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Analysis software for the preparation of the antenna characteristics in the wireless system

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Preface

First and foremost, we would like to express my heartfelt gratitude to our supervisor, Jose Chilo and examiner, Niklas Rothpfeffer, who give us considerable help to complete this thesis. Second I would like to thank all of our college teachers who have enlarged our knowledge and horizon during my studying. Third we would like to thank our friends and classmates who help a lot..

Abstract

With the development of the wireless communication system, the antenna has been widely used as an important tool in data transmission. However, there are many characteristic parameters for antenna need to be calculated by complex calculation. For example the mutual input impedance of dipole antenna, the Directivity coefficient and the Gain coefficient. Therefore, it is quite practically hard to implement by hand, especially for student who was studying on it. In order to solve this problem, this thesis has establishes the calculation procedure for the complex parameters of antenna by using MATLAB software.

Key works:

MATLAB, GUI, SCIENTIFIC CALCULATOR, ANTENNA

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1. Introduction

1.1 Background

When study the subject antenna there are many significant electrical parameter calculations which are quite complicated. It is necessary to integrate the value of complex functions. To complete the overall process calculation, it will waste a lot of time. Teacher usually gives students some common numerical form for consulting. In this way, students would make no account of the computational method of important parameters. Since they only apply ready-made results, nevertheless, when they solve the practical problems they don't even know where to start. It is not good for training research-based learning of students.

MATLAB has powerful scientific calculations and visible functions. It is simple and easy to use. It is a basic tool and preferred platform which can help computers to design, analysis and algorithmic research. GUI is used widely which is more friendliness, intuitiveness, mobility. This article used MATLAB to design a GUI by scientific calculation interface. Thus researchers can calculate the complex calculation in an easy way of antenna parameter.

1.2 Aim of thesis

The purpose of this thesis is to draw up the software for calculation of important antenna parameters and software need to input parameter by students themselves. The mainly work is to make a working software interface. First of all researchers need to establish a main dialog box and make calculate parameters interface in the main dialog box. Then click parameter buttons what researchers need to calculate. In this way, researchers can enter the interface which shows the calculate parameters, input relevant conditions and formulas to get parameter results. The difficult points of this thesis are integral calculations and how to use the parameter and equation into the programming.

Students can input parameters to calculate relevant complex antenna parameters though the software. By calculating mutual radiation impedance, radiation impedance, directivity and gain coefficient of an antenna and so on, students can expand the understanding to the antenna's characteristic. Meanwhile, by calculating many sets of data, students also can strengthen the comprehending of the regularity which changes with parameters.

1.3 Delimitations

This thesis is mainly used for education of students. This article is focus on investigate the characteristic of dipole antenna's calculation by using Matlab GUI interfaces. The aim of this project is to establish a basic platform to research.

2 Theory

2.1 Antenna

2.1.1 The basics of the antenna dipole

An antenna is a device that is used to transfer guided electromagnetic waves (signals) to radiating waves in an unbounded medium, usually free space, and vice versa (i.e., in either the transmitting or receiving mode of operation). Antennas are frequency-dependent devices. Each antenna is designed for a certain frequency band. Beyond the operating band, the antenna rejects the signal. [1]

The principle of the antenna radiation is shown in picture 3.1. Wire alternating current through the electromagnetic radiation can occurred, the ability of radiation to the length and shape of the wire. If the two conductors in close proximity, the electric field are bound between two wires, then the radiation is very weak. If the two wires is open, the electric field on the spread in the surrounding space, and then radiation. Should be noted that when the wire length L is much smaller than the wavelength, the radiation is very weak; when the wire length L increases and the wavelength is comparable to the current in the wire will greatly increase, and thus will be able to form a strong radiation. [13]

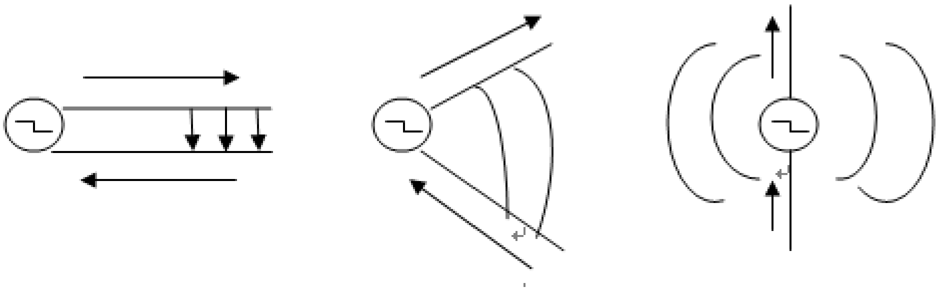


Figure.1 Antenna Radiations [2]

2.1.2 Symmetric dipole

Symmetric dipole: it is also called as oscillator antenna and is composed of two sections of straight wires with the equal length of *l*, and the transmission line is provided in the clearance between the two wires for feed: [1]

Symmetric dipole may be regarded as formed by transition of parallel-wire of terminal open circuit (as indicated in figure 2 and figure 3), so it may be approximately regarded that the current on symmetric dipole is distributed by means of pure standing wave.

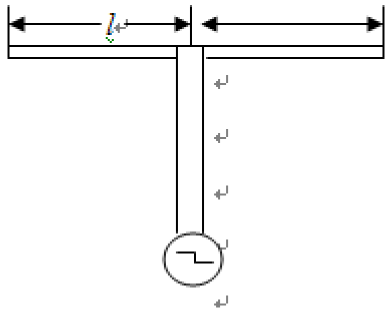


Figure.2 Structure diagram of symmetric dipole

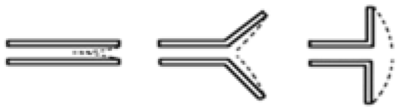
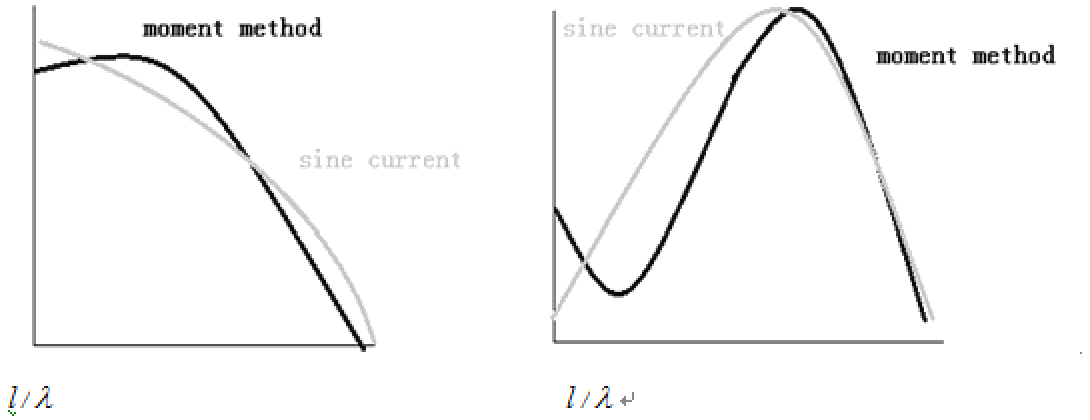


Figure.3 Transition of transmission line of open circuit to symmetric dipole [1]



a) $2l=0.5\lambda$ b) $2l=\lambda$

Figure.4 Full wave distribution of semi wave and full wave symmetric dipole

Analytic expression of current distribution is:

$$I(z) = \begin{cases} I_M \sin[\beta'(l+z)] & z<0 \\ I_M \sin[\beta'(l-z)] & z>0 \end{cases} \tag{2.1}$$

I_M: wave loop current amplitude on symmetric oscillator;

β': phase constant of symmetric oscillator current, $\beta' \approx \beta$.

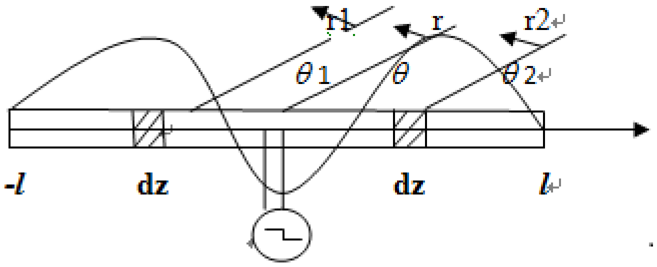


Figure.5 Coordinate system of the symmetric dipole

Divide the symmetric dipole into infinite number of element lengths and each element length may be regarded as a current element $I(z)\mathrm{d}z$.

The known radiation field of current element is

$$E_\theta = E(r,\theta,\varphi) = j\frac{Il}{2\lambda r}\eta_0 \sin\theta \mathrm{e}^{-\mathrm{j}\beta r} = \mathrm{j}\frac{60\pi\, Il}{\lambda r}\sin\theta\ \mathrm{e}^{-\mathrm{j}\beta r} \tag{2.2}$$

Select a current element on point z_1 of left arm and point z_2 of right arm on symmetric dipole:

$$I(z_1)\mathrm{d}z_1 = I_M \sin[\beta(l+z_1)]\mathrm{d}z_1 \qquad (z_1<0)$$

$$I(z_2)\mathrm{d}z_2 = I_M \sin[\beta(l-z_2)]\mathrm{d}z_2 \qquad (z_2>0)$$

$$\mathrm{r}_1 = \mathrm{r} - \mathrm{z}_1\cos\theta$$

$$\mathrm{r}_2 = \mathrm{r} - \mathrm{z}_2\cos\theta \tag{2.3}$$

Note: the observation point is far to the symmetric dipole, so it may be approximately regarded that $\theta_1 = \theta_2 = \theta$.

The complex amplitude of radiation field at $P(r,\theta,\varphi)$ of observation point:

$$\begin{aligned} \mathrm{d}E_1 &= \mathrm{j}\frac{60\pi I_M \sin[\beta(l+z_1)]\mathrm{d}z_1}{\lambda r}\sin\theta\, \mathrm{e}^{-\mathrm{j}\beta(r-z_1\cos\theta)} \\ \mathrm{d}E_2 &= \mathrm{j}\frac{60\pi I_M \sin[\beta(l-z_2)]\mathrm{d}z_2}{\lambda r}\sin\theta\, \mathrm{e}^{-\mathrm{j}\beta(r-z_2\cos\theta)} \end{aligned} \tag{2.4}$$

Note: in the formulas above, it may be approximately regarded that $r_1 = r_2 = r$ in denominator and it cannot be handled in this way in the exponent.

The radiation fields of various current elements are in $\hat{\theta}$ direction, so vector field superposition may be changed into algebraic addition or integral.

$$\begin{aligned} E_1 &= \int_{-l}^{0}\mathrm{d}E_1 = \mathrm{j}\frac{60\,\pi I_M}{\lambda\, r}\sin\,\theta\,\mathrm{e}^{-\mathrm{j}\beta r}\int_{-l}^{0}\sin[\,\beta(l+z_1)]\,\mathrm{e}^{\mathrm{j}\beta z_1\cos\theta}\,\mathrm{d}z_1 \\ E_2 &= \int_{0}^{l}\mathrm{d}E_2 = \mathrm{j}\frac{60\,\pi I_M}{\lambda\, r}\sin\,\theta\,\mathrm{e}^{-\mathrm{j}\beta r}\int_{0}^{l}\sin[\,\beta(l-z_2)]\,\mathrm{e}^{\mathrm{j}\beta z_2\cos\theta}\,\mathrm{d}z_2 \end{aligned} \tag{2.5}$$

The electric intensity vector in radiation field of the entire symmetric dipole is:

$$E_\theta(r,\theta,\varphi) = E_1 + E_2 = \mathrm{j}\frac{60 I_M}{r}\frac{\cos(\beta l\cos\theta) - \cos(\beta l)}{\sin\theta}\mathrm{e}^{-\mathrm{j}\beta r} \tag{2.6}$$

The same as that of current element, the symmetric dipole shall still meet the following requirement:

$$H_\varphi = \frac{E_\theta}{\eta_0} \tag{2.7}$$

2.1.3 Input impedance of symmetric dipole

The ratio of voltage at antenna input end and signal current is called as the input impedance of antenna. The input impedance has resistive component Rin and reactive component Xin and Zin= Rin+Xin. Existence of reactive component will decrease the extraction of signal power by antenna from feeder, so it must try to turn the reactive component to zero; that is, it shall try as possible to turn the input impedance of antenna to pure resistance. In fact, there is a small reactive component in the input impedance, even for the well-designed and debugged antenna. [3]

It may be regarded that the symmetric dipole is formed by gradual expansion of loss parallel-wire in terminal open circuit, so the equivalent transmission line method may be used to calculate the input impedance of symmetric dipole.

