A RESONANT DUMMY LOAD

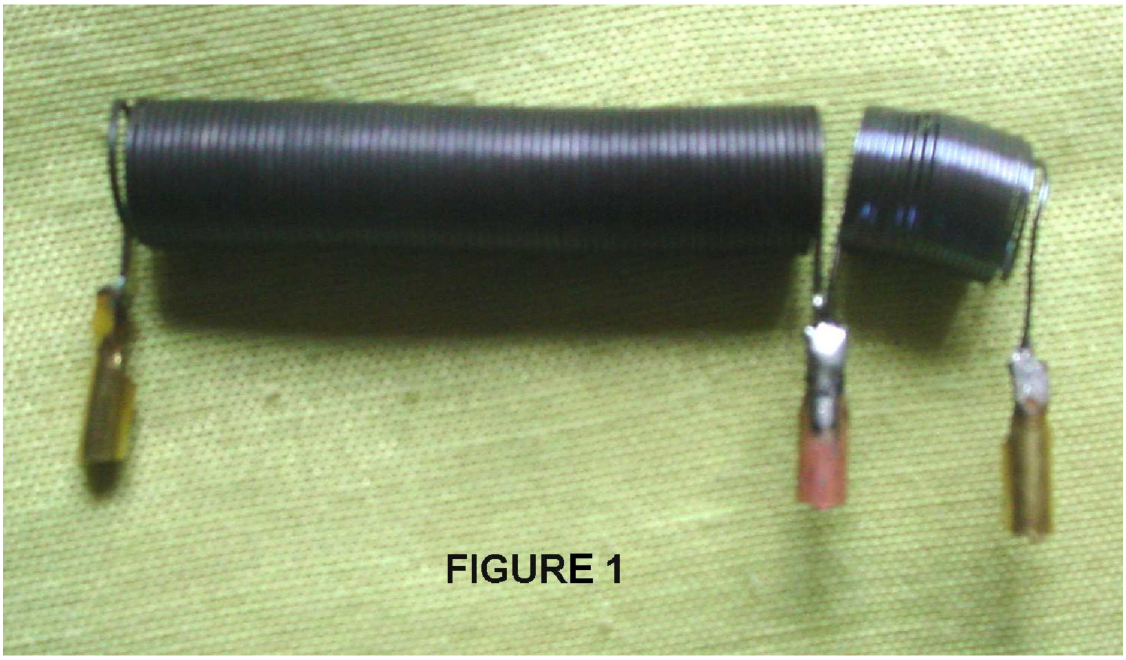
By Luiz Amaral
PY1LL/AC2BR

Introduction

Our specific problem is to build a dummy load for the 470-510kHz band for a 250W average output power transmitter for that band.
An ideal dummy load presents a pure resistive impedance **R** and independent of the frequency. As it is difficult to be build with common carbon resistors[1], the suggested solution is to use an inductive load (using electric showers resistances, very common in Brazil, as in Figure 1) would form a series **R-L** circuit on that band of frequencies, with a capacitor **C** also in series to compensate for the inductive reactance.
The impedance of the element **R-L** is, in the complex representation, $\mathbf{Z_{RL} = R + j,L.\omega}$ (**j** the imaginary unity, **L** the inductance and ω the angular frequency equal to $\mathbf{2.\pi .f}$, with **f** the linear frequency).
In a less mathematical language, it means that **R** is the resistive or real component of the impedance and $\mathbf{L.\omega}$ the reactive component, with **R** and **L** being independent of the frequency.
The capacity **C** must be such to get the resonance, that is, its reactance $\mathbf{-1/(\omega.C)}$ must be equal to $\mathbf{L.\omega}$ in module so that we get a total reactance equal to zero and therefore a constant resistive impedance equal to **R**.

