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Adapting Antenna and Cable to the Signal Processing Circuits

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Abstract— This document focuses on circuits for adapting the loop antenna and power cable to the signal processing circuits. Loop antenna is placed into humid – eventually wet – environment and the signal processing circuits are placed approximately in the distance of 40m from antenna. The device works on 1250 kHz frequency. The adaptation was simulated with the MICRO-CAP program.

Keywords— Antenna, MICRO-CAP, cable, resonance

I. INTRODUCTION

The studied antenna is scanning passage of vehicles and it is placed in humid/wet environment. Therefore, signal processing circuits cannot be situated in the same place as the antenna. There was a major signal attenuation and also a shift of the resonant frequency downwards when connecting these circuits with a cable. The aim of this work is to find elements, that can increase the resonant frequency at the point where signal is processed. Attenuation of this connection has to be minimal.

The original simplified model of circuit (Figure 1) includes loop antenna – represented by inductance L_2, transmitting antenna that is placed on passing vehicle – represented by inductance L_1, and their inductive coupling M when the vehicle passes through. The antenna is tuned on required operating frequency by capacitor C_T. Resistance R_T is representing the circuit of a receiver.

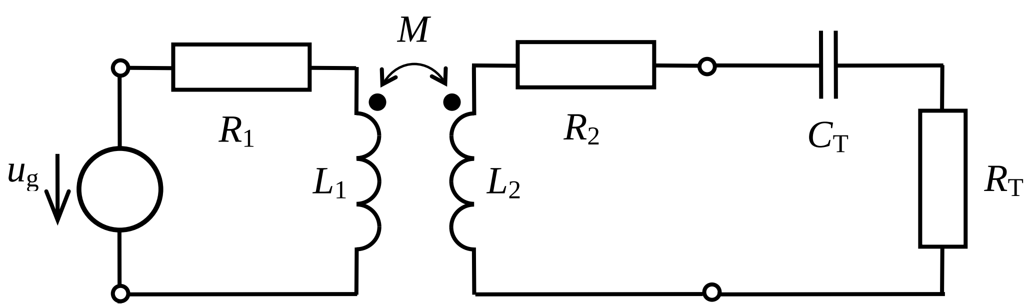

Fig. 1 Principal circuit connection

II. SUBSTITUTION OF SOLVED CIRCUIT

Following Thévenin´s theorem, the circuit from Fig. 1 can be replaced with loop antenna circuit from Fig. 2, where substitute impedance of the circuit is defined.

$$\hat{Z}_{2i} = R_2 + \frac{\omega^2 M^2 R_1}{R_1^2 + \omega^2 L_1^2} + j\omega\left(L_2 - \frac{\omega^2 M^2 L_1}{R_1^2 + \omega^2 L_1^2}\right), \tag{1}$$

However, with respect to modelling circuit in MICRO-CAP system, we stuck to the circuit from figure 1.

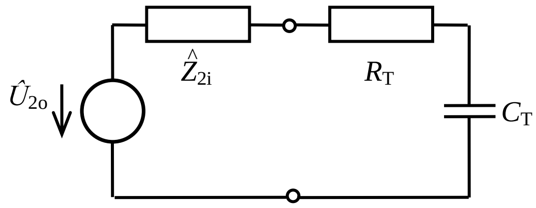

Fig. 2 Substitute scheme of loop antenna circuit

After the cable is included into antenna circuit, the scheme from figure 1 changes to scheme from figure 3. The cable is modelled by a T cell in two-port.

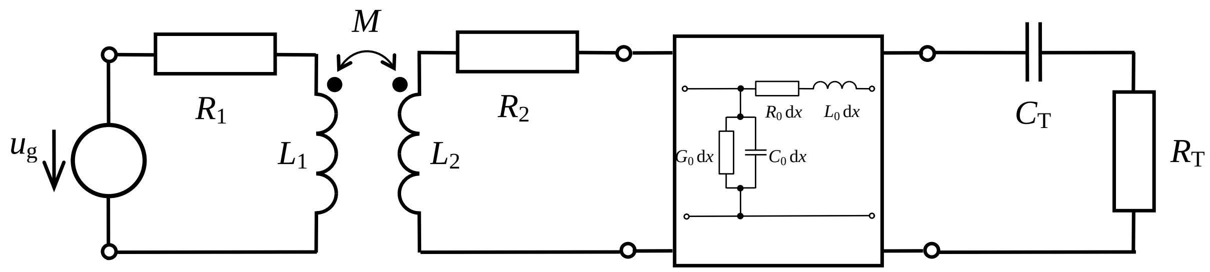

Fig. 3 Circuit model after cable inclusion

Concerning the fact, that the permeable frequency of given cable is 10 times higher than the resonant frequency of the loop antenna, we can replace the cable with spatially distributed parameters from Figure. 3 with its own parameters that are lumped with a T cell in our case (figure 4). For the parameters of T cell, the following is valid:

$$R_{C/2} = \frac{R_o \cdot l}{2}, \qquad L_{C/2} = \frac{L_o \cdot l}{2}, \qquad C_C = C_o \cdot l, \tag{2}$$

We are not taking into consideration the lead of the cable which is not stated by its manufacturer. The length of the cable is 40m.