The known equivalent impedance of loss open circuit parallel-wire is:

$$Z(l) = Z_0(1 - \mathrm{j}\frac{\alpha}{\beta})\coth[(\alpha + \mathrm{j}\beta)l] \qquad (2.8)$$

α and β in the formula above are the attenuation constant and phase constant of lossy parallel-wire respectively.

$$Z_0 = 120\ln\frac{2D}{d} \qquad (2.9)$$

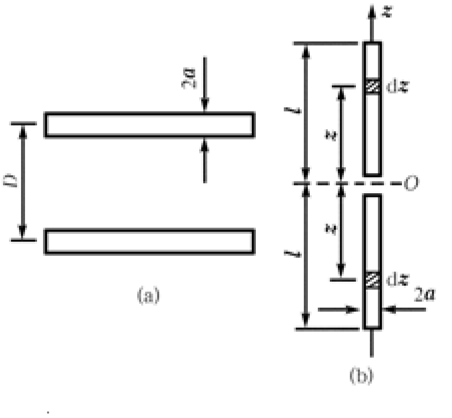


Figure.6 Schematic diagram of average characteristic resistance of symmetric dipole antenna

The symmetric dipole is a non-uniform distributed parameter system, so formula (2.9) cannot be used to calculate its characteristic resistance. As shown in figure 6, the distance D of parallel-wire in part (a) of figure 6 is uniform, but the distance $2z$ between the symmetry points of two arms of symmetric oscillator in part (b) of figure 6 continuously vary between 0 ~ $2l$. Therefore, we may replace the characteristic resistance of parallel-wire with the average characteristic resistance of symmetric oscillator, that is:

$$W_A = \frac{1}{l}\int_0^l 120 \ln \frac{2z}{a} \mathrm{d}z = 120(\ln \frac{2l}{a} - 1) \tag{2.10}$$

The formula 2.10 indicates that the thinner and longer the symmetric oscillator is, the higher W_A of its average characteristic resistance is; on the contrary, the thicker and shorter the symmetric dipole is, the lower of its average characteristic resistance is.

Practice shows that phase constant β '(which is the phase coefficient of antenna) of loss parallel-wire $\approx 1.05\beta$. β is the phase constant electromagnetic wave in free space.

It may be proved that the equivalent average distribution resistance of symmetric dipole may be calculated by radiation resistance R_Σ.

$$R_1 = \frac{R_\Sigma}{l\left[1 - \frac{\sin(2\beta' l)}{2\beta' l}\right]} \tag{2.11}$$

Then the equivalent attenuation constant is:

$$\alpha' = \frac{R_1}{2W_A} = \frac{R_\Sigma}{W_A l\left[1 - \frac{\sin(2\beta' l)}{2\beta' l}\right]} \tag{2.12}$$

Then:

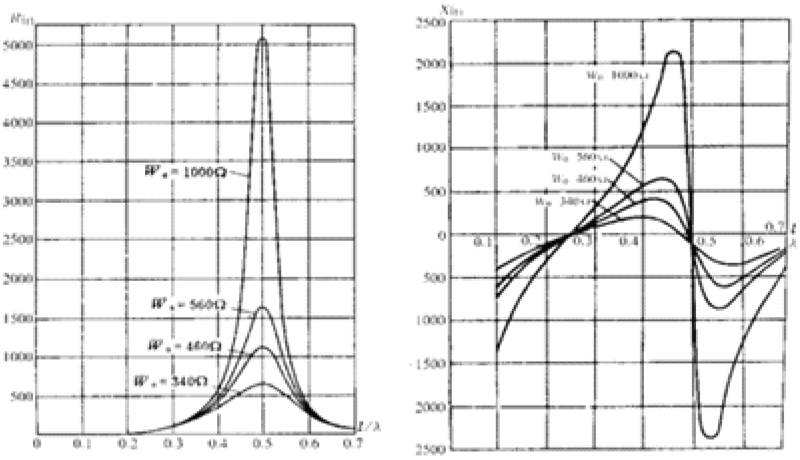
$$Z_{\mathrm{in}} = R_{\mathrm{in}} + \mathrm{j}X_{\mathrm{in}} = W_A\left(1 - \mathrm{j}\frac{\alpha'}{\beta'}\right)\coth[(\alpha' + \mathrm{j}\beta')l] \tag{2.13}$$

That is:

$$R_{\text{in}} = W_A \frac{\sinh(2\alpha' l) - \dfrac{\alpha'}{\beta'}\sin(2\beta' l)}{\cosh(2\alpha' l) - \cos(2\beta' l)} \tag{2.14}$$

And

$$X_{\text{in}} = -W_A \frac{\dfrac{\alpha'}{\beta'}\sinh(2\alpha' l) + \sin(2\beta' l)}{\cosh(2\alpha' l) - \cos(2\beta' l)} \tag{2.15}$$



Input impedance of the symmetric dipole.

Input resistance **Input reactance**

Figure.7 Input impedance of symmetric dipole

The input impedance relates to structure, dimension and operating wavelength of antenna. The semi wave symmetrical array is the most important elementary antenna and its input impedance is Zin=73.1+j42.5. If the length is shortened by (3-5)%, the reactive component in it can be eliminated to turn the input impedance of antenna to pure resistance and then the input impedance is Zin=73.1 (nominal value is 75Ω).

2.1.4 Radiation impedance of coupled symmetric dipole

Concept of coupled symmetric dipole: the voltage and current on symmetric dipole in antenna array vary because of the effect on it by the radiation field and induction field of the neighboring symmetric dipoles, so the radiation complex power varies with it, and now the characteristic of symmetric dipole is different to that when isolated and it is called as coupled symmetric dipole. [4]

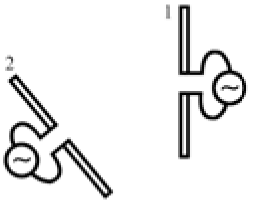


Figure.8 Coupled symmetric dipole [4]

The basic parameters of impedance equation and equivalent voltage equation of coupled symmetric dipole are shown as follows: [4]

$\dot{I}_{M1}$ —the complex amplitude of wave loop current when oscillator 1 isolated exists；

$\dot{S}_{11}$ — the corresponding radiation complex power called as self-radiation complex power.

$\dot{S}_{12}$ — the additional radiation complex power generated by oscillator 1 under the influence of oscillator 2(assume that oscillator 1 maintains its original wave loop current), called as radiation complex power.

$\dot{I}_{M2}$ —the complex amplitude of wave loop current when oscillator 2 isolated exists.

$\dot{S}_{22}$ —the corresponding self-radiation complex power；

$\dot{S}_{21}$ — the additional radiation complex power generated by oscillator 2 under the influence of oscillator 1(assume that oscillator 2 maintains its original wave loop current), called as radiation complex power.

The total radiation complex powers of oscillator 1 and oscillator 2 are shown as follows:

$$\dot{S}_{\Sigma 1} = \dot{S}_{11} + \dot{S}_{12} \text{ and } \quad \dot{S}_{\Sigma 2} = \dot{S}_{21} + \dot{S}_{22} \tag{2.16}$$

Suppose:

$$Z_{11} = \frac{2\dot{S}_{11}}{|\dot{I}_{M1}|^2}, \quad Z_{g12} = \frac{2\dot{S}_{12}}{|\dot{I}_{M1}|^2}, \quad Z_{\Sigma 1} = \frac{2\dot{S}_{\Sigma 1}}{|\dot{I}_{M1}|^2},$$
$$Z_{22} = \frac{2\dot{S}_{22}}{|\dot{I}_{M2}|^2}, \quad Z_{g21} = \frac{2\dot{S}_{21}}{|\dot{I}_{M2}|^2}, \quad Z_{\Sigma 2} = \frac{2\dot{S}_{\Sigma 2}}{|\dot{I}_{M2}|^2} \tag{2.17}$$

(2-4-2)

Compare equation (2.15) and equation (2.16) to get the impedance equation of coupled symmetric dipole:

$$Z_{\Sigma 1} = Z_{11} + Z_{g12} \text{ and } Z_{\Sigma 2} = Z_{g21} + Z_{22}45 \tag{2.18}$$

Suppose that the equivalent voltage of coupled symmetric dipole meets the following relation:

$$\dot{S}_{\Sigma 1} = \frac{1}{2}\dot{U}_1 \dot{I}_{M1}^* \text{ and } \quad \dot{S}_{\Sigma 2} = \frac{1}{2}\dot{U}_2 \dot{I}_{M2}^* \tag{2.19}$$

Where: the equivalent voltage is only the spiral vector voltage calculated by the respective current and radiation complex power of the two oscillators and is not the voltage somewhere on symmetric dipole.

$$\dot{U}_1 = \frac{2\dot{S}_{\Sigma 1}}{\dot{I}_{M1}^*} = \frac{|\dot{I}_{M1}|^2 Z_{\Sigma 1}}{\dot{I}_{M1}^*} = \dot{I}_{M1} Z_{\Sigma 1} \text{ and } \quad \dot{U}_2 = \frac{2\dot{S}_{\Sigma 2}}{\dot{I}_{M2}^*} = \frac{|\dot{I}_{M2}|^2 Z_{\Sigma 2}}{\dot{I}_{M2}^*} = \dot{I}_{M2} Z_{\Sigma 2} \tag{2.20}$$

Substitute equation (2-4-3) into the formula above to obtain the equation below:

$$\begin{aligned} \dot{U}_1 &= \dot{I}_{M1} Z_{11} + \dot{I}_{M1} Z_{g12} = \dot{U}_{11} + \dot{U}_{12} \\ \dot{U}_2 &= \dot{I}_{M2} Z_{g21} + \dot{I}_{M2} Z_{22} = \dot{U}_{21} + \dot{U}_{22} \end{aligned} \tag{2.21}$$

In the formula above, $\dot{U}_{11} = \dot{I}_{M1}Z_{11}$ is the equivalent voltage of oscillator 1 not influenced by oscillator 2 in open circuit and $\dot{U}_{12} = \dot{I}_{M1}Z_{g12}$ is the additional voltage of oscillator 1 affected by oscillator 2; $\dot{U}_{22} = \dot{I}_{M2}Z_{22}$ is the equivalent voltage of oscillator 2 not influenced by oscillator 1 in open circuit and $\dot{U}_{12} = \dot{I}_{M1}Z_{g12}$ is the additional voltage of oscillator 2 affected by oscillator 1. It is obvious that the additional voltage $\dot{U}_{12}$ of oscillator 1 shall be in proportion with current $\dot{I}_{M2}$ of oscillator 2 and that the additional voltage $\dot{U}_{21}$ of oscillator 2 shall be in proportion with current $\dot{I}_{M1}$ of oscillator 1. That is:

$$\dot{U}_{12} = \dot{I}_{M1}Z_{g12} = \dot{I}_{M2}Z_{12} \quad \text{and} \quad \dot{U}_{21} = \dot{I}_{M2}Z_{g21} = \dot{I}_{M1}Z_{21} \quad \dot{U}_{12} = \dot{I}_{M1}Z_{g12} = \dot{I}_{M2}Z_{12} \tag{2.22}$$

In the formula above, Z_{12} is the mutual radiation impedance of oscillator 1 under the influence of oscillator 2; and Z_{21} is the mutual radiation impedance of oscillator 2 under the influence of oscillator 1. Substitute formula (2.21) into formula (2.20) to obtain:

$$\begin{aligned} \dot{U}_1 &= \dot{I}_{M1}Z_{11} + \dot{I}_{M2}Z_{12} \\ \dot{U}_2 &= \dot{I}_{M1}Z_{21} + \dot{I}_{M2}Z_{22} \end{aligned} \tag{2.23}$$

This is the equivalent voltage equation of coupled symmetric dipole. 4-port network in figure 2.8 may be used for remember the equivalent voltage equation of coupled symmetric dipole. According to the circuit in figure 2.8, the equivalent voltage equation, i.e. (2.22), may be obtained directly.

