A Method for Calculating the Resonant Frequency of Meander Line Dipole Antenna by Using Antenna's Geometrical Parameters

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Abstract— **This paper presents the method for calculating the resonant frequency of Meander Line Dipole Antenna (MLDA) in the UHF frequency range. Two types of meander line antennas have been designed for passive RFID tag antennas. The design, analysis and characterization of the two proposed antennas are performed using simulation software FEKO. Two methods have been proposed to calculate the resonant frequency of a meander line dipole antenna by calculating its inductance. One method proposed by T. Endo and another method has been proposed in this paper and the proposed method contributes 90% as closely as desired. For example in MLDA-2 antenna the resonant frequency are 1.16 GHz and 1.01 GHz calculated by T. Endo and proposed method respectively when the no. of meander is 8. According to this method the resonant frequency and other antenna characteristics mainly depend upon the number of meander line, horizontal and vertical length, the separation of the twist arms, wire radius, total physical length and wire length of the antenna structure. The capacitance and inductance are introduced after squeezing the dipole antenna. The capacitance and inductance of the antenna are also a function of the antenna's shape and dimension. The resonant characteristics have been found by calculating their inductances and compared to the result from simulation software FEKO. The result showed a good agreement with the simulation.**

Keywords—Meander line dipole antenna; RFID; resonant frequency; dipole antenna; inductance ;capacitance.

I. Introduction

Radio Frequency Identification (RFID) is a technology that uses electronic tags placed on objects, people or animals to relay identifying information to an electronic reader by means of radio waves. An RFID system usually consists of two components: tags and readers. A reader interrogates a tag by sending an electromagnetic (EM) signal, and then the tag sends back its unique identification information or additional data such as product information. RFID systems use frequencies varying from around 100 kHz to over 5 GHz. The simple and passive nature of UHF RFID tag communication makes it a low cost without the need for maintenance and complicated structures [1]. Meander antennas is a new class of wire structure made from meander section and is the most usage of antenna that use in the design of WLAN and RFID system. Some papers introduced the antenna efficiency and gain [2]-[5]. Recently Koch fractal dipole antenna is engaged to be tag antenna, but radiation efficiency is low and the structure is complex [6]. In result meander line dipole antennas are chosen to be the tag antennas due to their simple and reduced structure and high radiation efficiency. Some papers focused on only the resonant frequency and gain of MLDA with the variation of antenna parameter [7]-[9]. They have not mentioned the overall capacitance effect and the effect of the radius on the resonant frequency of the meander line dipole antenna. Some papers introduced the meandering effect on dipole antenna characteristics by using frequency independent lumped element [10]-[12]. In this thesis paper the resonant frequency has been calculated by inductive circuit model method. Besides the resonant frequency, the effects of the capacitance and inductance on resonant frequency after bending the dipole antenna have been investigated in this paper.

II. Meander Line Dipole Antenna Model and Analysis

The Resonant frequency of the Meander Line Dipole Antenna (MLDA) can be derived in a method proposed by T. Endo [11]. In this method a center feed meander dipole antenna was decomposed into short ended transmission- line section. Every section was modeled with lumped element analysis with transmission-line equations. The resonant frequency of the MLDA has been calculated by the equation of the total inductance of the antenna wire. In this Paper another method proposed to calculate the resonant frequency by calculating its inductance. The aim of this paper was to design two types of meander line dipole antenna that are defined by MLDA-1 and MLDA-2 to investigate the change of resonant frequency after bending the dipole antenna. In MLDA-1 the physical length, H of the antenna remains fixed, whereas the total length of the wire, L is increased as the folds are increased as shown in Fig. 1.

For MLDA-2 the total length of the wire, L is kept constant, whereas the physical length, H is acceptably to be changed as shown in Fig. 2. Besides the inductance and capacitance, the resonant frequencies were calculated for both of the antennas.