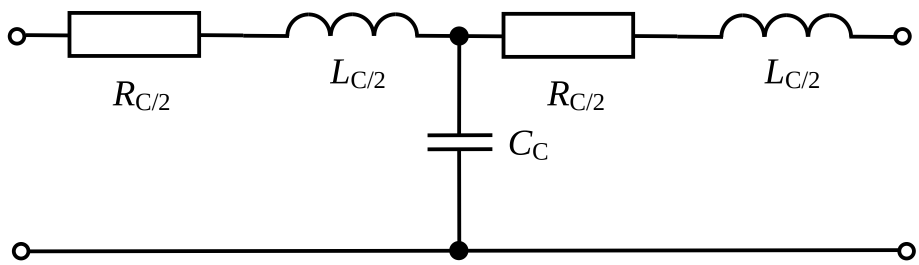

Fig. 4 Substituting the cable with a T cell

III. ADJUSTMENT OF RESONANCE FREQUENCY

If there is a case, when the circuit is not modelled in the MICRO-CAP system, it would be possible to simplify the model of the cable considering the chosen resonant frequency and values of longitudinal parameters of the cable only with its transverse capacity C_C, which would be connected in parallel to the capacitor with C_T value on Figure 1. Consequently, the increase in resulting capacity then lowers the resonant frequency of the loop antenna circuit.

Two options of optimization the resonant frequency were considered – using a serial capacitor or a parallel inductor with the condition that the R_T and C_T parameters of original circuit from Figure 1 must be preserved. For the design of tuning parameters, the optimizing module of MICRO-CAP system was used. Maximizing the voltage on the cable output, that occurs when the output current of the cable has maximum value, was necessary. Simplified substitute circuit with tuning capacity is shown on figure 5. Estimation of angular frequency when there is a maximal current after inclusion of serial capacity C_A is done by following:

$$\omega_C = \sqrt{\frac{\dfrac{1}{L_2 \dfrac{C_A(C_T+C_C)}{C_A+C_T+C_C}} - \dfrac{1}{\tau_1^2} \pm \sqrt{\left(\dfrac{1}{\tau_1^2} - \dfrac{1}{L_2 \dfrac{C_A(C_T+C_C)}{C_A+C_T+C_C}}\right)^2 + 4\dfrac{1}{\tau_1^2}\dfrac{1-k^2}{L_2 \dfrac{C_A(C_T+C_C)}{C_A+C_T+C_C}}}}{2(1-k^2)}}, \quad (3)$$

where

$\tau_1 = \dfrac{L_1}{R_1}$ a $k = \dfrac{M}{\sqrt{L_1 L_2}}$. The relationship is valid provided that $R_T << \dfrac{1}{\omega C_T}$, which is in our case fulfilled.

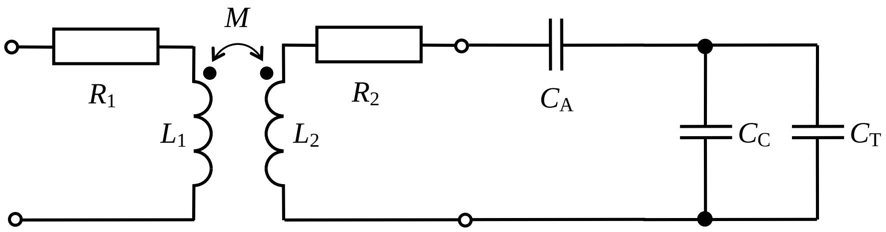

Fig. 5 Simplified substitute circuit with tuning capacity

A simplified substitute circuit with tuning inductance is shown on Figure 6. Estimation of angular frequency when there is a maximal current after inclusion of parallel inductance L_A is done by following:

$$\omega_L = \sqrt{\frac{\dfrac{1}{\dfrac{L_2 L_A}{L_A + L_2(1-k^2)}(C_C+C_T)} - \dfrac{1}{\tau_1^2} \pm \sqrt{\left(-\dfrac{L_2 L_A}{L_A + L_2(1-k^2)}(C_C+C_T) + \dfrac{1}{\tau_1^2}\right)^2 + 4\dfrac{1-k^2}{\tau_1^2 \dfrac{L_2 L_A}{L_A+L_2}(C_C+C_T)}}}{2(1-k^2)}}. \quad (4)$$