Therefore the common solution to mutual radiation impedance of coupled symmetric dipole is induced EMF method, which is complex; actually, it may check up the corresponding tables and curves directly to solve it.

The calculation formulas of mutual resistance and mutual reactance may be calculated by induced EMF method.

$$
\begin{aligned}
R_{12} &= 30\int_{-l_1}^{l_1} \sin[\beta(l_1-|z_1|)]\left[\frac{\sin(\beta r_1)}{r_1}+\frac{\sin(\beta r_2)}{r_2}-2\cos(\beta l_2)\frac{\sin(\beta r_0)}{r_0}\right]\mathrm{d}z_1 \\
X_{12} &= 30\int_{-l_1}^{l_1} \sin[\beta(l_1-|z_1|)]\left[\frac{\cos(\beta r_1)}{r_1}+\frac{\cos(\beta r_2)}{r_2}-2\cos(\beta l_2)\frac{\cos(\beta r_0)}{r_0}\right]\mathrm{d}z_1
\end{aligned}
\tag{2.24}
$$

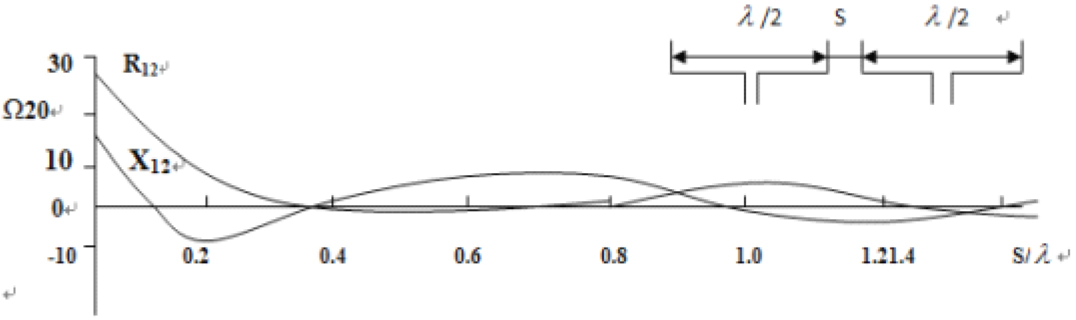


Figure.9 Mutual resistance and mutual reactance curve of coupled semi wave symmetric dipole of coaxial line arrangement

Figure.9 shows the curve of variation of mutual resistance and mutual reactance of coupled semi wave symmetric dipole ($l_1 = l_2 = l = 0.25\lambda$) of coaxial line arrangement with distance. In the figure, s is the distance between two endpoints with which the coupled symmetric dipole is confronting. The figure shows that amplitude of variation of mutual resistance R_{12} and mutual reactance X_{12} is reduced gradually as the distance s increases.

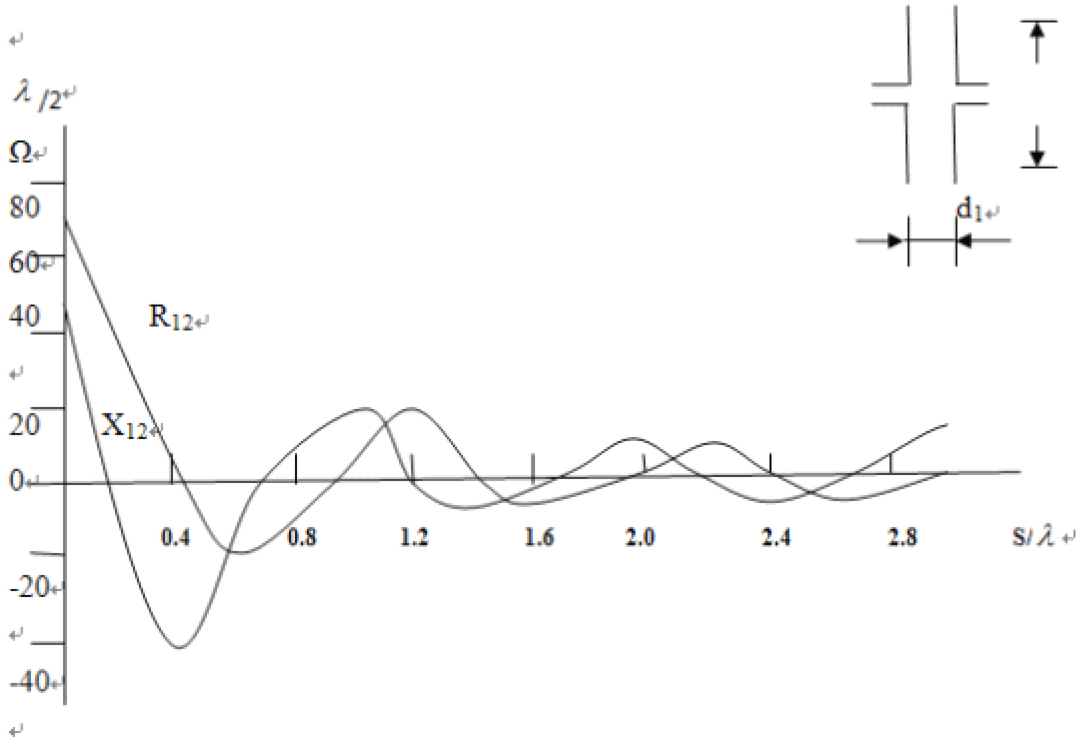


Figure.10 Mutual resistance and mutual reactance curves of coupled sine wave symmetric dipole of level arrangement

If the distance between the two symmetric dipoles of level arrangement decreases until to touch each other, a oscillator will be formed and then the self-radiation impedance of the symmetric dipole is:

$$\begin{aligned} R_{11} &= 60\int_0^l \sin[\beta(l-z_1)]\left[\frac{\sin(\beta r_1)}{r_1}+\frac{\sin(\beta r_2)}{r_2}-2\cos(\beta l)\frac{\sin(\beta r_0)}{r_0}\right]\mathrm{d}z_1 \\ X_{11} &= 60\int_0^l \sin[\beta(l-z_1)]\left[\frac{\cos(\beta r_1)}{r_1}+\frac{\cos(\beta r_2)}{r_2}-2\cos(\beta l)\frac{\cos(\beta r_0)}{r_0}\right]\mathrm{d}z_1 \end{aligned} \qquad (2.25)$$

As for the sine wave symmetric dipole, self-radiation impedance is:

$$Z_{11} = R_{11} + jX_{11} = 73.1 + j42.5\ (\Omega)$$

2.1.5 Directivity factor and gain coefficient of antenna

Directivity factor is a parameter representing the energy concentration degree of antenna electromagnetic wave and is related to both directional characteristic and impedance characteristic of antenna. [5]

Directivity factor is a parameter used to indicate the degree of electromagnetic wave radiated by antenna intensively to a direction (i.e. sharpness of directional pattern). In order to determine the directivity factors of antenna, an idea non-directional antenna is generally used for a standard for comparison. [5]

The directivity factor of any directional antenna refers to the ratio of total radiant power of non-directional antenna and total radiant power of the directional antenna under the condition that the equal electric intensity is generated on the receiving point. According to the definition above and because of unequal radiation intensities in various directions of directional antenna, the directivity factors of antenna differ from the different observation points, and the directivity factor is largest in the direction of maximum radiated electric field. Except otherwise specified, the directivity factor of the direction of maximum radiation is in general the directivity factor of directional antenna. [6]

Definition 1: ratio of maximum radiation intensity and average radiation intensity.
Definition 2: ratio of power flux density in the direction of maximum radiation and power flux density of ideal non-directional point source of antenna with the same distance and radiation power;
Definition 3: ratio of the square of field intensity of in the direction of maximum radiation and the square of ideal non-directional point source of antenna with the same distance and radiation power;

$$D = \frac{U_{\max}}{U_0} \Big|_{P_\Sigma = P_0} = \frac{S(r,\theta_M,\varphi_M)}{S_0(r)} \Big|_{P_\Sigma = P_0} = \frac{E^2(r,\theta_M,\varphi_M)}{E_0^2(r)} \Big|_{P_\Sigma = P_0} \tag{2.26}$$

Substitute formula (1-4-25) and (1-4-5) into (1-4-27)) to obtain:

$$D = \frac{U_{\max}}{\frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi} U(\theta,\varphi)\sin\theta \, \mathrm{d}\theta \, \mathrm{d}\varphi} = \frac{4\pi f_{\max}^2}{\int_0^{2\pi}\int_0^{\pi} f^2(\theta,\varphi)\sin\theta \, \mathrm{d}\theta \, \mathrm{d}\varphi} \tag{2.27}$$

The normalized directivity function may also be used to calculate the directivity factor.

$$D = \frac{4\pi}{\int_0^{2\pi}\int_0^{\pi} F^2(\theta,\varphi)\sin\theta\,\mathrm{d}\theta\,\mathrm{d}\varphi} \tag{2.28}$$

The radiation resistance may be used directly to calculate the directivity factor, because that:

$$R_\Sigma = \frac{2P_\Sigma}{|I|^2} = \frac{30}{\pi}\int_0^{2\pi}\int_0^{\pi} f^2(\theta,\varphi)\sin\theta\,\mathrm{d}\theta\,\mathrm{d}\varphi \tag{2.29}$$

A conclusion may be drawn that:

$$D = \frac{120 f_{\max}^2}{R_\Sigma} \tag{2.30}$$

The directivity factor may be calculated by effective length and radiation resistance, because that:

$$f_{\max} = \frac{\pi l_e}{\lambda} = \frac{\beta l_e}{2} \tag{2.31}$$

We can deduce a conclusion:

$$D = \frac{30(\beta l_{eM})^2}{R_\Sigma} = \frac{30(\beta l_{e\mathrm{in}})^2}{R_{\Sigma\mathrm{in}}} \tag{2.32}$$

Note that the effective length, radiation resistance and $f_{\max}$ above are the electric parameters with reference to the same current.

For example， the directivity factor D of current element = $\frac{120(\pi l/\lambda)^2}{80(\pi l/\lambda)^2}$=1.5；

The directivity factor D of sine wave symmetric dipole = $\frac{120\cdot 1^2}{73.1}$=1.64；

The directivity factor D of full wave symmetric dipole = $\frac{120\cdot 2^2}{199}$=2.41.

Because that:

$$D = \frac{U_{\max}}{U_0} \Big|_{P_\Sigma = P_0} = \frac{S(r,\theta_M,\varphi_M)}{S_0(r)} \Big|_{P_\Sigma = P_0} = \frac{E^2(r,\theta_M,\varphi_M)}{E_0^2(r)} \Big|_{P_\Sigma = P_0}$$

$$P_\Sigma = P_0 = \frac{1}{2} E_0 H_0^* = \frac{E_0^{\ 2}}{2\eta_0} \cdot 4\pi r^2 = \frac{E_0^{\ 2}}{240\pi} \cdot 4\pi r^2 = \frac{r^2 E_0^{\ 2}}{60}$$

We can deduce a conclusion:

$$E_{\max}(r) = E(r,\theta_M,\varphi_M) = \sqrt{D} E_0 = \frac{\sqrt{60 P_\Sigma D}}{r} \tag{2.33}$$

Formula （2.33） show that the field intensity in the equation is the amplitude on the direction of maximum radiation(θ_M, φ_M), and if it is required to calculate the effective value, substitute 60 under radical sign with 30.

Antenna efficiency: ratio of radiation power P_Σ and input power P_{in}, that is:

$$\eta_A = \frac{P_\Sigma}{P_{\text{in}}} \tag{2.34}$$

Loss power: difference between input power P_{in} and radiation power P_Σ

$$P_l = P_{\text{in}} - P_\Sigma \tag{2.35}$$

The loss power of antenna results from conductor resistance, medium leakage conductance and other factors.