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Both MLDA-1 and MLDA-2 antennas, all the horizontal segments are of equal length l and all vertical segments are of equal length w. Total length L of the wire can be represented in terms of number of meander sections M i.e. $L = (6l+4w)$ when M = 2. Dimension of MLDA-1is shown in Table I and MLDA-2 is shown in Table II.

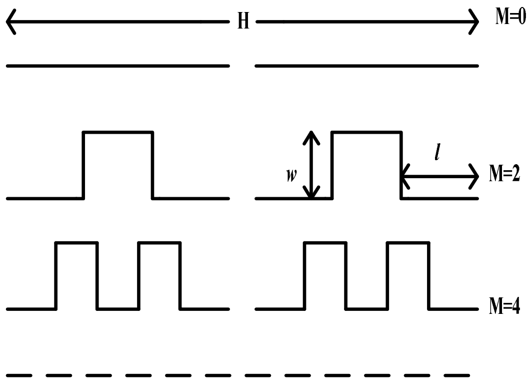

Fig. 1. Dipole antenna compared to MLDA-1 by increasing M where the physical length H is kept constant.

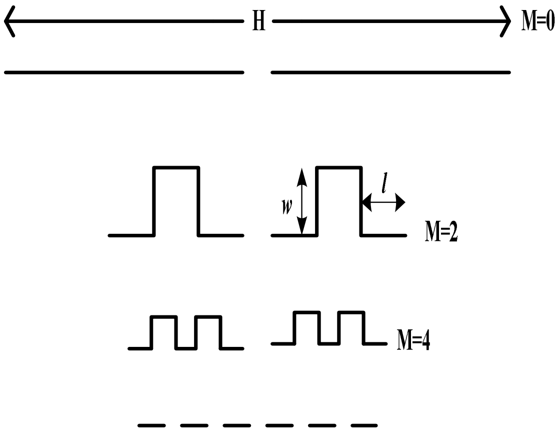

Fig. 2. Dipole antenna compared to MLDA-2 with increasing M where the total length of the wire L is kept constant.

It is an assumed that the wire conductor was used for making the MLDA, whose radius is r.

A. *Method Proposed by T. Endo*

The derivation of MLDA's resonant frequency processed as follows by T. Endo [13]

The characteristic impedance of the short- terminated line can be expressed in the following equation:

$$Z_0 = \frac{\eta}{\pi} \log \frac{l}{r} \tag{1}$$

TABLE I. ANTENNA DIMENSION WITH CONSTANT PHYSICAL LENGTH

Meanders (M)	Total wire length L(mm)	Total physical length H(mm)	l(mm)	w (mm)
0	129	129	129	0
2	153	129	21.5	6
4	177	129	12.9	6
6	201	129	9.22	6
8	225	129	7.16	6

TABLE II. ANTENNA DIMENSION WITH CONSTANT WIRE LENGTH

Meanders (M)	Total wire length L(mm)	Total Physical length H(mm)	l(mm)	w (mm)
0	129	129	129	0
2	129	78	13	12.75
4	129	75	7.5	6.75
6	129	72	5.14	4.75
8	129	65	3.61	4

Where, η is the intrinsic impedance and l is the distance between two lines. The input impedance Z_{in} is given by the following equation:

$$Z_{in} = Z_0 \frac{Z_L + jZ_0 \tan \beta w}{Z_0 + jZ_L \tan \beta w} \tag{2}$$

Let us consider that all meander lines are terminated in a short circuit. Then (2) becomes:

$$Z_{in} = jZ_0 \tan \beta w \tag{3}$$

Where, β is called wave number and its value is equal to $2\pi/\lambda$ and w is the vertical segment height of the meander line. According to the T. Endo the height w of the meander line is sufficiently small compared to the wavelength. Therefore, the $\tan \beta w$ can be expanded into three orders on condition that $\beta w << 1$.

$$\tan \beta w = \beta w + \frac{1}{3}(\beta w)^3 \tag{4}$$

The expression of input impedance can be obtained

$$Z_{in} = j\omega L = jZ_0\{\beta w + \frac{1}{3}(\beta w)^3\} \tag{5}$$

Substituting the value of (1) into (5), inductance formed by each meander line can be shown to be:

$$L_M = \frac{\mu_0 w}{\pi} \log \frac{l}{r} \{1 + \frac{1}{3}(\beta w)^2\} \tag{6}$$

If the number of meander section is M, then the total inductance obtained from the meander line is $L = M \times L_M$.

