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Single-layer air coil

There are plenty of programs for calculating cylindrical coils. But what you will certainly not find so quickly is a tool that simultaneously estimates parasitic capacitance and parallel resonance, suggests the optimal coil and also displays the geometric dimensions in natural size as an addition.

Note: The underlying formulas are approximations, i.e. more or less inaccurate.
For simplicity, it is assumed that the wire thickness is negligible compared to the diameter of the cylinder, so its influence remains small and it can be disregarded.

Preparation:
In order for your monitor to display the coil on a scale of 1:1, you must calibrate the graphic display as follows before using the program for the first time:

Measure the width of the white image field with a ruler and enter the value in the "Width" field. This value is not lost, but is automatically available again after starting the program again!

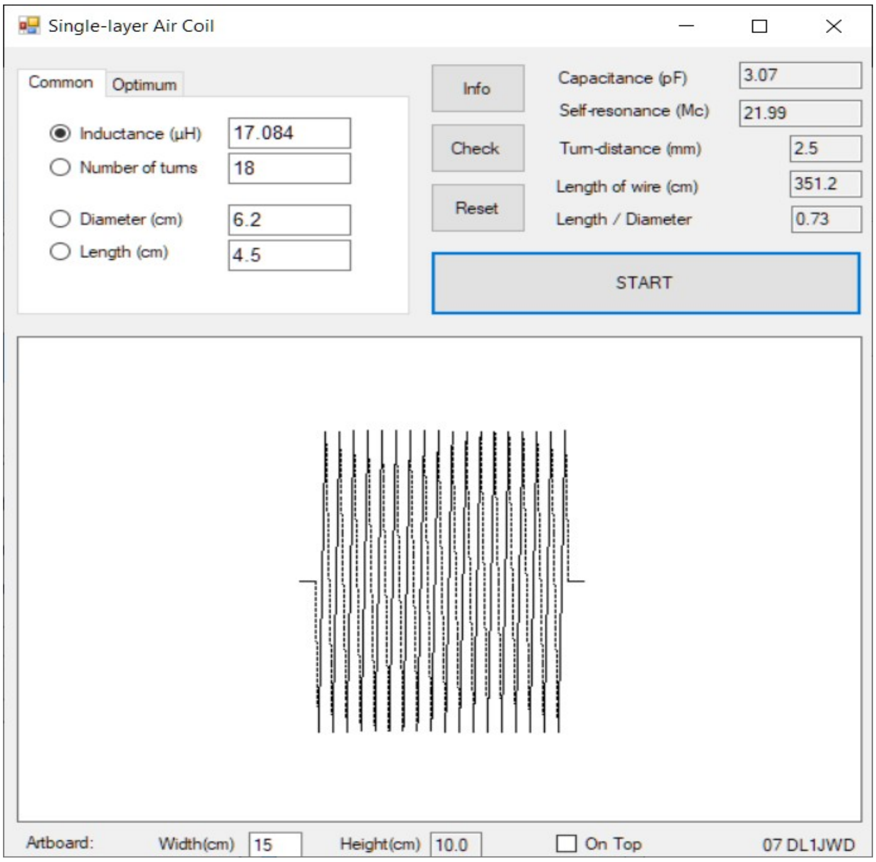
Example 1:

In the "Artificial Station Earth MFJ -931" there is a switchable air coil with 18 turns, the diameter 6.2cm and the length 4.5cm.

What is the maximum inductance of this coil (switch position L)?

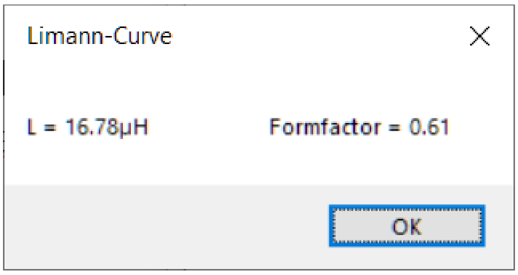
On the tab page "Common" you mark the field for the desired size with the small round button, in our case "Inductance".
In the other fields you enter the given values.

After clicking on "START" you will not only get the result (approx. 17µH), but also the side view of the coil on a scale of 1:1:



Since the coil capacitance is about 3pF, the first parallel resonance is about 22MHz.
From this it can be concluded that the MFJ-931 can no longer be operated on the 15m band and higher, at least in switch position L (see coil computer)!