The chosen solution

For simplicity I decided to choose the simplest solution to control: to use wire resistors even if it creates an inductive load. At least in Brazil, it is cheap and very easy to find wire resistors for electrical showers, in my case, the brand Lorenzetti® model Max-Ducha that is split in two parts for the operations ‘winter’ and ‘summer’ (as common in such showers) as in Figure 1.



[1] **The referred difficulty is due the high price of high dissipation non-inductive carbon resistors. The price of commercial dummy loads for higher power is also high.**

Combining 5,500W and 4,400W resistances for 220V it is possible to get a total resistance value of 50Ω with a tolerance of 2% with two longer parts of the 5,500W resistance and two full 4,400W resistances.
Once assembled the circuit with the referred resistance combination, it was adjusted for 50Ω with an alternating voltage of 60Hz. However two problems arose when trying to use the dummy load on 500kHz band with the resonance capacitor:
1 – The resistive component value was much greater than 50Ω .
2 – The calculated capacitor value to get resonance by measuring the reactive inductance also was well different from the practical one, that is, the resonant frequency was very far from the expected.
A deeper study showed that the problems occurred due the skin effect of the conductor, increasing the resistance with frequency and also due a very important distributed capacitance **γ** of the resistive coil.
The equivalent circuit may be simplified as in Figure 2.

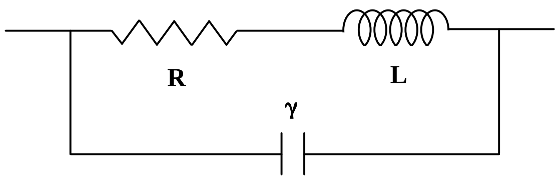


FIGURE 2

The existence of that distributed capacitance **γ** complicates too much the impedance **Z** of the circuit that now has a real component **r** different from **R** and dependent[2] of **γ, ω** and **L** (see Appendix).

$$Z = R(\omega) / [(1 - \omega^2 . L . \gamma)^2 + \omega^2 . R^2(\omega) . \gamma^2] \quad [I]$$

Note that, if we make **γ = 0** in **[I]**, we get **r = R(ω)**, as we must expect for the ideal case with no distributed capacitance.
Here a test was performed for verifying if our problem was really due that distributed capacitance. If we stretch the coil wire (it has a helical spring behavior), both the inductance **L** and the capacitance **γ** vary and **r** also varies (as the total wire length doesn't change, the value of **R(ω)** stays constant). But, if we introduce into the coil a ferrite core, **L** varies, with **R(ω)** and **γ** kept constant. If **r** now varies, it is due the first term of the denominator of **Z**, as its second term and the numerator don't vary.
The experiment was performed showing that **r** depends of **L** and is crescent with it, what justifies an expression for **Z** as in **[I]**.
This shows that there is a strong dependence between **r** and **L** due the distributed capacitance **γ**.
The solution therefore is to make **γ** and **L** as smaller as possible. To diminish **L**, I tried to wind the resistive wire with the odd windings in one direction and the even ones in the opposite direction (coiling with alternate windings inverted) on a pavement ceramics plate.
This also affects the distributed capacitance **γ**. It exists obviously a trade-off between **L** and **γ** minimizations, not always easy to quantify.
One problem of such winding method is that its ends are on opposite points of the coil, making its bond to the coaxial connector rather difficult. Another way to wind the wire is showed in Figure 3[3], where the ends are close, making easy the physical mounting of the system with the capacitor **C** and the connector.
For the adjustment ease, I used a shorting bar for trimming the value of the resistance **r** (50Ω in our case). In the working frequency we slide the shorting bar to adjust **r**. The capacitor **C** is mounted on the same ceramics insulating base and as a padder[4], adjusted to get the resonance of the device, that is, **C** must show

[2] This dependence in ω has two sources, the indirect by the skin effect, explicit in the form R(ω), and the direct one by the denominator of the expression [I].
[3] This was suggested by Gilson, PU5MPL.
[4] The capacitor was assembled on a homemade basis, as the existent in the 500kHz transmitter project, as a published article of the same author.

