimum and maximum number of turns entered by the user. The resulting graph allows selection of the appropriate tapping point for R_{ANT} anywhere within the range of tapping points. Using the spreadsheet, “what if” calculations can be done quickly to determine the effects of changing coil diameter, winding pitch etc. The “known” input data is entered into the red coloured cells in the spreadsheet, including:

Operating frequency (kHz)

Antenna capacitance C_{ANT} (pF) - The antenna capacitance can be estimated using various formulae (see, for example, ON7YD’s LF antennas web pages, <http://wireless.org.uk/on7yd/>). A simple estimate can be made by assuming the downlead has a capacitance of 6pF/m, and the top loading wires 5pF/m. Alternatively, the capacitance can be measured using an RF bridge of some form.

Coil diameter (m),

Winding pitch (mm) – The coil inductance and impedance transformation is quite sensitive to changes in coil diameter and winding pitch, so it is a good idea to measure these carefully. Coil diameter is taken as (former diameter + wire diameter). Winding pitch is approximately equal to the diameter of the wire over the insulation; it is best measured by winding 20 or more turns onto the former and dividing the length of the winding by the number of turns.

Transmitter output impedance (Ω) – Usually 50

Coil Q estimate – The Q of the coil can be measured, however, if a measurement is not available, a rough “guesstimate” is adequate; provided the resulting coil loss resistance is small compared to R_{ANT} , it will not make a huge difference. For smaller coils (~100 - 150mm) wound with enamelled wire, Q of 200 – 300 is typical. Large diameter coils achieve Q of about 300 – 500. Big litz wire coils can have Q of 1000 or more. PVC insulated wire results in lower Q compared to air-spaced or Teflon insulation.

Maximum and Minimum tapping points (turns) – the range of tapping points over which the matching antenna resistance will be calculated

Stray capacitance “fiddle factor” – The total stray capacitance C_0 of the coil and connections is estimated by multiplying the coil diameter by the 150pF/m “fiddle factor”, which seems to give reasonable results in practice; it can be changed if desired. Again, a rough “guesstimate” is sufficient.

The main output data from the spreadsheet is the graph of matched antenna resistance R_{ANT} vs. tapping point turns. You can interpolate any antenna resistance/tap combination from the curve. Other output data (in the blue cells) also includes:

- Stray capacitance and total capacitance in the system
- The required loading coil inductance (with the tap at zero turns) to achieve resonance
- The additional inductance needed to maintain resonance with the maximum tapping point in use (The coil is “shunted” by the TX output impedance connected to the tap, which reduces the effective inductance as the number of turns increases.) This may be provided by a variometer, or whatever other means is used to fine-tune the antenna to resonance.
- The estimated total number of turns required to achieve resonance at the minimum and maximum tapping points. Of course, you will probably want to add some extra turns and taps at the “hot” end of the coil to allow for different antenna capacitances. The extra turns have only a slight effect on the matched resistance in most cases.

Editing any of the input data values causes all the cells and the graph to be immediately updated.

Measurement Results

As a practical test of the accuracy of the calculation method and formulae given above, the values of antenna resistance and capacitance required to achieve a match to 50Ω were determined for several different tapping points on each of three loading coils, and compared with the results calculated using the spreadsheet. The loading coils were made with different diameters, length/diameter ratio, and winding pitch, in order to validate the calculations under a range of conditions. Coil 1 was 273 turns of approx. 1mm diameter enamelled wire on a 109mm diameter former and coil 2 was wound with 228t of 2mm diameter tefzel-insulated stranded wire on a 198mm diameter former. Coil 3 had a “short, fat” geometry with 153t of 1mm enamelled wire on a 198mm diameter former. The measured results are indicated by the circles in Figures 2 – 4, while the solid line represents the calculated resistance.