If the current I_{in} on the antenna's feeding point is used for reference, then:

$$R_{\text{in}} = \frac{2P_{\text{in}}}{I_{\text{in}}^2}, \quad R_{\Sigma\text{in}} = \frac{2P_\Sigma}{I_{\text{in}}^2} \quad \textit{and} \quad R_{l\text{in}} = \frac{2P_l}{I_{\text{in}}^2} \tag{2.36}$$

The following relation shall exist between them

$$R_{\text{in}} = R_{\Sigma\text{in}} + R_{l\text{in}} \tag{2.37}$$

Note: the loss resistance $R_{l\text{in}}$ is not equal to the DC resistance R (resistance), even if the loss is caused by antenna conductor. DC resistance R (resistance) of antenna conductor is measured under DC or uniform distributed current, but the current amplitude distribution $I(z)$ on antenna in general is in-uniform.

Substitute formula (2.36) and (2.37) respectively into (2.34) to obtain:

$$\eta_A = \frac{R_{\Sigma\text{in}}}{R_{\text{in}}} = \frac{R_{\Sigma\text{in}}}{R_{\Sigma\text{in}} + R_{l\text{in}}} \tag{2.38}$$

Two approaches to promote the antenna's efficiency:

1. Reduce loss resistance $R_{l\text{in}}$; and
2. Increase radiation resistance $R_{\Sigma\text{in}}$.

The gain coefficient of antenna is generally called also as maximum gain or antenna gain. It refers to the ratio of the total input power of standard antenna (non-directional) and the total input power of directional antenna under the condition that the equal electric intensity is generated on a certain point in the direction of maximum field intensity, which is called as the maximum gain coefficient of the antenna. It reflects the effective utilization degree of radio-frequency power by antenna better than that of antenna's directivity factor. Mathematics may be used to deduce that the maximum gain coefficient of antenna is equal to the antenna's directivity factor multiplied by antenna efficiency. [6]

The definition mode of antenna′s gain coefficient is quite similar to that of antenna′s directivity factor.

$$G = \frac{U_{\max}}{U_0 \mid_{P_{in}=P_0}} = \frac{S(r,\theta_M,\varphi_M)}{S_0(r) \mid_{P_{in}=P_0}} = \frac{E^2(r,\theta_M,\varphi_M)}{E_0^2(r) \mid_{P_{in}=P_0}} \tag{2.39}$$

Suppose that the input power of antenna can radiate to the free space completely, and then the imaginary average radiation intensity converted from input power is:

$$U_0' = \frac{P_{in}}{4\pi} \tag{2.40}$$

Because $$\eta_A = \frac{P_\Sigma}{P_{\text{in}}} \tag{2.41}$$

So $$U_0' = \frac{P_\Sigma}{4\pi\eta_A} = \frac{U_0}{\eta_A}$$

$$G = \frac{U_{\max}}{U_0'} = \frac{U_{\max}}{U_0}\eta_A = D\eta_A \qquad (2.42)$$

Therefore， gain coefficient G reflects the characteristics of antenna conversion and radiation electromagnetic power more completely than that directivity factor D.

$P_\Sigma D = P_{in}\eta_A D = P_{in} G$, so the antenna's radiation field on the direction of maximum radiation may also be expressed as follows:

$$E_{\max}(r) = \frac{\sqrt{60P_\Sigma D}}{r} = \frac{\sqrt{60P_{\text{in}} G}}{r} \qquad (2.43)$$

Where: F is the field intensity direction function.

2.2. Matlab background

Since the 1980s, electronic computers, especially the software of electronic computers has achieved great development. In many software, mathematics technology application software develop a school of their own. Until the mid of 1990s, there has appeared on 30 several mathematics technology application software on international. MATLAB in numerical calculation is the best of one, and Mathematical and Maple is separated symbol computer software former two. In math technology application software, MATLAB is a typical representative of the numerical computing, and may be the first software which we come into contact with math technology application software, in automatic control, communication, finance and other fields has a wide range of application. MATLAB is released in the face of scientific computing, visualization and interactive programming; the math works company by the U.S. high-tech computing environment. It numerical analysis, matrix computation, scientific data visualization, as well as nonlinear dynamic system modeling and simulation, and many other powerful features are integrated in an easy to use Windows environment, scientific research, engineering design and the need for effective numerical calculation many fields of science to provide a comprehensive solution, and largely out of the traditional non-interactive programming language (such as C, Fortran), edit mode, and represents the advanced level of today's international scientific computing software. [7]

Application development software

The MATLAB product family can be used for the following work: [8]

- Numerical Analysis
- Numeric and symbolic computation
- Engineering and scientific graphics
- Control System Design and Simulation
- Digital image processing techniques
- Digital signal processing technology
- Design and simulation of communication systems

The MATLAB has widely used range of applications, including signal and image processing, communications, control system design, test and measurement, financial modeling and analysis, and computational biology and other many applications. Additional Toolbox (available separately dedicated set of MATLAB functions) extends the MATLAB environment to solve particular types of problems in these application areas.

2.3 Matlab GUI introduce

The user interface (or interface) refers to the tools and methods of interaction between man and machine (or program) can become a window to exchange information with the computer, such as keyboard, mouse, track ball, microphone. Graphical user interface (Graphical User Interfaces, GUI) is by the window, the cursor buttons, menus, text and other objects (Objects) consisting of a user interface. Selected by certain methods (such as a mouse and keyboard) to activate these graphic objects enables a computer to produce a certain action or change, such as computing and graphics.[9]

The user interface is the user and the hardware, software, interactive communications intermediary, through the user interface; the user to the software instructions to perform a function, the software uses the hardware, other software to implement the directive, and results of the implementation in the form of graphics or text return to the user. Early user interface is mostly the most typical form of a text-based DOS system. The user to enter a command, the system by calling the software, hardware resources to implement the directive, and the form of text to return to the results of the implementation. Today, for most users, DOS (and similar user interface system) seems to be a taboo enigmatic world, not only tedious, and the work efficiency is low; people prefer a WYSIWYG user interface system, the graphical user interface (Graphical user Interface, referred to as the GUI). The graphical user interface is constituted by the window, the cursor keys, menus, text and other elements of the user window, click on these elements, the user can very easily accomplish a function is selected, the characteristics of this WYSIWYG especially good in drawing and other applications.[10]

The graphical user interface program can be divided into two relatively independent sub-modules, interface modules, and modules, interface modules to accept user input and the input data and requests for action submitted to the work module; work module is usually done in the background data processing tasks, and the results submitted to the interface. Accordingly, GUI programming interface design and programming can be divided into two parts. [11]

3. Process and Result

3.1 The antenna parameter calculation software design

3.1.1 Flow chart of design a GUI interface

MATLAB program design is relatively simple. The main purpose of GUI program is to establish all kinds of interfaces to implement the function which is designed in the beginning. The design gives scientific computing general appearance. As for each block need to be refer to their corresponding function.

GUI design summary flow chart as shown as Figure 11:

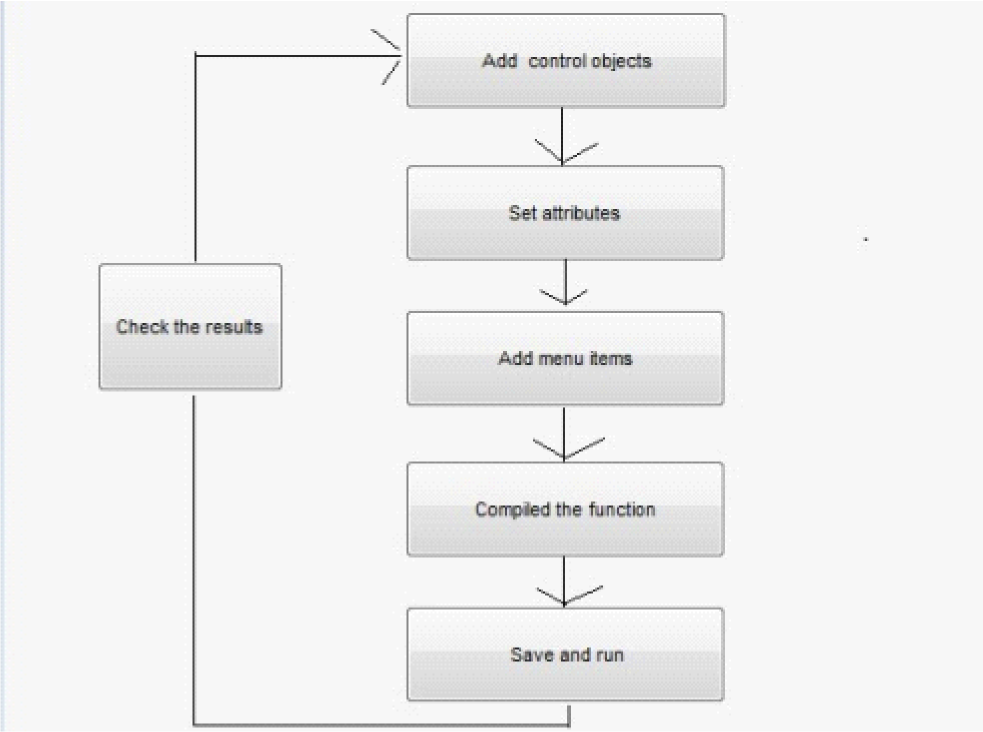


Figure.11 Flow chart of the process

Here is the process of GUI design as shown below:

1.Open GUI design window, add the relevant control objects。

2. Open the properties of the object and set corresponding attributes of the object.

3. Add menu items

4. Write code to achieve the control function
5. Save and run the graphical user interface
6. Substituting numerical verify results

3.2The specific process

3.2.1 Generation of Main-dialog box

In this thesis student focus on using the matlab graphical user interface (GUI) to accomplish the antenna parameter calculation software design. Before doing this project need to know how to use the GUI to generate the user interface and How to add the appropriate code in the CALLBACK function.

Select the default settings, click the OK button, dialog box appears. Add three buttons in the dialog box. Double-click those three buttons. Changing the name of the three buttons in the Property Inspector options, input impedance, mutual radiation impedance, directional coefficient and gain coefficient. The Main dialog interface as shown as Figure 12.