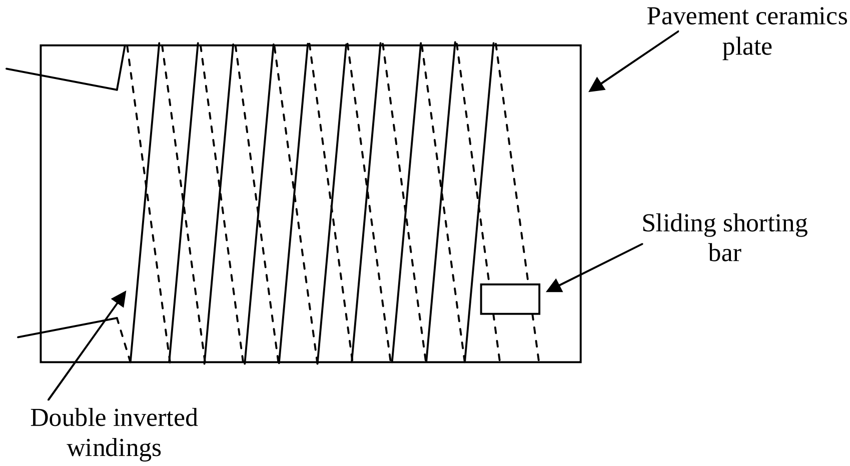


FIGURE 3

a reactance to compensate for the inductive reactance **X** of the coil given by the imaginary component of the expression **[I]**.
When adjusting **C**, may be we have to reposition the shorting bar for a fine adjust of the value of **r**.

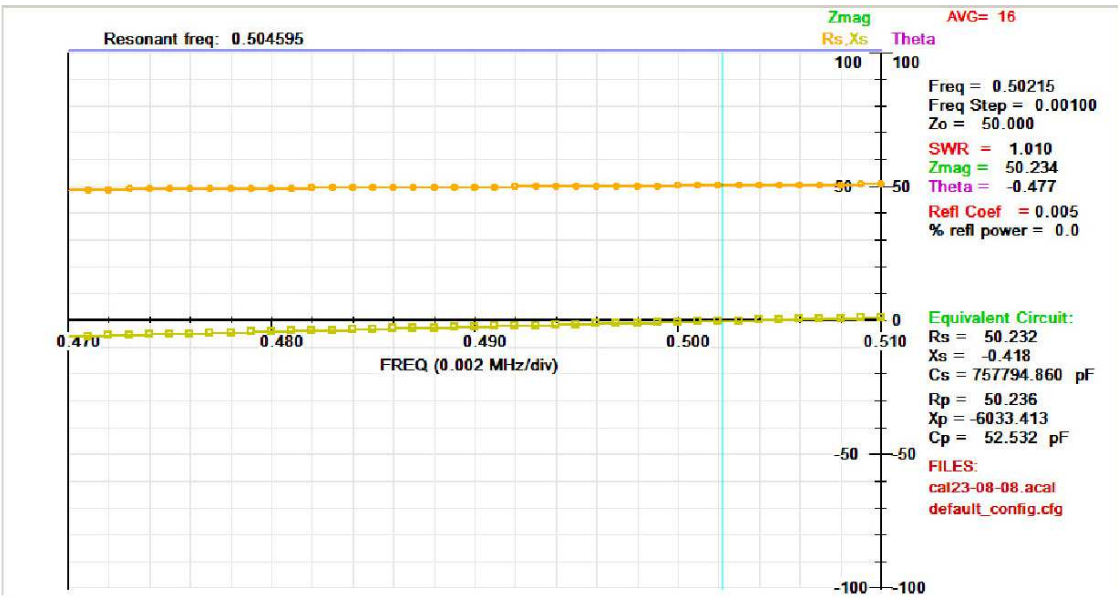


FIGURE 4

So, with two adjustable elements (shorting bar and **C**) we can obtain resistive impedance with the desired value (50Ω) with good precision.
In practice we verified that the coiling of Figure 3 showed values very similar to those with inverted alternate turns, but with much more assembling ease.
Figure 4 shows the result obtained after the adjustment of both elements to get resonance on 504kHz (the frequency of the programmed test transmissions). We can see the curves of **r** (formed by small squares) and of **X** (formed by small circles) in function of the frequency since 470kHz up to 510kHz. We verify that they vary too little as the table below:

