IMPEDANCE TRANSFORMERS for RECEPTION

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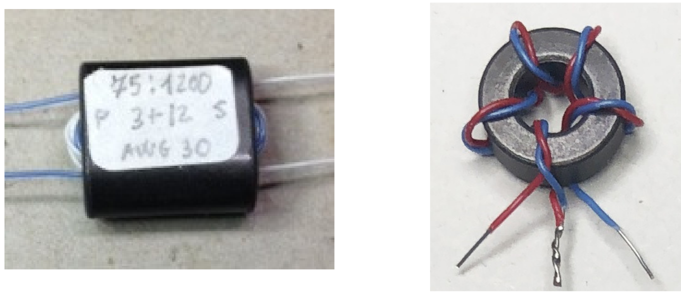
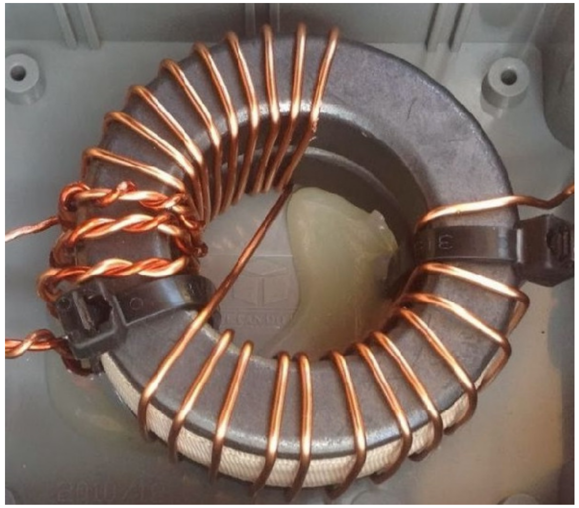
The impedance transformer for reception.

The receiving transformer is used to match the impedance of the receiving antenna to the transmission line that connects the antenna to the radio. It is therefore an impedance transformer for small signals. Therefore, the receiving transformer does not differ from those for power, for TX, except for the fact that they do not have to handle the typical powers of those for transmission.



RX transformers.



TX power transformer.

The ideal transformer

The symbol of the ideal transformer is represented here on the side. Where V_p, I_p, and n_p are respectively the voltage, current, and number of turns of the primary winding, while V_s, I_s, and n_s are those of the secondary winding. The two windings are coupled and are traversed by the same time-varying magnetic flux. The dot always indicates the direction of the alternating voltage.

The equations governing the electrical operation of the transformer are:

1. $\boldsymbol{i_p n_p = i_s n_s}$ The primary and secondary ampere-turns are equal.
2. $\boldsymbol{v_p i_p = v_s i_s}$ The power in transit is constant.

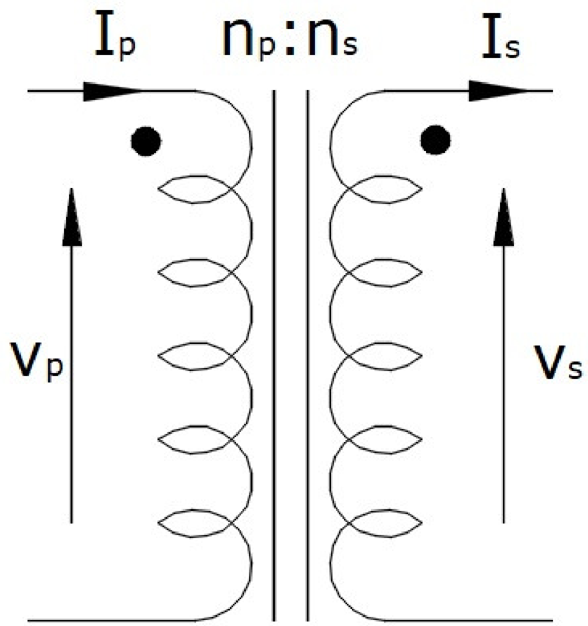
Furthermore, the ratio $\boldsymbol{\frac{n_p}{n_s} = N}$ is called the **turns ratio**.

From equations 1 and 2 above, equations 3 and 4 can be derived:

3. $\boldsymbol{\frac{i_p}{i_s} = \frac{n_s}{n_p}}$ The ratio of currents is equal to the **inverse of the turns ratio**.
4. $\boldsymbol{\frac{v_p}{v_s} = \frac{n_p}{n_s}}$ The ratio of voltages is **equal to the turns ratio**.