The self-inductance of a cylindrical conductor of physical length H is given by:

$$L_S = \frac{\mu_0}{2\pi} H (\log \frac{2H}{r} - 1) \tag{7}$$

Where μ_0 is free space permeability. The total inductance of the MLDA is obtained by using (6) and (7)

$$L_T = L_s + M \times L_M \tag{8}$$

For a linear dipole antenna that resonates at the frequency *f,* the self-inductance of the conductor is given by the following equation where λ is the wavelength.

$$L_D = \frac{\mu_0}{\pi}\frac{\lambda}{4}((\log\frac{\lambda}{r}-1) = \frac{\mu_0}{\pi}\frac{c}{4f}(\log\frac{c}{f*r}-1) \tag{9}$$

Where, c is the speed of a light in free space. It is assumed that the MLDA resonate at the same frequency which the half wave dipole does. As a result the inductive reactance of the MLDA will be the same as the dipole antenna inductive reactance. The resonant frequency can be found by calculating the inductive reactance of the MLDA. Hence, $L_T = L_D$.

$$\frac{\mu_0}{2\pi}H(\log\frac{2H}{r}-1) + M\frac{\mu_0 w}{\pi}\log\frac{l}{r}\{1+\frac{1}{3}(\beta w)^2\} = \frac{\mu_0}{\pi}\frac{c}{4f}(\log\frac{c}{f*r}-1) \tag{10}$$

B. Proposed Method

The derivation of MLDA's resonant frequency processed as follows by another method.

The self-inductance of the straight wire can be expressed in the following form,

$$L_S = \frac{\mu_0 H}{2\pi}(\log\frac{2H}{r}-1) \tag{11}$$

Where, H is the total physical length of the cylindrical wire and r is the radius and μ is the permeability of the free space. The mutual inductance m of two parallel wires of length w, radius r and distance apart l is given by

$$m = \frac{\mu_0 w}{2\pi}(\log\frac{2w}{l}-1) \tag{12}$$

Since the meander antenna has a return circuit of two parallel wires each of length w (the current flowing in opposite direction in the two wires), the self-inductance of the circuit will be,

$$L_M = 2L_1 - 2m \tag{13}$$

Where, L_1 is the self-inductance of either wire taken by itself and m is their mutual inductance. Finally (13) can be written as follows

$$L_M = 2*\frac{\mu_0 w}{2\pi}(\log\frac{2w}{r}-1) - 2*\frac{\mu_0 w}{2\pi}(\log\frac{2w}{l}-1)$$
$$L_M = \frac{\mu_0}{\pi}w\log\frac{l}{r} \tag{14}$$

The total inductance of the MLDA is obtained by using (11) and (14)

$$L_T = L_S + M * L_M \tag{15}$$

For a linear dipole antenna that resonates at the frequency *f,* the self-inductance of the conductor is given by the following equation where λ is the wavelength.

$$L_D = \frac{\mu_0}{\pi}\frac{\lambda}{4}((\log\frac{\lambda}{r}-1) = \frac{\mu_0}{\pi}\frac{c}{4f}(\log\frac{c}{f*r}-1) \tag{16}$$

The resonant frequency can be found by calculating the inductive reactance of the MLDA. Hence, $L_T = L_D$

$$\frac{\mu_0 H}{2\pi}\log(\frac{2H}{r}-1) + M*\frac{\mu_0}{\pi}w\log\frac{l}{r} = \frac{\mu_0}{\pi}\frac{c}{4f}(\log\frac{c}{f*r}-1) \tag{17}$$