Frequency (kHz)	**r** (Ω)	**X** (Ω)	
470	48.21	-6.14	(equivalent to a 55.12nF capacitor)
504	50.05	0.13	(equivalent to a 41nH inductor)
510	50.29	1.18	(equivalent to a 0.37µH inductor)

There is no need therefore for retuning of the dummy load when we go through the entire band, though we can do it.

Figure 4, however, shows on the vertical line the frequency of 502.15kHz (chosen randomly in the band), where the resistive and reactive components are **Rs** and **Xs**, this capacitive and equivalent to a capacity **Cs**.

Figure 5 shows the equivalent circuit with the capacitor **C** inserted and that resonates with **X**.

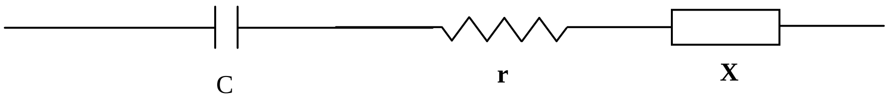


FIGURE 5

Figure 6 shows the photo of the ceramic plate assembled with the female connector (PL-259) but without the capacitor and Figure 7 its bottom view.

For the measurements were used an antenna analyzer model AIM-4170 from Array Solutions®, a function generator model MFG-4202 from Minipa® (Brazilian) with output impedance equal to 50Ω and an oscilloscope model V-223 from Hitachi®.

The measurements with the function generator and oscilloscope was based on the fact that, when the load of a non-inductive load is equal to that of the generator, we have a voltage divider by a factor of 2, that is, with the load connected, the voltage must be one half of that of the open circuit (with no load). These results were perfectly confirmed by using the antenna analyzer.