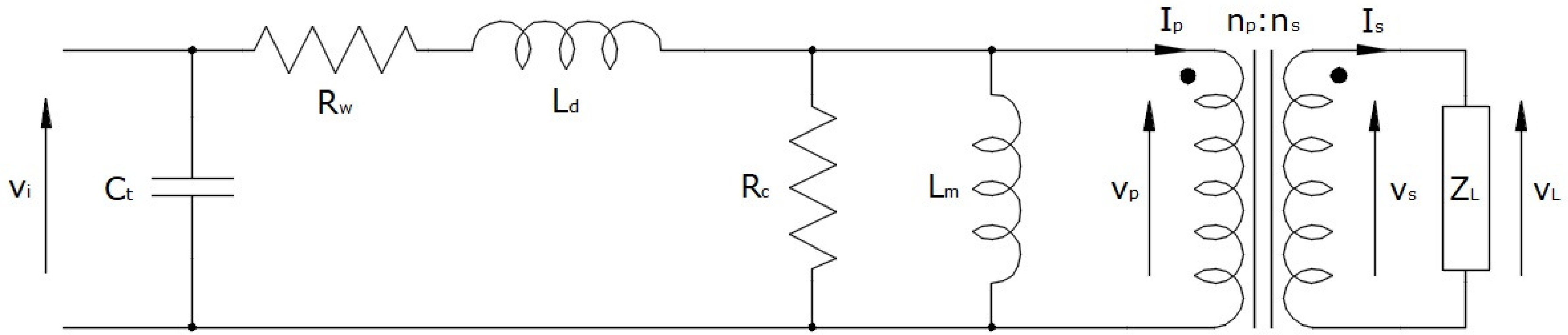
From which it follows that the **ratio of impedances** is:

5. $\boldsymbol{\frac{Z_p}{Z_s} = \left(\frac{n_p}{n_s}\right)^2}$



The model of a real transformer in RF.

The real transformer is quite different from the ideal one just seen. In fact, it is modeled with various devices representing the parasitic elements of the real component. Below is the model used in RF.

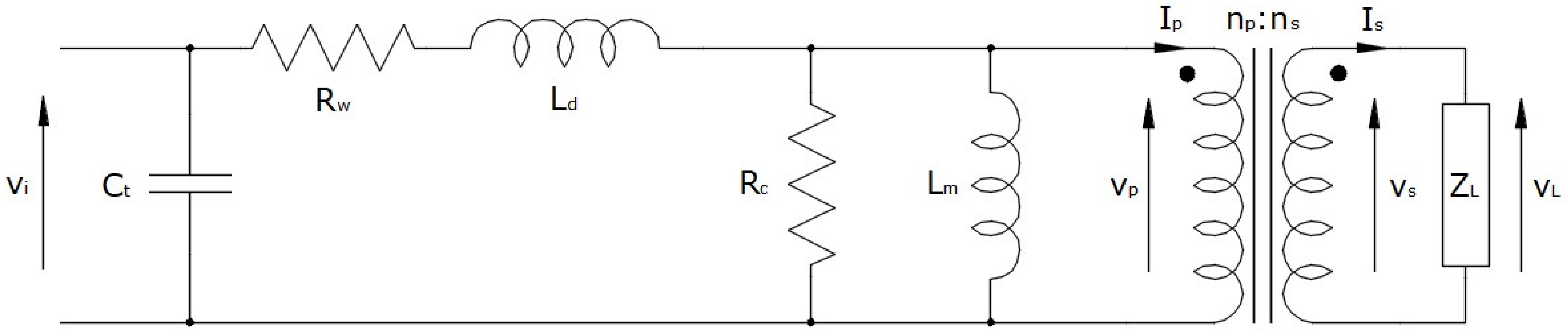


The model include:

- The capacity C_t: parasitic capacitance between turns, both in the primary and secondary.
- The resistance R_w: resistance of the conductors in both the primary and secondary.
- The inductance L_d: leakage inductance, due to magnetic fluxes that do not link the windings.
- The resistance R_c: not a true resistance but represents losses in the magnetic material.
- The inductance L_m: is the magnetizing inductance of the transformer.
- The ideal transformer.
- Load impedance Z_L.

Bandwidth of a real transformer

Each parasitic element affects the bandwidth of the transformer.



- The capacitance C_t and the inductance L_d determine the upper cutoff frequency. There is no way to avoid the parasitic effects of these two elements, but they can be minimized with appropriate construction measures.
- The inductance L_m is the main contributor to the lower cutoff frequency. In a well-made transformer, the coupling coefficient k between the primary and secondary is approximately 1 (0.998), so the self-inductance of the primary is practically equal to the magnetizing inductance L_m.