With the button "Check" you can display the result of an alternative calculation method for comparison purposes, which is not based on the approximate formula used, but on an integration via the magnetic field distribution:



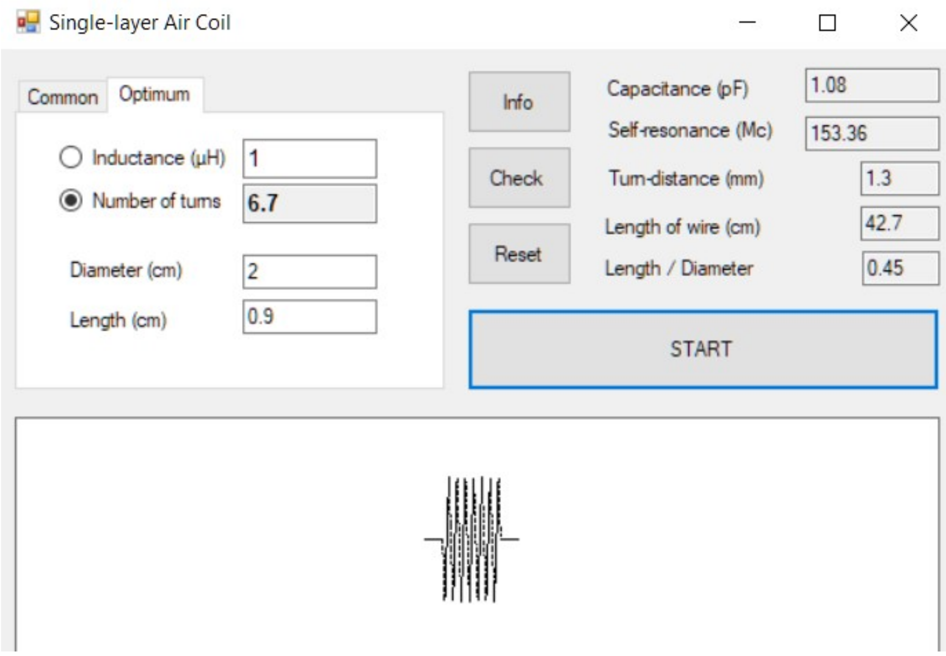
Example 2:

Since the beginnings of broadcasting technology, it has been known that a ratio l/D = 0.45 applies to a so-called "optimal" coil. The coil is therefore almost half as long as its diameter.
This achieves the desired inductance with the shortest possible wire length.

How large must the number of turns and length of an optimal 1µH coil be if a winding body with a diameter of 2cm is available?

This time you select the tab page "Optimal" and mark the "Number of turns" as the parameter you are looking for.

When entering the diameter, you notice that the coil length is automatically in proportion
l/D = 0.45. Now click the "START" button:



In practice, l/D is usually slightly larger than 0.45, so the coil is more or less stretched.

For a high coil quality, there are the following recommendations for the ratio length to diameter:
KW coils: l / D = 1 ... 2
FM coils: l / D = 0.5 ... 1,5

The winding distance, as indicated by the program, is not to be confused with the space between the windings, but it is measured between the central axes of adjacent windings.
It should be equal to the wire diameter, at least for VHF coils, so that the coil capacity remains small.
A later exact adjustment of the inductance (by compressing or distancing the windings) is also easier if the winding distance is not too tight.

Theory

The starting point for calculating the inductance of a single-layer cylindrical coil is the Biot-Savart law, it specifies how to calculate the magnetic field strength generated at point P of space by a thin conductor loop in which a current I flows.

A longer calculation with several simplifications then leads to the known approximation formula for the inductance of a single-layer cylindrical air coil with the number of turns N and the length l:

$$L \approx \frac{\mu_0 N^2 A}{l + 0.45\, D}$$

Here, A is the cross-sectional area for the winding diameter D

$$A = \pi D^2 / 4$$

and μ0 is the magnetic field constant

$$\mu_0 = 4\pi \cdot 10^{-7} \text{ Vs/Am}$$

For the units μH and cm, this results in the well-known size equation:

$$L \approx \frac{N^2 D}{45 + 100 \frac{l}{D}}$$

Logically, with a short coil with the same number of turns, the magnetic coupling between the individual turns increases, resulting in a higher inductance.
Conversely, pulling the windings apart reduces the inductance.