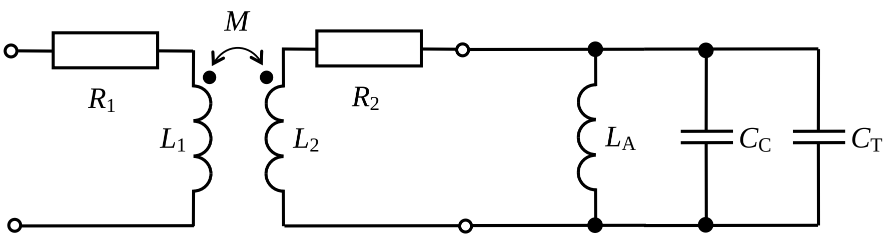

Fig. 6 Simplified substitute circuit with tuning inductance

It is obvious from the relationships (3) and (4) that the frequency value is influenced, among others, by time constant of transmitting antenna τ_1 and a coupling coefficient *k*. The coupling coefficient is very small with antennas, so that we can assume, that its influence on relationships described at (3) and (4) is practically none. If the resistance R_1 will have small limit, the time constant will have large limit. In these relationships, the square of the time constant has inverted values. Therefore, the elements where the square is present are not valid and for both frequencies the following can be stated:

$$f_{\mathrm{C}} = \frac{1}{2\pi\sqrt{L_2 \dfrac{C_{\mathrm{A}}\left(C_{\mathrm{T}}+C_{\mathrm{C}}\right)}{C_{\mathrm{A}}+C_{\mathrm{T}}+C_{\mathrm{C}}}}} \quad \text{and} \quad f_{\mathrm{L}} = \frac{1}{2\pi\sqrt{\dfrac{L_2 L_{\mathrm{A}}}{L_{\mathrm{A}}+L_2}\left(C_{\mathrm{C}}+C_{\mathrm{T}}\right)}}. \qquad (5)$$

The above mentioned relationships apply for simplified conditions. If all parameters of the model are taken precisely, the analytic relationships would be excessively complicated and can be confusing. That is why the only option is to use simulating software such as MICRO-CAP.

IV. SIMULATING CIRCUITS IN MICRO-CAP SOFTWARE

Simulations in MICRO CAP system were carried out for following parameters: $u_{\mathrm{gp\text{-}p}}$ = 2V, R_1 = 122 Ω, L_1 = 678 µH, R_2 = 2 Ω, L_1 = 806 µH, M = 16 µH, R_{T} = 54 Ω, C_{T} = 2.2 nF, $R_{\mathrm{C/2}}$ = 780 mΩ, $L_{\mathrm{C/2}}$ = 13 µH, C_{C} = 6 nF.

The value of tuning capacity which was calculated by optimizing module of MICRO-CAP system is C_{A} = 2,9 nF after rounding. The value of tuning inductance is L_{A} = 268 µH. Appropriate frequency characteristics of output current are shown on figures 6 and 7. From the pictures, it is obvious, that it is more suitable to use tuning capacity, because the maximal current output is approx. 3 times higher.

