Small loop antenna analysis: computer program

B. A. Bowles and C. W. P. Attwell present a computer program which analyses an electrically small loop antenna having a capacitive matching network

Electrically small loop antennas are used where medium and high frequency radio transmission is required using an antenna having a minimum volume. The small electrical size of the antenna leads to a relatively large reactive input impedance which is equalised with a matching network so that the efficiency of the transmission system is optimised. Generally, the matching network is designed to operate at resonance but frequently the transmitted signal spectrum requires the antenna and matching network characteristics to be known over a range of frequencies centred on the resonant frequency. For example, the variation of the network output impedance with frequency can affect the operation of either the receiver or the transmitter.

The overall frequency response of the transmission system is also of interest particularly for digital transmission in which the intersymbol interference is influenced by the amplitude and phase of the transmission transfer function.

This paper presents a computer program which analyses an electrically small loop antenna having a capacitive matching network. The program is written in H.P. Basic for a Hewlett Packard 9830A desk-top calculator and the results are displayed graphically on a Hewlett Packard 9862A plotter. The parameters of interest are the magnitude and phase of:

(a) the matching network input impedance (Z_i),
(b) the antenna current in the "transit mode" (I_A),
(c) the output voltage of the matching network in the "receive mode" (V_L).

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The equivalent circuit

Smith[1] has shown that the most efficient matching network for an electrically small loop antenna consists only of capacitors. The equivalent circuit for the antenna together with a matching network having up to three matching components is shown in Figure 1. Expressions for the parameters of interest have been derived previously[2] by the authors and are given by Equations 1, 2, 3.

The computer program

The computer program is listed in the Appendix and has five main sections, these being.

(a) input of plotting parameters.
(b) input of the component values.
(c) the choice of the required function to be plotted.
(d) routines which analyse the function.

Eq

$$\frac{I_A}{V_s} = \frac{Z_3 + jZ_4}{\{[Z_1 + R_s(Z_3 - Y_1)] + j[(Z_2 + R_s(Z_4 + Y_2)]\}\{Z_6 + jZ_7\}} \quad (1)$$

$$\frac{V_L}{V_i} = \left(\frac{Y_3}{Y_4 + jY_5}\right)\left(\frac{[Z_3 - Y_1 + jR_L(Z_4 + Y_2)]}{[R_L(Z_3 - Y_1) + Z_1] + j[R_L(Z_4 + Y_2) + Z_2]}\right) \quad (2)$$

$$Z_i = \frac{Z_1 + jZ_2}{(Z_3 - Y_1) + j(Z_4 + Y_2)} = R_i + jX_i \quad (3)$$

where

$Z_1 = 1 - \omega^2 L(C_1 + C_2)$ | $Z_2 = \omega R(C_1 + C_2)$
$Z_3 = -\omega^2 C_1 C_2 R$ | $Z_4 = \omega C_2(1 - \omega^2 LC_1)$
$Z_6 = 1 - \omega^2 LC_1$ | $Z_7 = \omega C_1 R$
$Y_1 = \omega C_3 Z_2$ | $Y_2 = \omega C_3 Z_1$
$Y_4 = 1 - \omega^2 LC_4$ | $Y_5 = \omega C_4 R$
$Y_3 = \frac{C_2}{C_2 + C_3}$ | $C_4 = C_1 + \frac{C_2 C_3}{C_2 + C_3}$

$\omega = 2\pi f$
$R_s = R_T$ (transmit mode)
$R_L = R_T$ (receive mode)

Fig. 1: A capacitive matching network for an electronically small loop antenna.