It is considered that the capacitive reactance of the MLDA remains the same as that of the linear half wave dipole antenna. The wire radius has an effect on the resonant frequency. Let us consider that the inductance per unit length L_1 and the capacitance per unit length C_1 between the conductors of two parallel wires are defined as the function of the wire radius r by the following equation [14]:

$$L_1 = \frac{\mu_0}{\pi}\cosh^{-1}(\frac{l}{2r}) \tag{18}$$

$$C_1 = \frac{\pi\varepsilon}{\cosh^{-1}(\frac{l}{2r})} \tag{19}$$

Where*,* l is the distance between the two wires. Finally, the resonant frequency depends on the number of meander line, horizontal and vertical length, the separation of the twist arms, wire radius and the physical and total wire length of the antenna structure. The overall capacitance, C of the antenna can be determined by calculating their inductance with the help of (8) and (15) at different resonant frequency and the equation can be expressed as

$$C = \frac{1}{(4\pi f)^2 L} \tag{20}$$

III. Comparison with Simulation Results and Discussion

In this paper the simulation software FEKO was used to calculate the resonant frequency compared with the two inductive methods. The simulation of the antenna system was carried out via MOM method. To solve (10) and (17) iteration method was used. The meander line dipole antenna with different number of meander sections (M = 2, 4, 6, 8) were designed by FEKO as shown in Fig. 1 and Fig. 2 where, the gap between dipole arm is 2 mm and the radius of the wire is 0.3 mm. First an antenna was designed where the physical length of the antenna remains fixed, whereas the total wire length is permitted to increase as the bends are added (see TABLE I). The reflection co-efficient of MLDA-1 using by FEKO as shown in Fig. 3, where the numbers of meanders section M is increasing from 0 to 8. The simulation results are compared to the result of two proposed methods. It is determined that a regular decrease in the resonant frequency of the antenna with increasing meander section M (see Fig. 4).

It is seen that a change of length, L causes a change of the total inductance. Because of this change of inductance, the overall capacitance changes by increasing the numbers of bends as seen in TABLE III. Another antenna was designed where, the total length of the wire, L is kept constant, whereas the physical length H is acceptable to be changed.

The reflection co-efficient of MLDA-2 with the increase in meander section M as shown in Fig. 5. The total length of the wire was kept constant while the physical length was varied, not only the inductance changed, but the overall capacitance also changed with the increase in the number of meander sections M (see TABLE IV).

The simulation results are compared to the result of two proposed methods. It was observed that a regular increase in the resonant frequency of the antenna with increasing M as shown in Fig. 6. The resonant frequency increased due to the change of mutual inductance after twisting the dipole antenna.

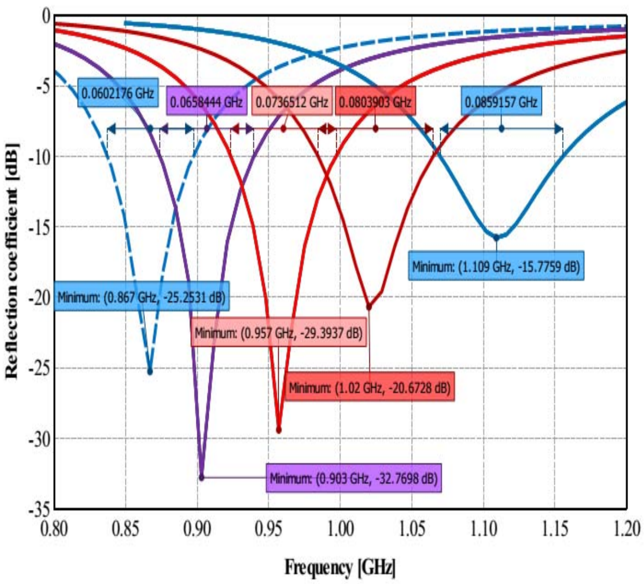

Fig. 3. Reflection co-efficient of MLDA-1 by using FEKO with the increase in M where the physical length H is kept constant.