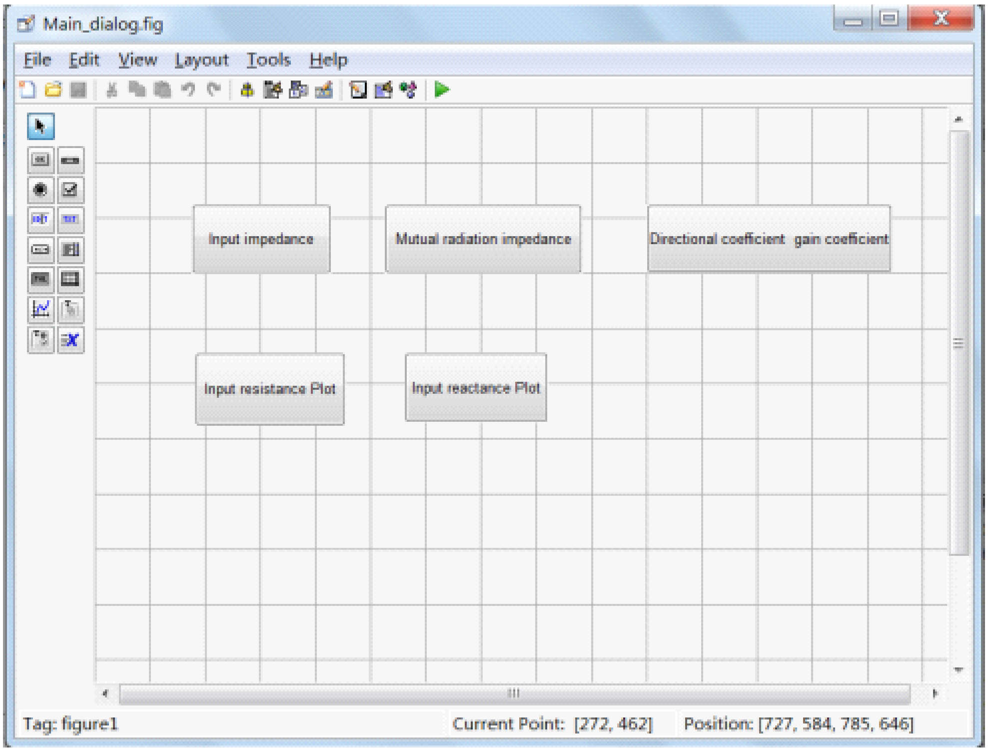
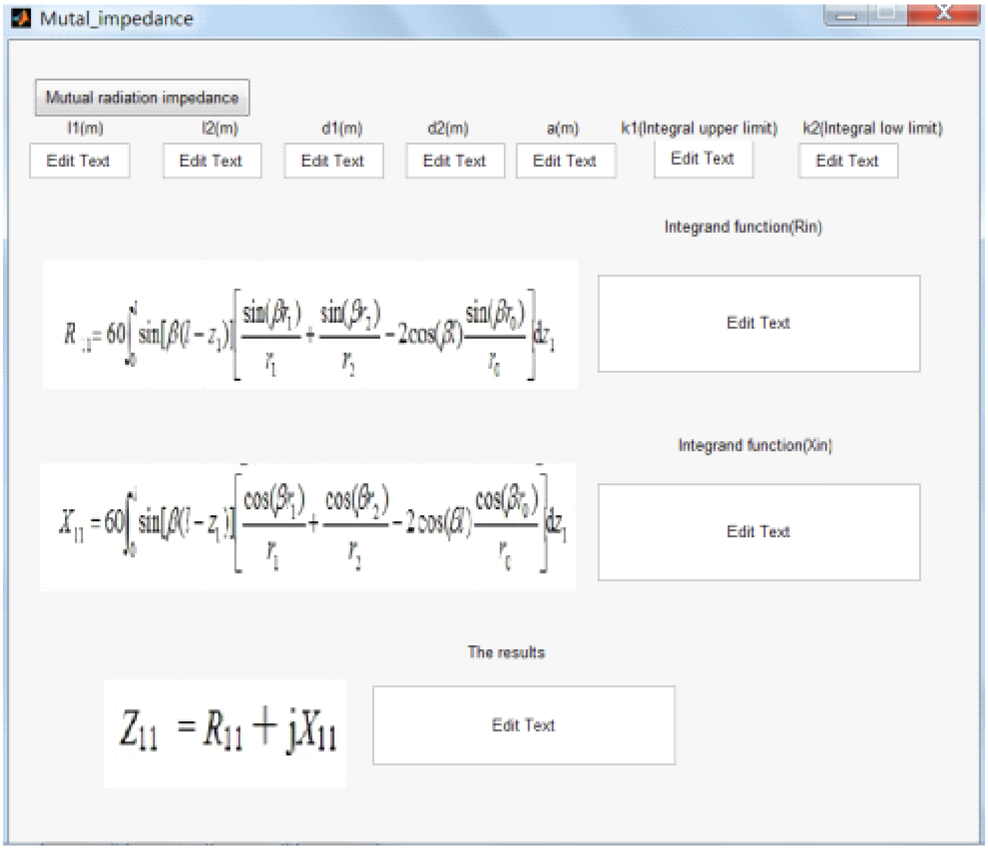


Figure 12 Matlab Main dialog interface

3.2.2 Generation of sub-dialog box

Similar step of the main dialogue, click the MATLAB GUIDE. But here should point out that Storage path is the same as the main dialog. Generated three sub-dialog box as shown below. Set sub-dialog box as calculate mutual radiation impedance Named Mutal_impedance.fig. Add button and edit box and set them as in a correct way. The results are shown in Figure 13.



$$R_{11}=60\int_0^l \sin[\beta(l-z_1)]\left[\frac{\sin(\beta r_1)}{r_1}+\frac{\sin(\beta r_2)}{r_2}-2\cos(\beta l)\frac{\sin(\beta r_0)}{r_0}\right]dz_1$$

$$X_{11}=60\int_0^l \sin[\beta(l-z_1)]\left[\frac{\cos(\beta r_1)}{r_1}+\frac{\cos(\beta r_2)}{r_2}-2\cos(\beta l)\frac{\cos(\beta r_0)}{r_0}\right]dz_1$$

$$Z_{11}=R_{11}+jX_{11}$$

Figure 13 Mutual radiation impedance interface

For the Mutal impedance sub-dialog box student could insert the variables to calculate the mutal-radiation impedance. Using the formulas which are obtained from the theoretical part. Set sub-dialog box; calculate the input impedance, named mutal_impedance.fig. Similarly add buttons and edit boxes to adjust each tag of the boxes into a correct way. The results are shown in Figure 13.

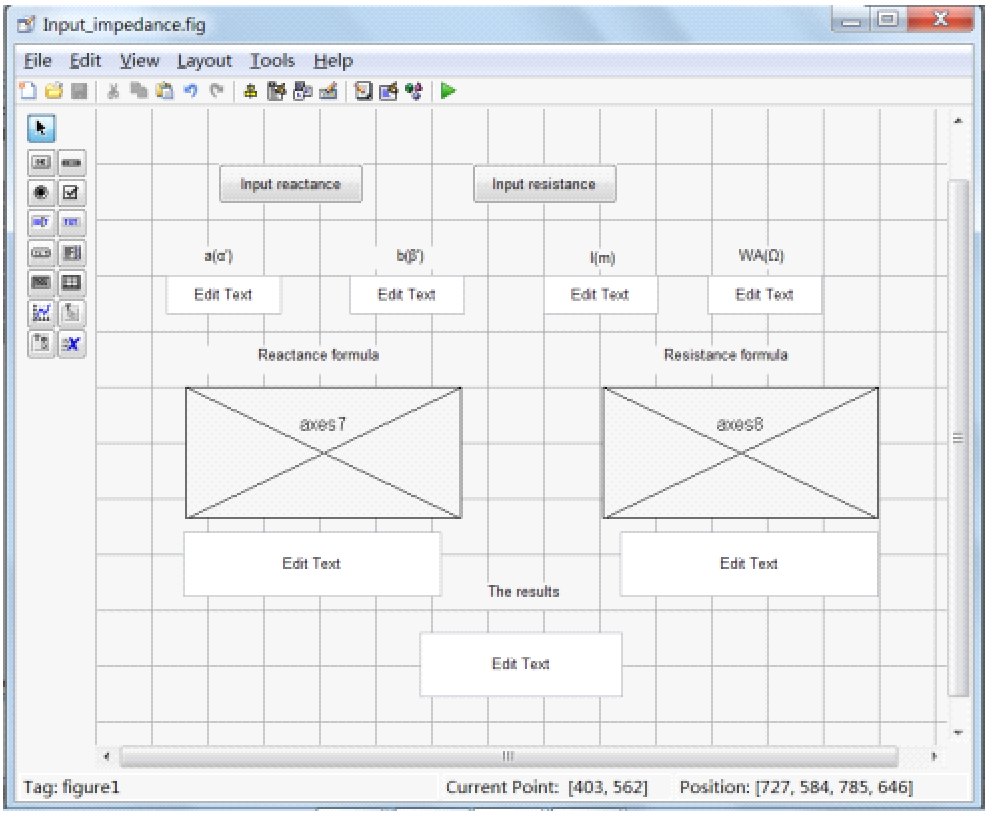


Figure 14 Input impedance calculation interface

For input impedance calculation sub-dialog box, it is used to calculate the input impedance of the antenna. As can be seen from the figure inserting the length and the attention coefficient to calculate the reactance and the resistance impedance of the antenna. Similarly add buttons and edit boxes as usual. The results are shown in Figure14.

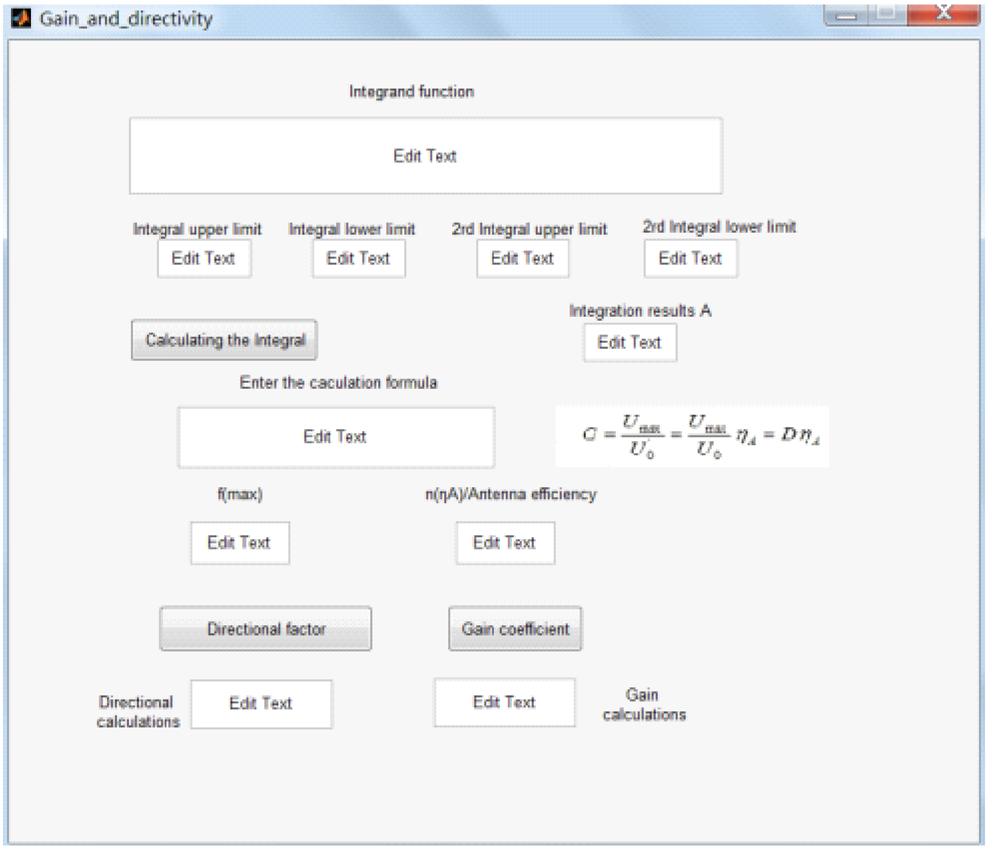
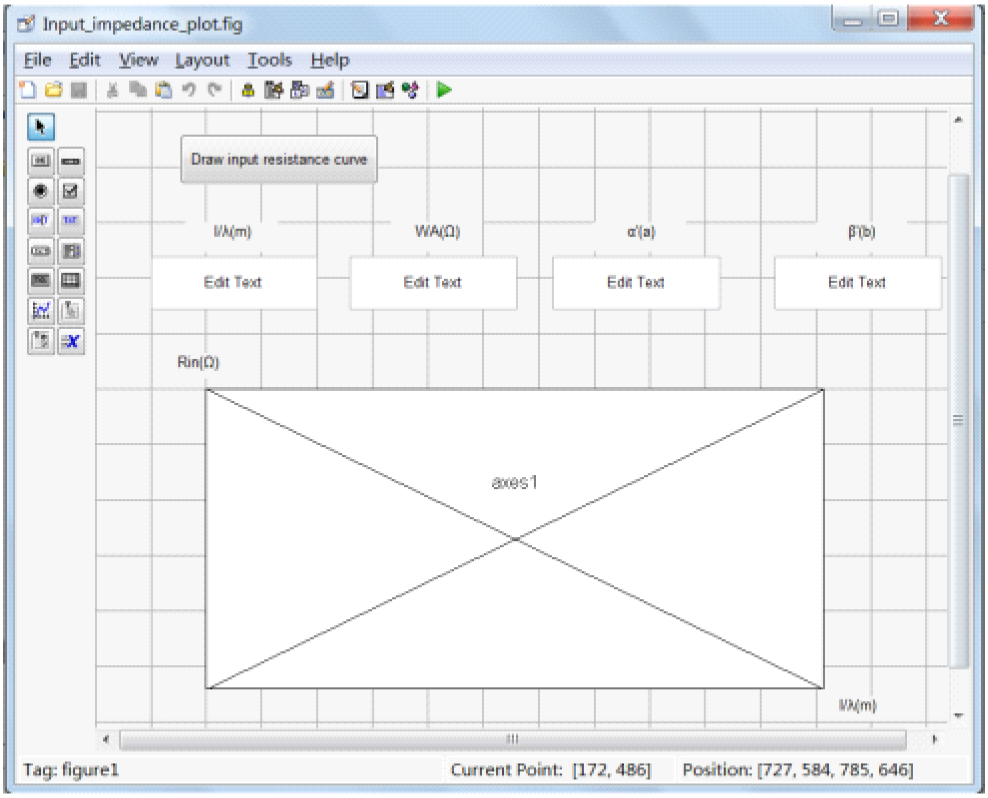


Figure 15 The calculated directivity coefficient and gain coefficient interface

In this sub-dialog it contained the Directional factor and Gain factor calculation. First integrate the wanted function to get the integration result A. Then insert the f(max) and the antenna efficiency to get the result of Directional factor and Gain coefficient of antenna. Similarly add buttons and edit boxes for each label corresponds to correct box. The results are shown in Figure 15.