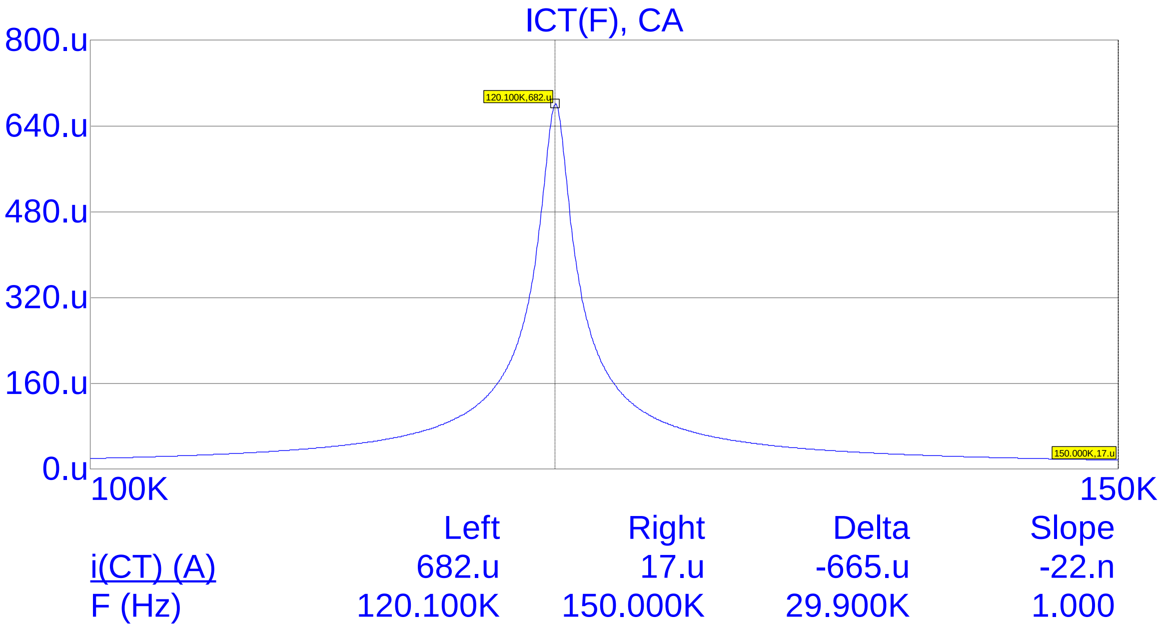

Fig. 6 Frequency characteristics of output current of the cable, C_{A} = 2,9 nF

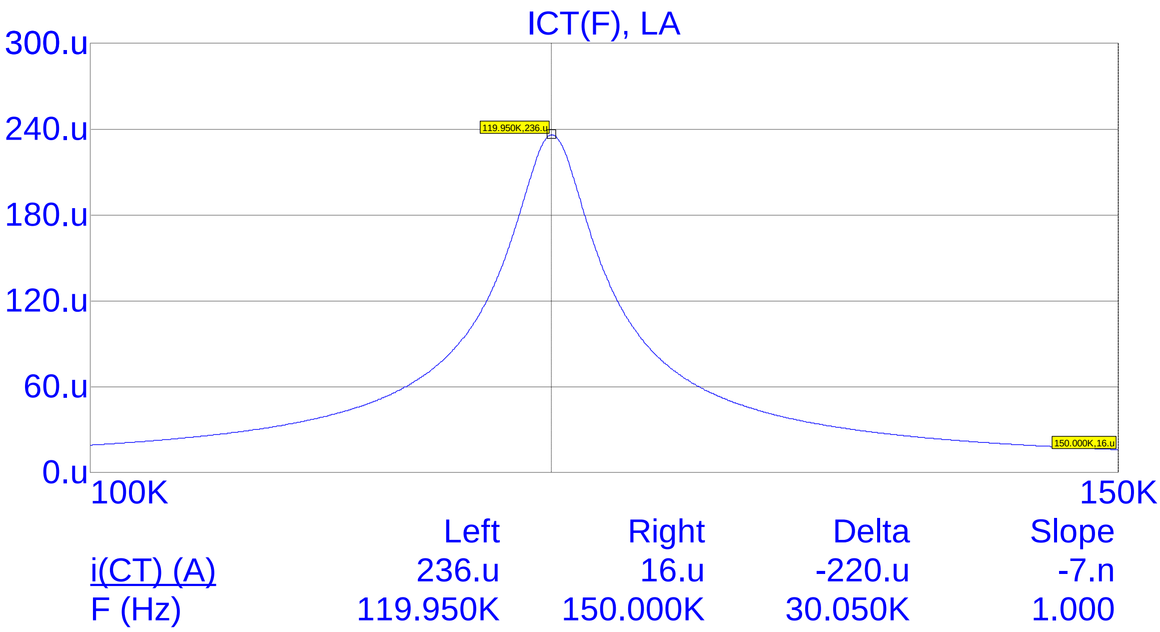

Fig. 7 Frequency characteristics of output current of the cable, L_A = 268 µH

V. Conclusions

In conclusion we can say that even the MICRO-CAP system has its limitations and problems when modelling the cables with the use of TLine model. Those limitations can be avoided using the cascading of T or Π cells according to desired frequency range. It was satisfying to use only one T cell for modelling in our case because the permeable frequency of the cable has the value of approximately 1.2 MHz. Optimizing module of the MICRO CAP system enables to easily find the value of desired parameters, that are in our case the tuning capacity C_A and the inductance L_A; so that the antenna is tuned on desired frequency of 120 kHz even after using the cable. From the simulation of these two circuits, it can be stated that it is more appropriate to use the tuning capacity than tuning inductance, which ensures higher value of output voltage of the cable

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