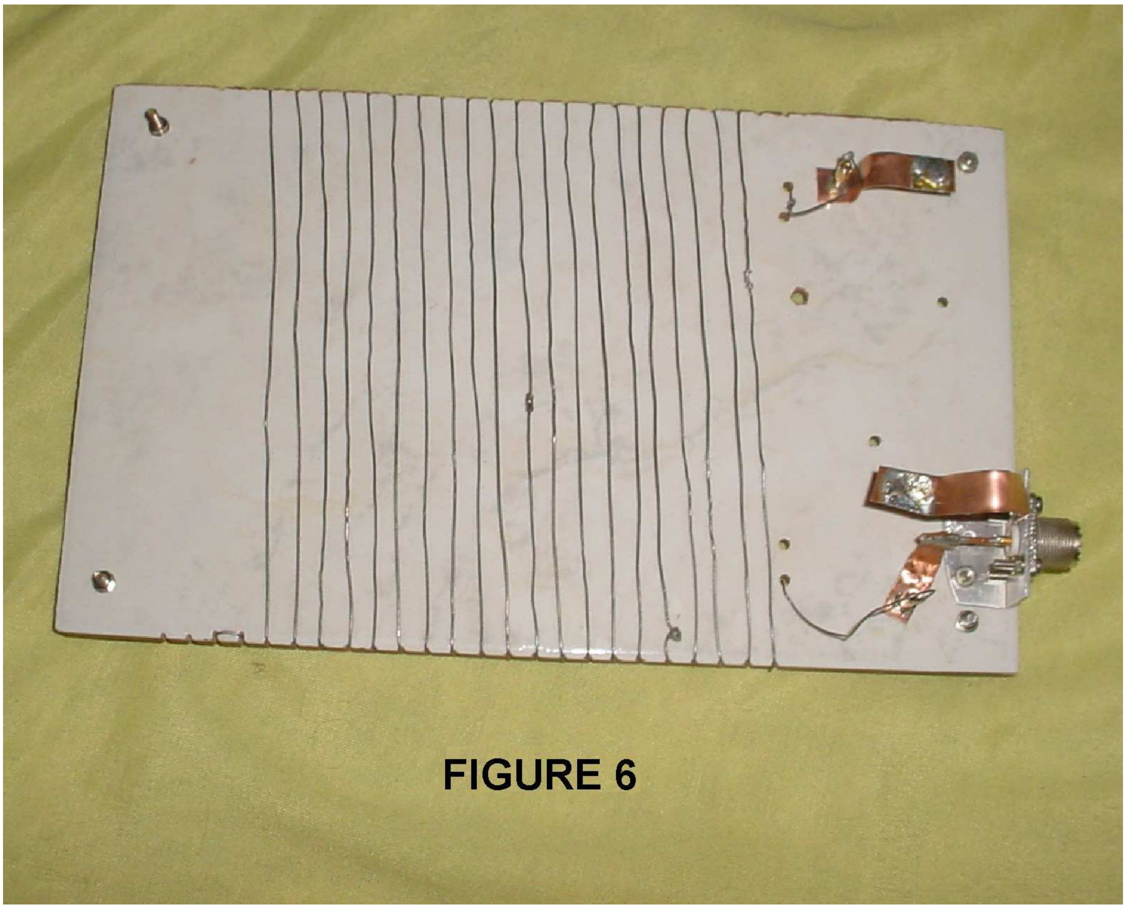


FIGURE 6

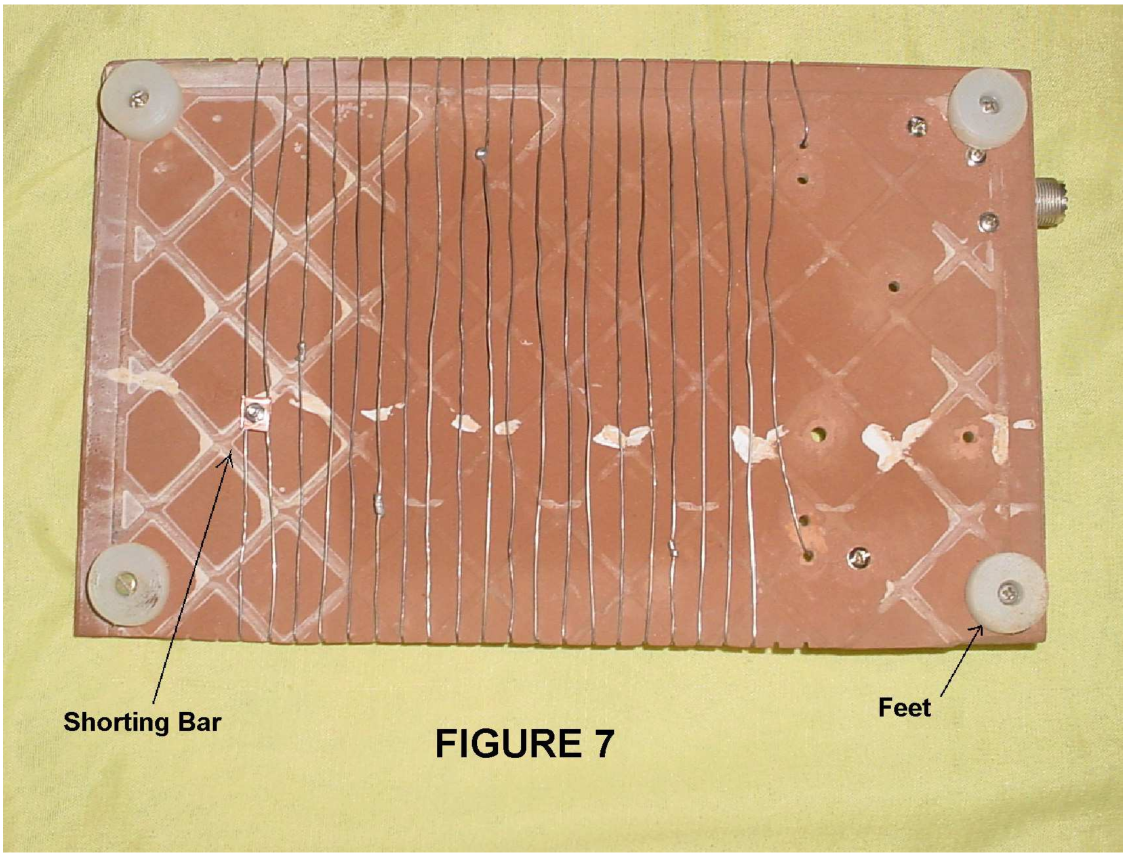


FIGURE 7

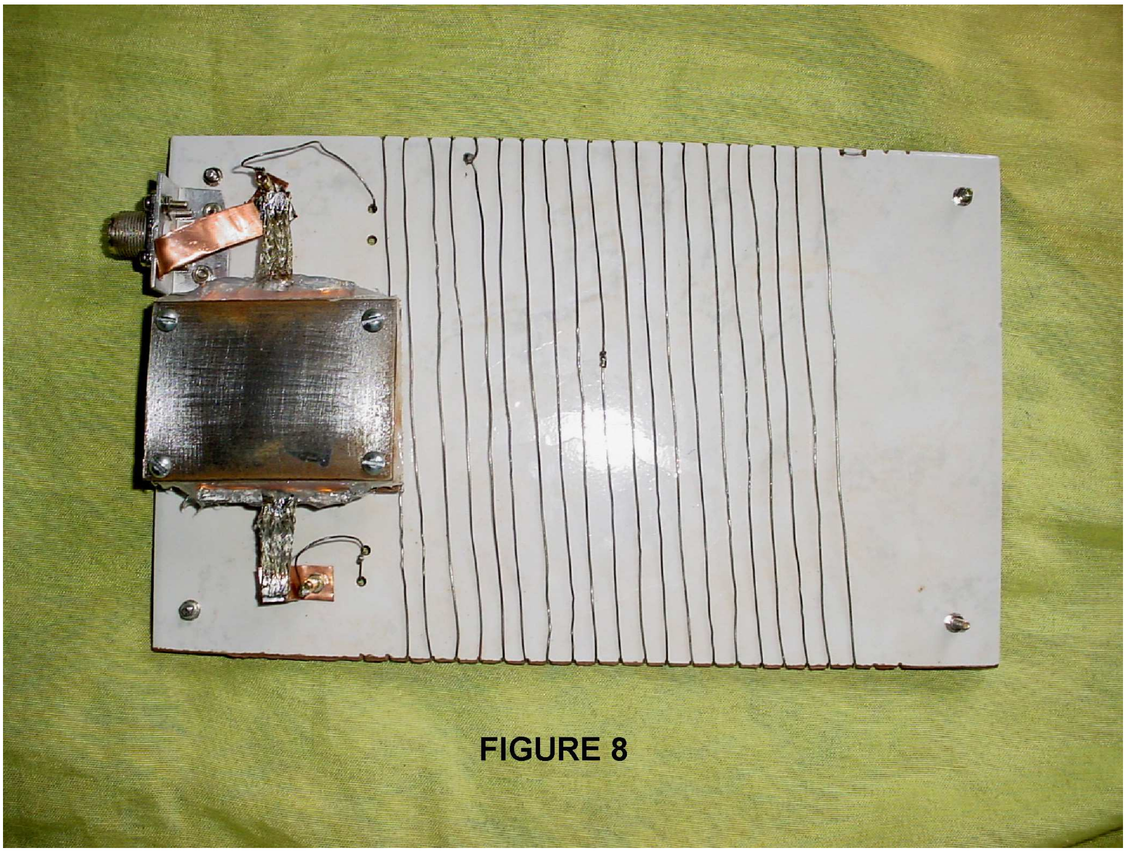


FIGURE 8

Figure 8 shows the dummy load ready with its resonance capacitor. The AIM-4170 was used for observe the resonance by adjusting the four bolts of the capacitor (that we see in Figure 8) that adjust its capacity and the shorting bar position that adjusts the resistive component, normally 50Ω on the frequency of interest.
It is possible to exist some interaction between both adjusts, that is, after adjusting one parameter, it is possible to trim the other one until the bets result is obtained (this is mainly due the residual existence of a distributed capacitance of the coil).
It is important to remember that all adjustments must be done far from metallic surfaces to avoid undesirable interactions that can modify the values of the parameters.

Conclusion

The presented solution was the construction of a resonant load (narrow band) to replace a high cost high power resistive load (broad band).
The usable band of the load, in practice, is far greater than the necessary to cover the band of our interest from 470kHz to 510kHz, especially with the use of a padder capacitor together a shorting bar (the system may be retuned to be adapted to the recently IARU approved 472-479kHz band) .