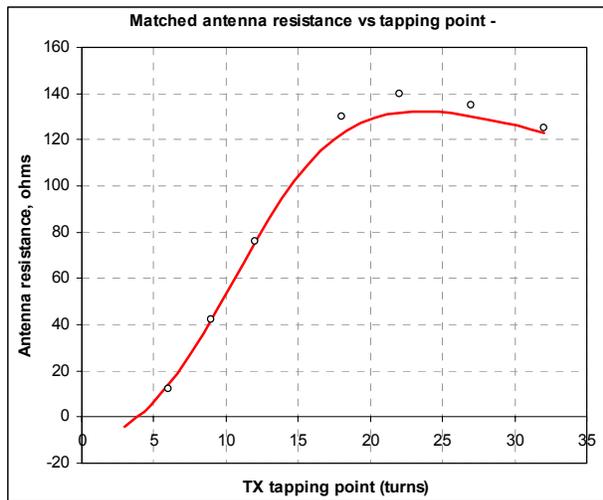


Figure 2 Coil 1 – 273t, 110mm diameter, 1.02mm pitch

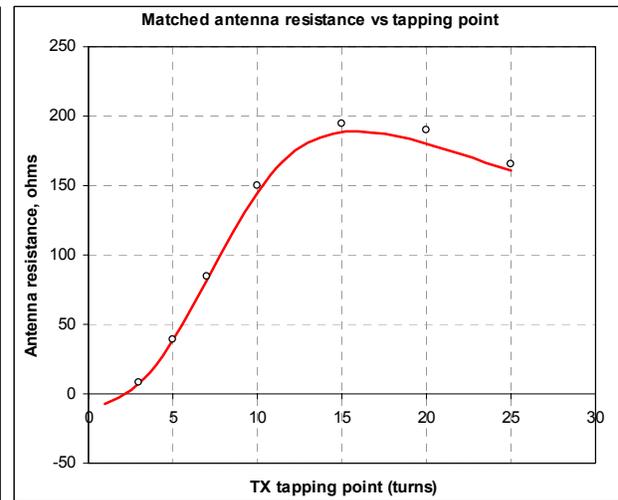


Figure 3 Coil 2 – 228t, 200mm diameter, 1.96mm pitch

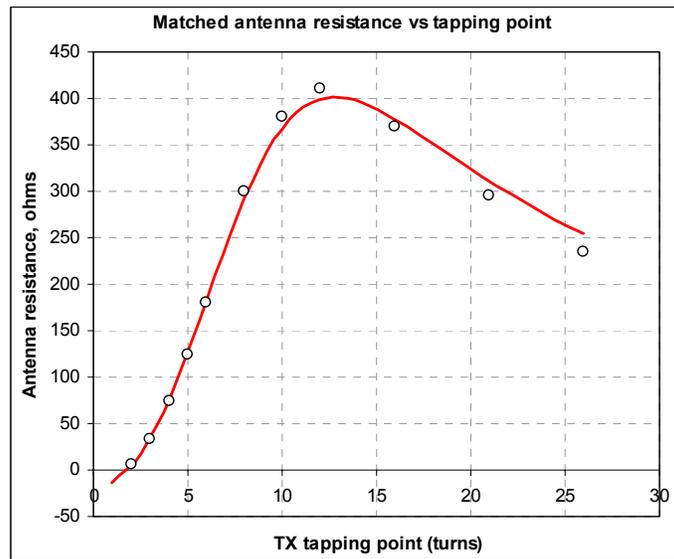


Figure 4 Coil 3 – 153t, 200mm diameter, 0.94mm winding pitch

Conclusions

As expected, due to the variables involved, the calculation of the tapping point by the spreadsheet is not exact, but quite good. These calculations certainly seem to be good enough to make an intelligent choice for number of turns and tapping points when designing a loading coil for amateur LF antennas

There is a definite upper limit to the antenna resistance that can be matched by any given coil, which is determined by the diameter and winding pitch of the coil. “Short, fat” coils with large diameters and close-pitch windings can match higher antenna resistances than “long, thin” coils, as can be seen by comparing Figs. 2 - 4. This is due to the closer coupling between the windings of “short, fat” coils.

You can “reverse engineer” an existing loading coil by entering the coil diameter, winding pitch, etc. and then adjusting the value of antenna capacitance until the estimated number of turns corresponds with the actual coil. I would be interested to know how your results compare with the spreadsheet!

Cheers, Jim Moritz
 73 de M0BMU
james.moritz@btopenworld.com