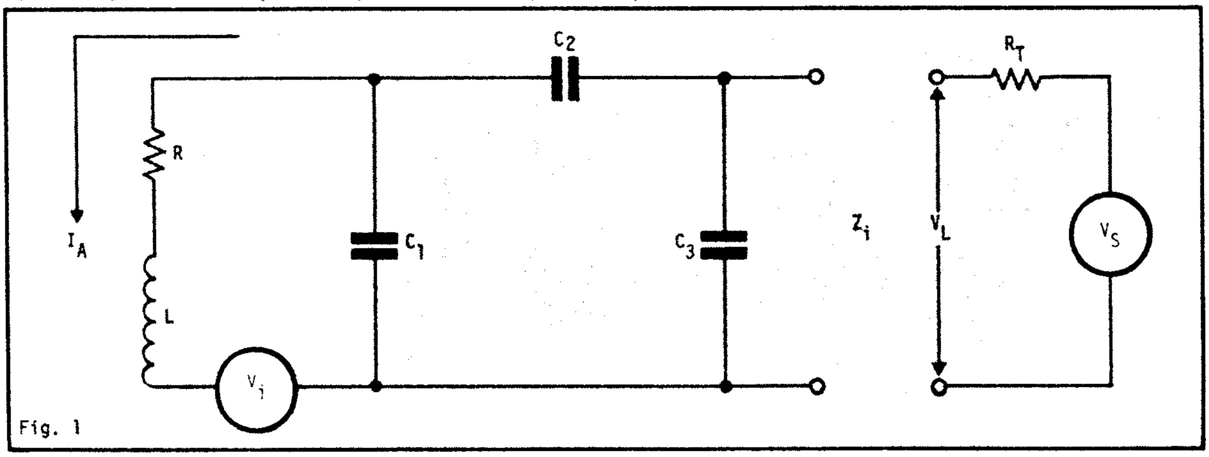

Fig. 1

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(e) output of the results to the plotting unit.

In the first three sections the user can specify the parameters he requires using the keyboard when prompted by requests on the display.

When a particular function plot has been completed the user can elect to continue on the same diagram either, another function, or the same function but with different components.

An example

The computer program was used to plot the input impedance with frequency for three matching networks having a resistive output impedance at resonance with the following values:

(a) $R_o = 500\ \Omega$
(b) $R_o = 50\ \Omega$
(c) $R_o = 4\ \Omega$

The component values were calculated by ignoring C_1 and the reactive component of the output impedance; R_o is then given by:

$$R_o = \left(\frac{(2\pi f_o L)^2}{R}\right)\left(\frac{C_2}{C_2+C_3}\right)^2 \quad (4)$$

where:
f_0 = the resonant frequency.
The resonance condition is given by:

$$[(2\pi f_o)^2 L]^{-1} = C_1 + \frac{C_2 C_3}{C_2+C_3} \quad (5)$$

Hence the values of C_2 and C_3 can be found by solving equations (4) and (5).

The antenna under consideration is required to be resonant at 913 kHz and has the following parameters,

$L = 21.4\ \mu H$
$R = 1.23\ \Omega$

The calculated component values are:

(a) $C_2 = 1.78$ nF; $C_3 = 7.04$ nF
(b) $C_2 = 1.52$ nF; $C_3 = 22.30$ nF
(c) $C_2 = 1.45$ nF; $C_3 = 78.60$ nF

The results are presented in Figure 2 with the frequency axis normalised to 913 kHz. Two items are of particular interest, these being that zero phase always occurs below the resonant frequency and also that zero phase never occurs for $R = 4\ \Omega$. This type of matching network is therefore unsuitable for obtaining a low resistive output impedance with the antenna under consideration.

Conclusion

A computer program has been presented to analyse an electrically small loop antenna together with a capacitive matching network.

The program can be used to compare various types of matching arrangements and to derive the frequency response of a particular transmission system assuming the attenuation of the transmission medium is known. ☐

The program listing referred to in the text can be obtained by circling RES number 250

References

1. Smith, G S Radiation efficiency of electrically small multi-turn loop antennas *IEEE Transactions on antennas and propagation* vol AP-20, September 1972, p656-657.
2. Bowles, B. A., Austin, B A., and Attwell, C W P Electrically small loop antennas, part 1 Electronic Engineering, vol 50, No 613, November, 1978, p48-57

Fig. 2: Plot of impedance phase against frequency for different output impedances