Tag: figure1 Current Point: [172, 486] Position: [727, 584, 785, 646]

Figure 16 Input resistance curve interface plot

In this sub_dialog setting a plot to implement the input resistance curve with the change of length/wavelength. Insert boxes include the attention coefficient, equivalent impedance and the length/wavelength for the antenna. Similarly add buttons and edit boxes to set them as in a correct way. The results are shown in Figure 16.

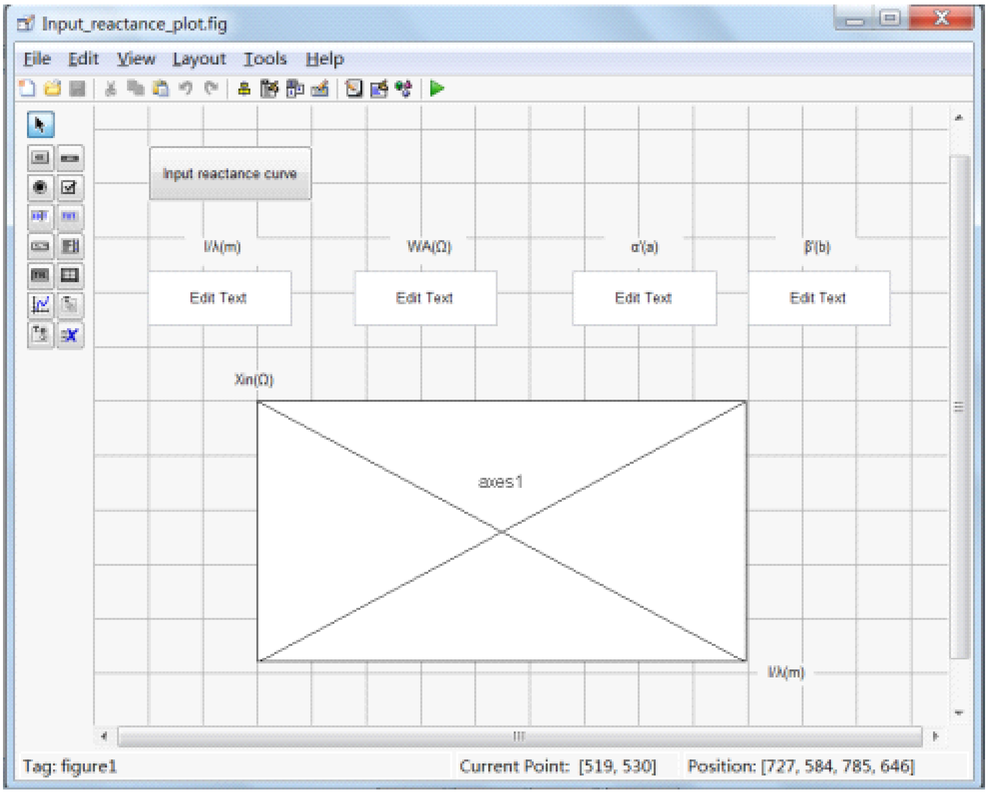


Figure 17 Input reactance curve interface plot

In this sub_dialog setting a plot to implement the reactance curve with the change of length/wavelength. Insert boxes include the attention coefficient, equivalent average resistance and the length/wavelength for the antenna. Similarly add buttons and edit boxes to set them as in a correct way. The results are shown in Figure 17.

4. Result

4.1 Interface functional verification

Open the Main_dialog.fig file will show the figure below; this is the main dialog for the whole interface.

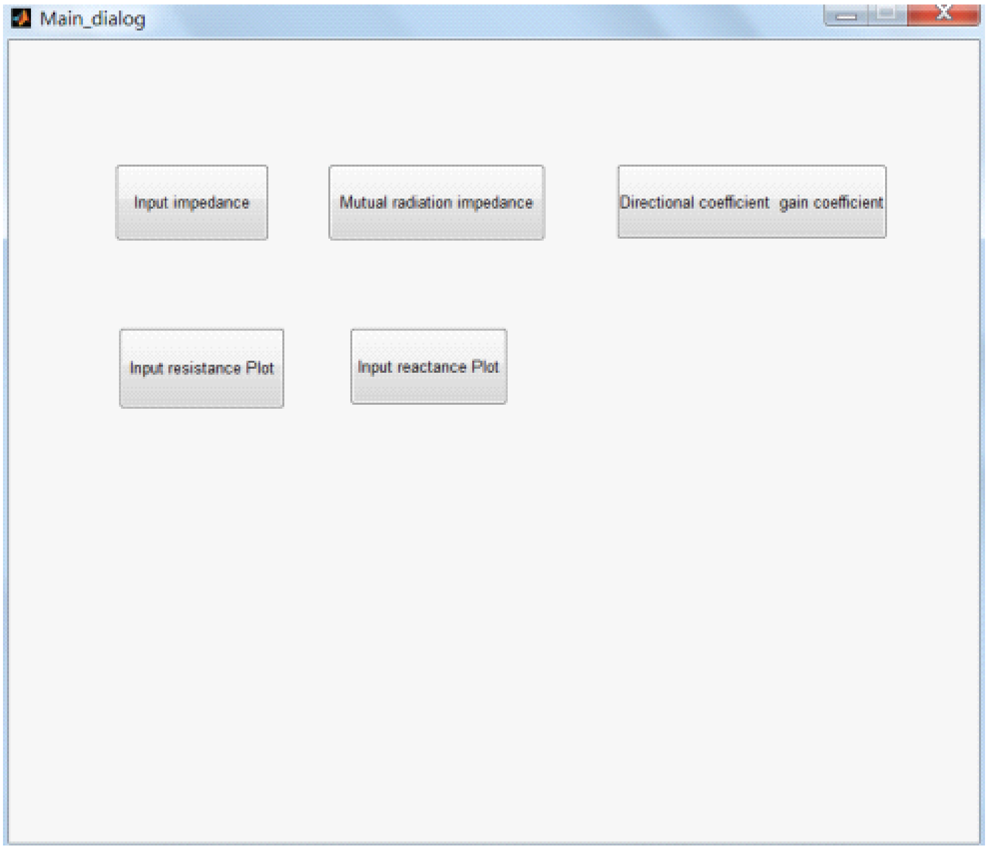
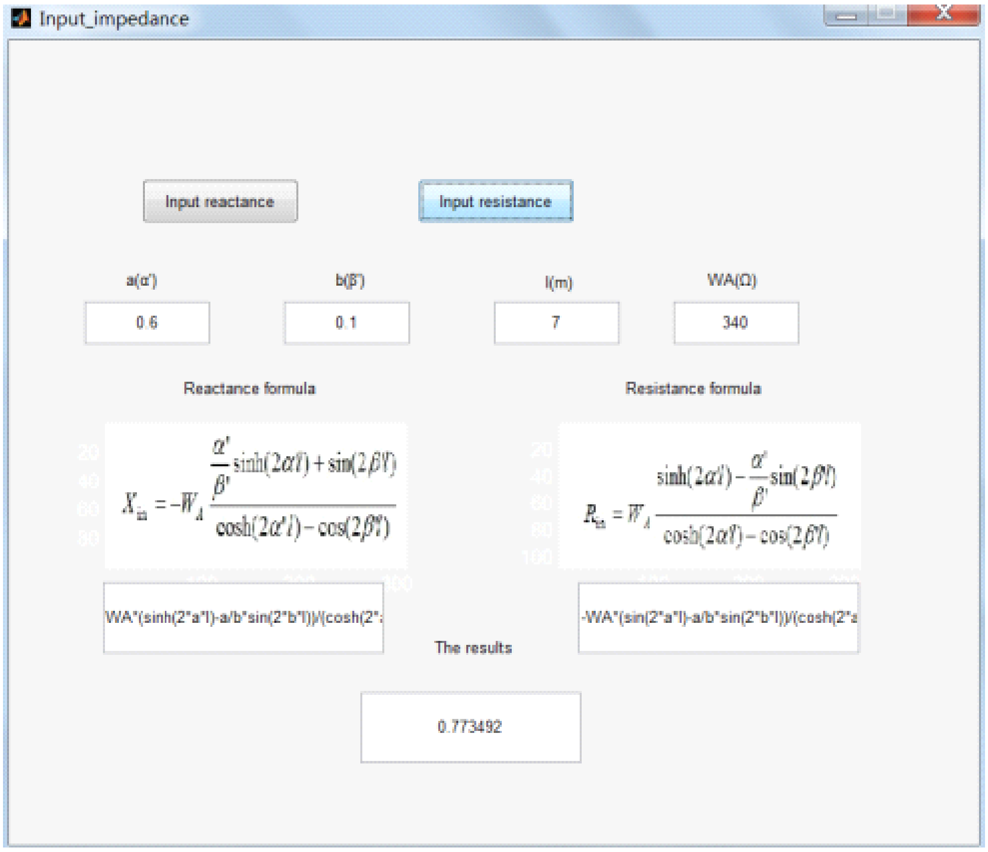


Figure 18 Main interface dialog

In the result part for main dialog interface, students can click the bottom which shown on the interface block to related interface. For example, if students click input resistance plot bottom it will lead to the interface that plot the corresponding figure of input resistance.