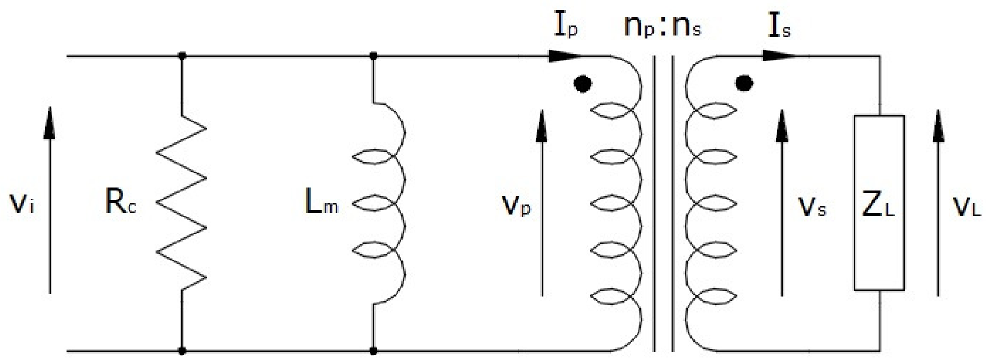
I would like to remind you that the coupling coefficient k is obtained by measuring the primary inductance with the secondary open (L_{po}) and with the secondary short-circuited (L_{pc}). Then the following formula is applied:

$$k = \sqrt{1 - \frac{L_{pc}}{L_{po}}} \approx 1$$

The magnetizing inductance is obtained as $L_m = kL_{po} \approx L_{po}$ while the leakage inductance is $L_d = (1 - k^2)L_{po}$.

The model of a real transformer at center frequency

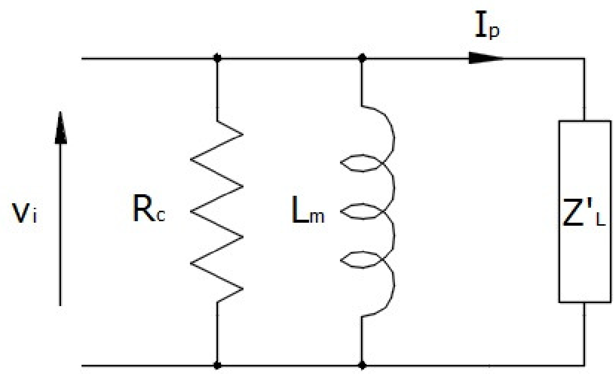
At the center frequency, i.e., between the lower and upper cutoff frequencies, the main parasitic effect is due to the magnetizing inductance L_m and the loss resistance R_c. The resistance R_w in the conductors is usually neglected.
Therefore, the model at the center frequency is simplified as shown here on the side.



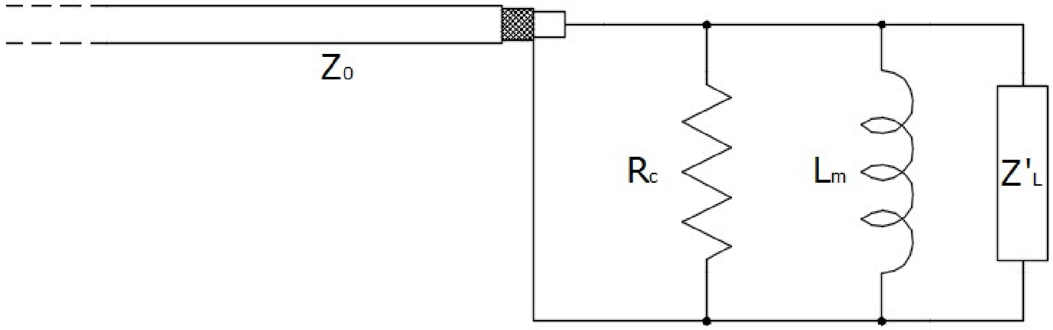
If we reflect the impedance from the secondary to the primary by multiplying it by the square of the turns ratio, we will obtain the final model.

$$Z'_L = \left(\frac{n_p}{n_s}\right)^2 Z_L$$

The apostrophe indicates that the value has been reflected from the secondary to the primary.



The real transformer in an antenna system



Every time we insert an impedance transformer into an antenna system, at the very least, we find ourselves in parallel with the load, the loss resistance R_c, and the magnetizing inductance L_m of the transformer. Unfortunately, this causes a mismatch in the load. Of course, we want the mismatch to be as inconspicuous as possible. To make it less significant, we must ensure that the parallel combination of the loss resistance R_c and the magnetizing inductance L_m is large enough to produce, at the minimum operating frequency, an impedance much greater than the load impedance, which is usually equal to that of the transmission line. But how large?
If we want S11 to be less than -20dB, it must be at least 5 times the impedance of the line Z_0. So, if the line is 50 Ohms, the magnitude of the impedance at the minimum frequency must be at least 250 Ohms.
In the description, I am providing a convenient Excel sheet that already performs all the calculations with ferrites.