The parasitic capacity

... and derived from this the first parallel resonance, the program estimates according to the Medhurst formula from the 1940s, as it is mainly used to calculate Tesla transformers:

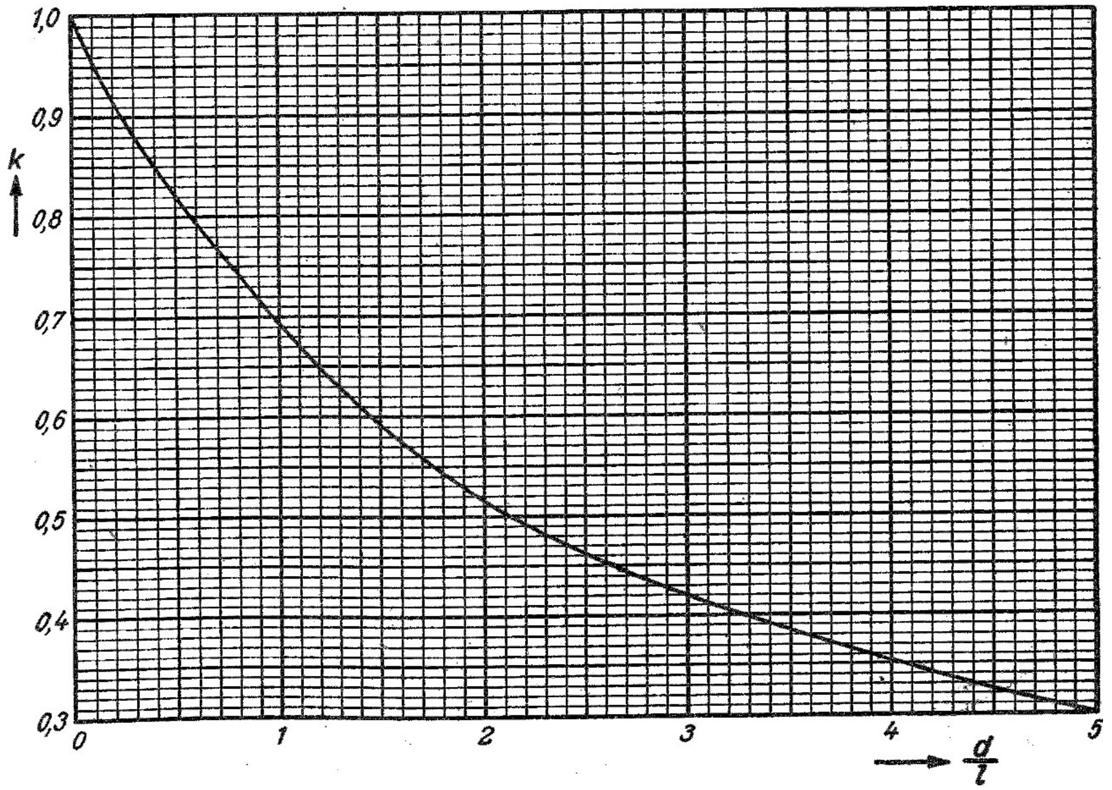
$$Cp = 0.144\, l + 0.161\, r + 0.746 \sqrt{r^3 / l}$$

with the coil length l and the winding radius r = D / 2.

Exact determination of the inductance

The exact calculation of the inductance requires a complex integration via the magnetic field distribution by means of higher mathematics, the simple approximation formulas used by my program are therefore more or less error-prone.

For comparison purposes, I have used the curve taken from /1/, from which a so-called form factor k can be read as a function of the ratio diameter to length:



The inductance results from this to:

$$L(\mu H)=\frac{\pi^2 D^2 N^2}{l}10^{-3}k$$

In my program I have placed an approximating function over the above curve, so that L for D/l <= 5 (l/D > = 0.2) can be calculated and can be called up via the "Control" button.

About the coil quality

The ratio l/D = 0.45, which is valid for the "optimal" coil, does not automatically have to lead to a coil with the highest possible quality, in which the wire thickness (skin effect!) also plays a major role.

In /2/ the mathematically interested OM finds a courageous publication, because unfortunately today mathematical formulas exert a rather deterrent effect on a growing majority of hams.

Bibliography

/1/ Limann,O.; Hassel,W.: Hilfsbuch für Hochfrequenz-Techniker, Bd.1 , 2.A. Franzis, 1959

/2/ Zwicky, P., HB9DFZ: Optimierung der Güte einlagiger zylindrischer Luftspulen. FUNKAMATEUR 62 (2013) H.10, S. 1080-1084