4.2 Input impedance function verification



a(α'): 0.6
b(β'): 0.1
l(m): 7
WA(Ω): 340

Reactance formula

$$X_{in} = -W_A \frac{\frac{\alpha'}{\beta'}\sinh(2\alpha' l) + \sin(2\beta' l)}{\cosh(2\alpha' l) - \cos(2\beta' l)}$$

WA*(sinh(2*a*l)-a/b*sin(2*b*l))/(cosh(2*

Resistance formula

$$R_{in} = W_A \frac{\sinh(2\alpha' l) - \frac{\alpha'}{\beta'}\sin(2\beta' l)}{\cosh(2\alpha' l) - \cos(2\beta' l)}$$

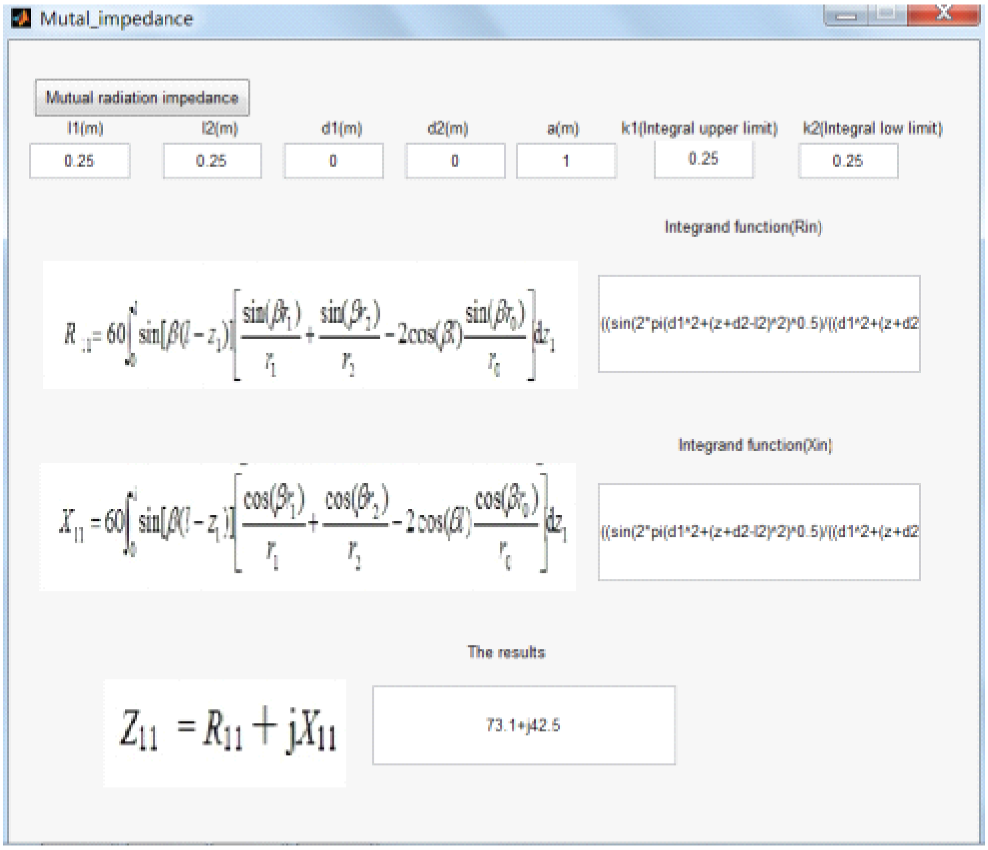
-WA*(sin(2*a*l)-a/b*sin(2*b*l))/(cosh(2*a

The results: 0.773492

Figure 19 Calculate the input resistance interface

According to the formula for calculating the input resistance, the parameters ‘a’, ‘b’, ‘WA’ and ‘l’ should be implemented. Where ‘a’ is the attention coefficient and ‘b’ is the phase coefficient while the wave propagation. Since the dipole is not uniformly distributed parameter systems so the impedance that should implement can be used as average impedance ‘WA’. Click on the main interface input impedance button to enter the input impedance interface. Enter ‘a’ = 0.6, ‘b’ = 0.1, ‘l’ = 7, ‘WA’ = 340 and the formula to calculate the input impedance, numerically get the value of the input resistance is 0.773 and in the same way get the input reactance is -2040.31.By verify with the formula that given in previous ,the result is correct.

4.3 Mutual radiation impedance function verification



l1(m): 0.25
l2(m): 0.25
d1(m): 0
d2(m): 0
a(m): 1
k1(Integral upper limit): 0.25
k2(Integral low limit): 0.25

Integrand function(Rin)

$$R_{11}=60\int_0^l \sin[\beta(l-z_1)]\left[\frac{\sin(\beta r_1)}{r_1}+\frac{\sin(\beta r_2)}{r_2}-2\cos(\beta l)\frac{\sin(\beta r_0)}{r_0}\right]dz_1$$

```
((sin(2*pi(d1^2+(z+d2-l2)^2)^0.5)/((d1^2+(z+d2
```

Integrand function(Xin)

$$X_{11}=60\int_0^l \sin[\beta(l-z_1)]\left[\frac{\cos(\beta r_1)}{r_1}+\frac{\cos(\beta r_2)}{r_2}-2\cos(\beta l)\frac{\cos(\beta r_0)}{r_0}\right]dz_1$$

```
((sin(2*pi(d1^2+(z+d2-l2)^2)^0.5)/((d1^2+(z+d2
```

The results

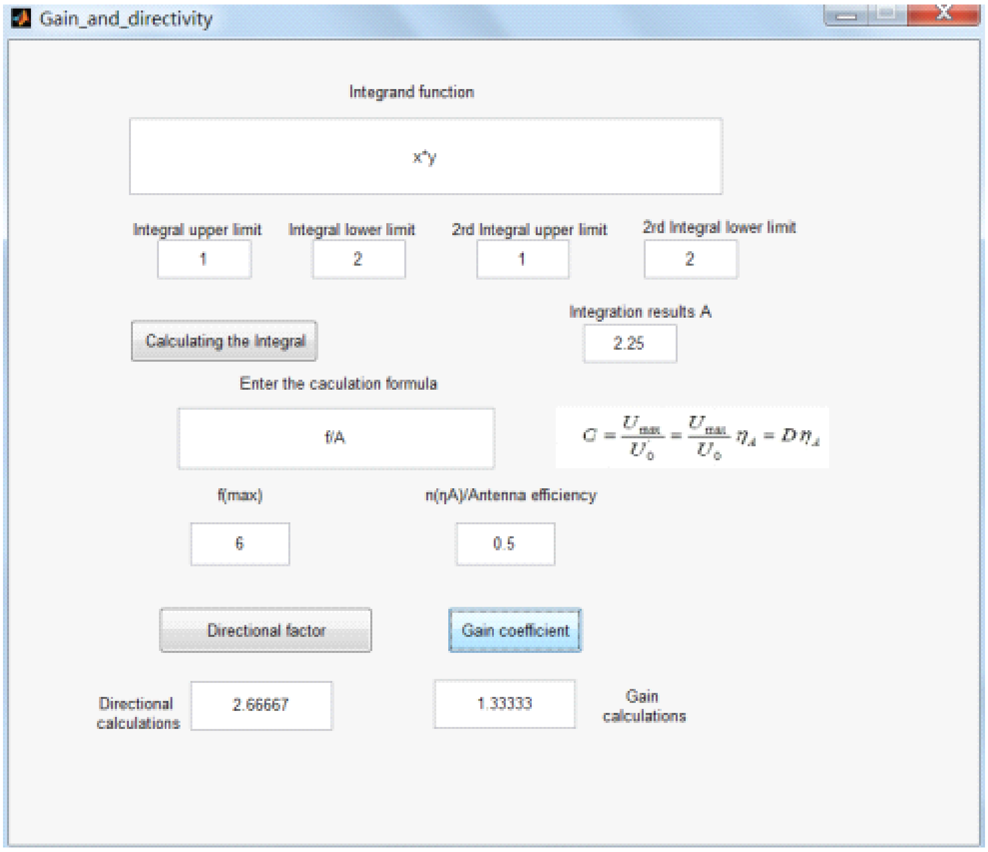
$$Z_{11}=R_{11}+jX_{11}$$

73.1+j42.5

Figure 20 Calculate the mutual impedance interface

For the mutual radiation impedance calculation refer to the previous theory, the ‘k1’ and ‘k2’ are integral upper limit for both resistance and reactance. ‘l1’ and ‘l2’ are 0.25λ since its an arranged coaxially coupled half-wave dipole system. ‘d1’ and ‘d2’ are length between two dipole but in this case its equal to zero since here is a mutal system. Click on the main interface mutual radiation impedance button get into the mutual radiation impedance calculation interface, According to the formula which given the value ‘l1’=0.25, ‘l2’=0.25, ‘d1’=0, ‘d2’=0, ‘a’=1, the integral upper limit is 0.25 and the lower limit is 0.Click to calculate the mutual radiation impedance calculation results are show as below: Similarly can enter to calculate the imaginary part of the formula to get the result is 42.5. The result is basically right by calculating the verification results.

4.4 The directional coefficient and the validation of the gain coefficient



Integrand function: x*y

Integral upper limit: 1

Integral lower limit: 2

2rd Integral upper limit: 1

2rd Integral lower limit: 2

Integration results A: 2.25

Enter the caculation formula: f/A

$$G = \frac{U_{\max}}{U_0'} = \frac{U_{\max}}{U_0}\eta_A = D\eta_A$$

f(max): 6

n(ηA)/Antenna efficiency: 0.5

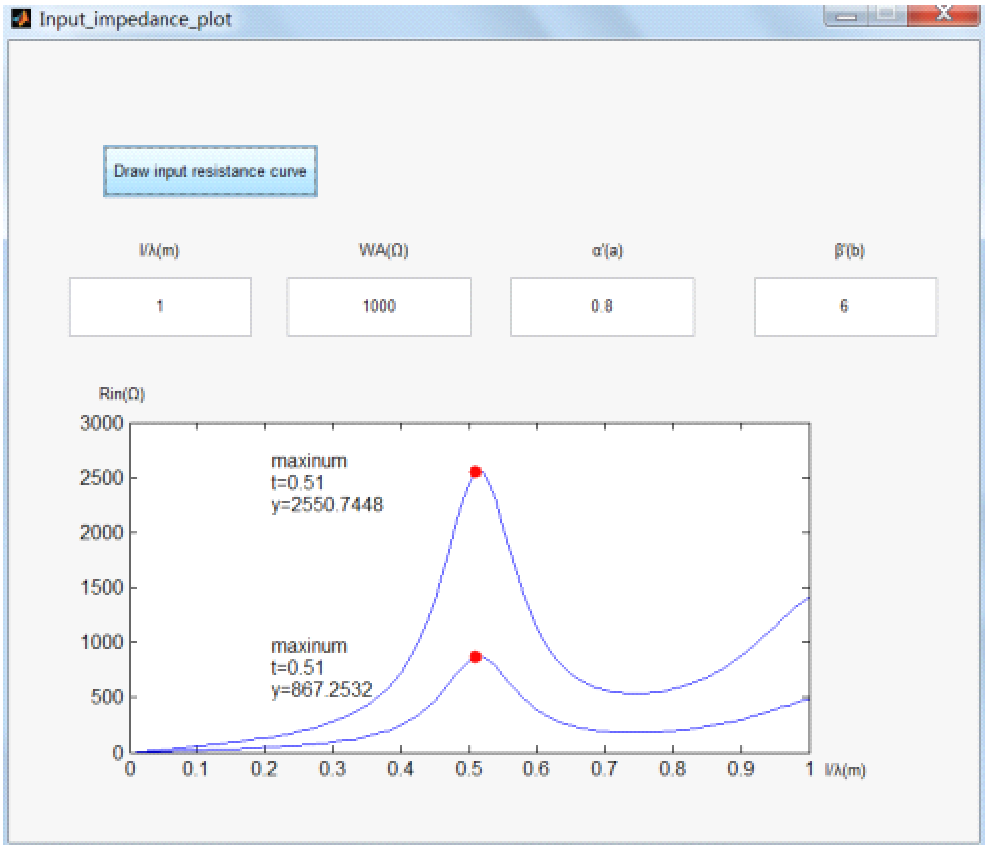
Directional calculations: 2.66667

Gain calculations: 1.33333

Figure 21 The calculated directivity coefficient and gain coefficient interface

In antenna Directivity coefficient and Gain coefficient calculation, the ‘n’ (Antenna efficiency) and the electronic force ‘f’ are needed. Due to the radiation intensity of the directional antenna in the respective directions, therefore the directivity of the antenna coefficient is different. But from the direction of maximum radiation electric field, the directional coefficient will be the maximum. As in this case parameter ‘f’ should be max. Click on the main interface directivity coefficient and gain coefficient button, Entering the directional coefficient and gain coefficients interface. For example, the integral function of x * y, click the calculated integrate button to get the integrate result A 2.25.At the same time enter the formula f/A, set the ‘f=8’, Directional coefficient can be calculated for 2.6667, set ‘n=0.5’, Computable gain coefficient for 1.3333.The result is shown in Figure 21.