As our load was mounted with more than one electrical shower resistive devices, because it is cheap and easy to get in the market[5], splices on the wire were necessary. For greater stability, all splices were soldered with tin. For this, it was necessary to scrape the wire ends to be soldered and twist them for mechanical strength and smaller the temperature of the splices to avoid solder melting during real operation. The preparation was made with a special flux (developed for aluminum, but working fine with resistive nickel alloys), from Brasweld® (Brazilian) called Alutin.
In an electric shower for 220V and 5,500W, that uses the chosen wire, the current is 25A. Under 110V, the current is 43A. With 450W average power (much greater than the 250W of my transmitter), the current would be 3A, therefore the expected temperature for the wire is very low, in special on the splices where the volume is bigger and the heat doesn't jeopardize the tin solders.

Appendix

The impedance **Z** of the circuit of Figure 2 is given by:

$$\mathbf{Z = (R + j \cdot \omega \cdot L) / (1 - \omega^2 \cdot L \cdot \gamma + j \cdot \omega \cdot R \cdot \gamma)}$$

This expression can be written as:

$$\mathbf{Z = \{R + j \cdot \omega \cdot [L \cdot (1 - \omega^2 \cdot L \cdot \gamma) - R^2 \cdot \gamma]\} / [(1 - \omega^2 \cdot L \cdot \gamma)^2 + \omega^2 \cdot R^2 \cdot \gamma^2]}$$

Taking the resistive **r** and reactive **X** components:

$$\mathbf{r = R / [(1 - \omega^2 \cdot L \cdot \gamma)^2 + \omega^2 \cdot R^2 \cdot \gamma^2]}$$

$$\mathbf{X = j \cdot \omega \cdot [L \cdot (1 - \omega^2 \cdot L \cdot \gamma) - R^2 \cdot \gamma] / [(1 - \omega^2 \cdot L \cdot \gamma)^2 + \omega^2 \cdot R^2 \cdot \gamma^2]}$$

When $\boldsymbol{\gamma}$ is small, we may write:

$$\mathbf{r = R / (1 - 2 \cdot \omega^2 \cdot L \cdot \gamma)}$$

When expanding the coil increasing its length, $\boldsymbol{\gamma}$ is a crescent function with **L** and therefore the expression '$\mathbf{1 - 2 \cdot \omega^2 \cdot L \cdot \gamma}$' decreases with **L**, increasing **r**. So, if only **L** is varied (with a ferrite) and **r** varies less than the process of the coil expansion, it means that $\boldsymbol{\gamma > 0}$ and is important in the process.

[5] The assembling is simpler with the use of 0.75mm diameter nickel-chrome wire got in the market because it has less puckers and doesn't need splices.