4.5 Input resistance curve Plot



l/λ(m) 1

WA(Ω) 1000

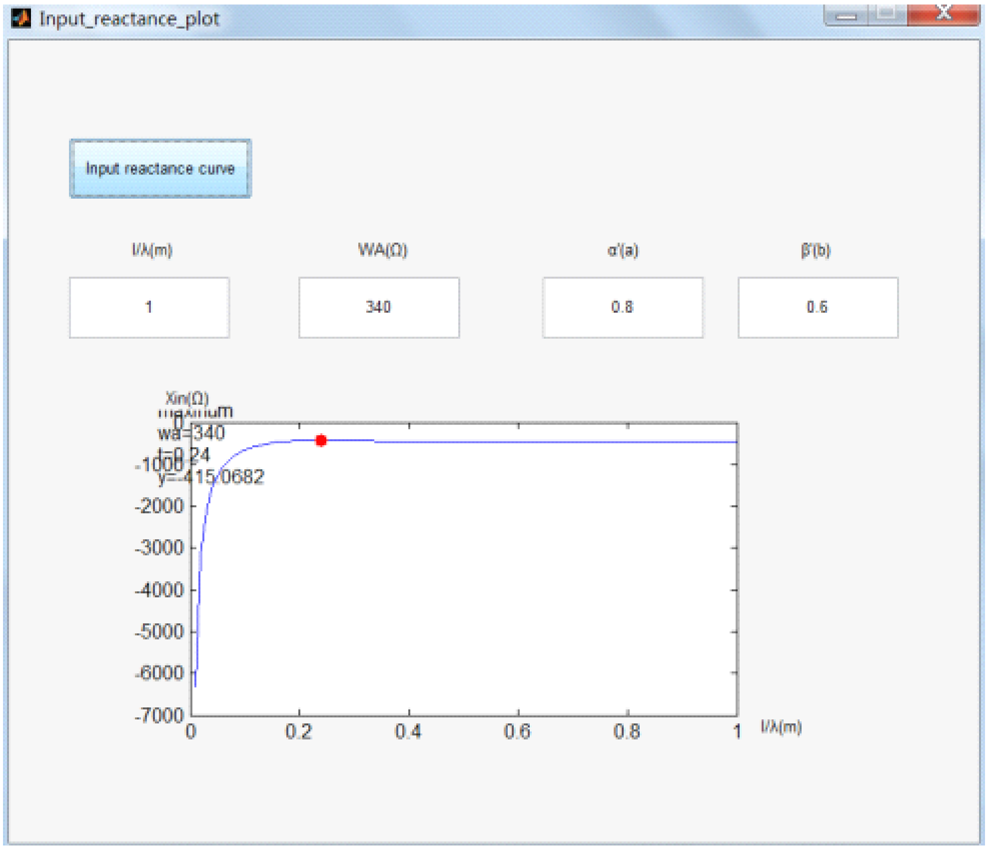
α'(a) 0.8

β'(b) 6

Figure 22 Input impedance plot interface

Here is the input impedance curve drawn by the parameter ‘l’ which is the length between dipole antennas divided by wavelength and the parameter input resistance Click on the main interface input resistance Curve button, Entering the values ‘l/λ=1’, ‘a=0.8’, ‘b=6’,make the input ‘WA = 233Ω’ and ‘WA = 1000Ω’ respectively. From the curve that can be obtained the relationship of the input resistor versus the length of ‘l / λ’. As can be seen from the graph with the increasing of length(l / λ) ,the input resistance will be increase slowly till 0.5(l/λ).After that the input resistance decrease and then increase a bit. At the same time maximum point and the other coordinate can also be found on the curve in Figure 22.

4.6 Input reactance Curve Plot



l/λ(m): 1
WA(Ω): 340
α'(a): 0.8
β'(b): 0.6

Figure 23 Input reactance plot interface

Here is the input reactance curve plot by the parameter 'l' which is the length between dipole antennas divided by wavelength and the parameter input reactance. Click on the main interface input reactance Curve button to get into the input curve drawing interface. Entering 'l/λ=1', 'a=0.8', 'b=6,' 'WA=340'.From the input reactance curve can be obtained with the relationship of the length(l / λ).As can be seen from this graph with the increasing by the length(l/λ) the input reactance won't change after a certain point. This is good because it can get rid of the reactance part to reduce interference. Also the maximum value can be found on the curve shown as Figure 23.

5. Discussion

This design is the first time we preparation software interface by using Matlab GUI. In this project students investigate the antenna characteristics and meet the design requirements which is corresponding with the antenna theory by using the design of Matalb GUI interface. At the beginning students supposed to implement this design by using VC++, but students found that there is too hard to insert the formula which obtained in the calculation part to compile. And another problem is difficult to carrying out the syntax check with matching brackets, expression evaluates. This is the main reason that students choose Matlab GUI interface to achieve the goal at last. In the matlab GUI designing it is successful realization of the calculation of the coefficients of antenna. In mutual impedance interface it works with entering the formula to calculate the value by only press the pushbutton .And in the input reactance/resistance part it would be easy to achieve the function by using the pushbutton. As for the input impedance plot/input reactance plot students set the function to plot the figure with corresponding to the theory.

6. Conclusion

The purpose of this paper is design an initial platform which can be used for education. Students would have learned more knowledge about the antenna system and how to calculate the parameters of antenna coefficient by using the interface function of Matlab. Matlab GUI can simplify the complex calculation process by given the values of needed parameters and formulas. Every interface are corresponding to its Callback function .In this paper we give a depth discussion and description of diploe antenna's input impedance and the antenna coefficient, such as input impedance, input reactance and mutual impedance of antennas. For this project it is just a initial design for the interface and we believe students can improve this in different conditions and to get the results better in the future.

7. Reference:

[1] Jin Lihong, 17-18 July 2011, *Application of MATLAB Software for Linear Algebra, pp: 1-3*

[2] Owczarek, M.S._, Inst. of Electron., Lodz Tech. Univ., Poland Langer, M. ; Wozny, J._; Nowak, J. 28-28 Feb. 2004,*Design of graphical user interface (GUI) for analog EDA tool, PP:* 560 – 562

[3] S. Lee, Y. Li, V. Kapila, 2004. *"Development of a Matlab-Based Graphical User Interface Environment for PICMicrocontroller Projects*", The 2004 American Society for Engineering Education Annual Conference & Exposition.

[4] N. Aliane, July 2009. "Matlab/Simulink-Based Interactive Module for Servo Systems Learning", IEEE Transactions onEducation, Volume: 53, Issue: 2, pp. 265 – 271.

[5] Bachiller, C. Departamento de Comunicaciones, Univ. Politecnica de Valencia Esteban, H. ; Cogollos, S. ; San Blas, A. ; Boria, V.E. , 2002, *Teaching of wave propagation phenomena using Matlab GUIs at the Universidad Politecnica of Valencia*, PP: 696 – 699, vol.1

[6] Kevanishvili, G.S. Georgian Tech. Univ., Tbilisi, Georgia Kotetishvili, K.V. ; Vashadze, G.K. ; Bolkvadze, D.R. 2002 A theory of symmetric dipole formed of thin rectangular metallic plates,PP**:** 21 - 24

[7] Lepeltier, Ph. Floc'h, J.M. ; Citerne, J. ; Piton, G. , Sept. 1986, *Self Impedance and Radiation Patterns of the Electromagnetically Coupled Microstrip Dipole,* PP: 649 – 654

[8] Trainotti, V. Fac. of Eng., Univ. of Buenos Aires, Buenos Aires, Argentina Figueroa, G. Sept. 2010, *Vertically Polarized Dipoles and Monopoles, Directivity, Effective Height and Antenna Factor,* VOL: 56, PP: 379 - 409

[9] E. A. Laport, (1952), *Radio Antenna Engineering.* NewYork: McGraw-Hill,C. A. Balanis, "Antenna Theory: A Review," Proc. IEEE, Vol. 80, No. 1, pp. 7–23

[10] Mingyang Li, Liu Min, Yang Fang, Aug.2011, *Antenna design,* Pubishing House of electronics Industry, BEIJING, PP: 1-8

[11] Ahmed A. Klshk, 2005, A.Balanis, *Antenna theory, analysis and design*, Third edition, John Wiley & Sons INC., Publication, PP: 1-65

8. Appendix

Code part:

```
functionvarargout = untitled4(varargin)

gui_Singleton = 1;

gui_State = struct('gui_Name',

'gui_Singleton',

'gui_OpeningFcn',

'gui_OutputFcn',

'gui_LayoutFcn',

'gui_Callback',

ifnargin&&ischar(varargin{1})

gui_State.gui_Callback = str2func(varargin{1});

end


ifnargout

        [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});

else

gui_mainfcn(gui_State, varargin{:});

end
```

8.1 Main dialogue code

```
symsz;

a= str2double(get(handles.edit1, 'String'));

b=str2double(get(handles.edit2, 'String'));

l=str2double(get(handles.edit3, 'String'));

WA=str2double(get(handles.edit4, 'String'));

e=get(handles.edit6,'string');
```

```
z1=e;
m=eval(z1);
set(handles.edit7,'string',m)

symsz;
a= str2double(get(handles.edit1, 'String'));
b=str2double(get(handles.edit2, 'String'));
l=str2double(get(handles.edit3, 'String'));
WA=str2double(get(handles.edit4, 'String'));
e=get(handles.edit5,'string');
z1=e;
m=eval(z1);
set(handles.edit7,'string',m)
```

8.2 Mutual radiation impedance

```
symsz;
l1= str2double(get(handles.edit1, 'String'));
l2=str2double(get(handles.edit2, 'String'));
d1=str2double(get(handles.edit3, 'String'));
d2=str2double(get(handles.edit4, 'String'));
a= str2double(get(handles.edit5, 'String'));
k1=str2double(get(handles.edit6, 'String'));
k2=str2double(get(handles.edit7, 'String'));
e=get(handles.edit8,'string');
z1=int(e,z,k1,k2);
m=eval(z1);
set(handles.edit9,'string',m);
```

8.3 The calculated directivity coefficient and gain coefficient

```
symsxy
a= str2double(get(handles.edit2, 'String'));
b=str2double(get(handles.edit3, 'String'));
c=str2double(get(handles.edit4, 'String'));
d=str2double(get(handles.edit5, 'String'));
e=get(handles.edit1,'string');
z=int(int(e,y,c,d),a,b);
m=eval(z);
set(handles.edit6,'string',m);
```

Add the following code in calculating the directional coefficient Callback function：

```
A=str2double(get(handles.edit6, 'String'));
f=str2double(get(handles.edit7, 'String'));
e=get(handles.edit10,'string');
k=e;
m=eval(k);
set(handles.edit9,'string',m)
```

```
n=str2double(get(handles.edit8, 'String'));
w=str2double(get(handles.edit9, 'String'));
s=n*w;
set(handles.edit11,'string',s);
```

8.4 input resistance curve

```
l= str2double(get(handles.edit1, 'String'));

WA=str2double(get(handles.edit2, 'String'));

a=str2double(get(handles.edit3, 'String'));

b=str2double(get(handles.edit4, 'String'));

t=0:0.01:l;

y=WA*(sinh(2*a*t)-(a/b)*sin(2*b*t))./(cosh(2*a*t)-cos(2*b*t));

[y_max,i_max]=max(y);

t_text=['t=',num2str(t(i_max))];

y_text=['y=',num2str(y_max)];

max_text=char('maxinum',t_text,y_text);

plot(t,y)

holdon

plot(t,zeros(size(t)),'k')

plot(t(i_max),y_max,'r.','MarkerSize',20);

text(t(i_max)-0.3,y_max-0.05,max_text);
```

8.5 Draw input reactance curve

```
l= str2double(get(handles.edit1, 'String'));

WA=str2double(get(handles.edit2, 'String'));

a=str2double(get(handles.edit3, 'String'));

b=str2double(get(handles.edit4, 'String'));

t=0:0.01:l;

y=-WA*((a/b)*sinh(4*pi*t)+sin(4*pi*t))./(cosh(4*pi*t)-cos(4*pi*t));

[y_max,i_max]=max(y);

t_text=['t=',num2str(t(i_max))];

y_text=['y=',num2str(y_max)];
```

```
max_text=char('maxinum',t_text,y_text,wa_text);

plot(t,y)

holdon

plot(t,zeros(size(t)),'k')

plot(t(i_max),y_max,'r.','MarkerSize',20);

text(t(i_max)-0.3,y_max-0.05,max_text);
```