The resonant frequency of both MLDA-1 and MLDA-2 antennas are plotted in Fig. 8 and Fig. 10 as a function of the wire radius r. Wire radius r is varied from 0.1 mm to 0.3 mm.

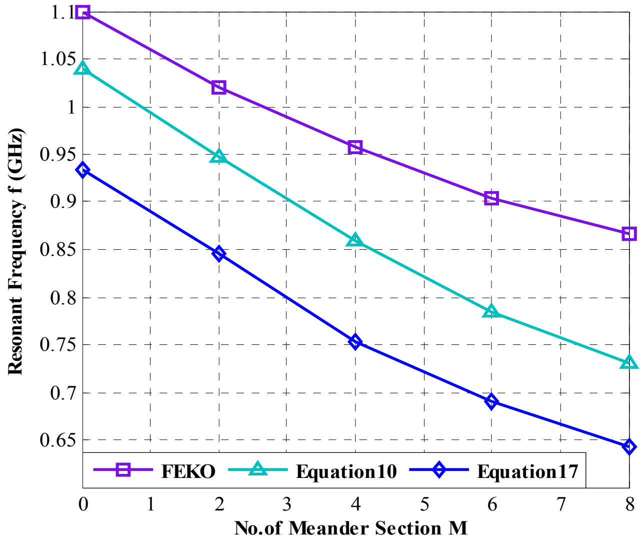

Fig. 4. Resonant frequency versus no. of meander line M for the straight line dipole antenna (M = 0) and the MLDA-1 (M = 2 to 8) when the total physical length of the antenna H remains constant.

In Fig. 7 and Fig. 9 Showed the simulation result where the radius was varied from 0.1 mm to 0.3 mm for both MLDA-1 and MLDA-2 antennas. The analytical result compared to the simulation result as shown in Fig. 8 and Fig. 10. The results made a good agreement with the simulation.

Since the wire radius was varied it has the effect on the resonant frequency of both antennas. This increase of radius will increase the resonant frequency (see Fig. 8 and Fig. 10).

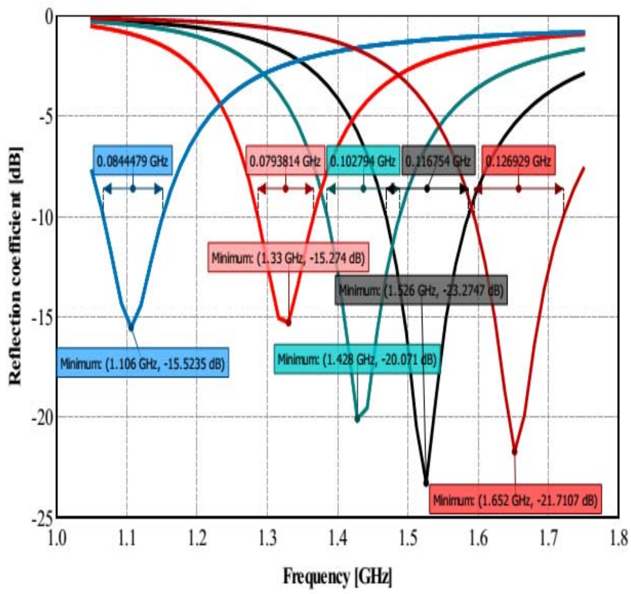

Fig. 5. Reflection co-efficient of MLDA-2 by using FEKO with the increase in M where the length of the wire L is kept constant.

It can be explained from (18) and (19) the inductance and capacitance are not a constant value, but depend upon the radius of the wire. As radius *r* will increase, the inductance decreases and therefore the capacitance between the two parallel lines will increase.

Basically, the inductance and capacitance have the very contrasting effects upon the resonant frequency, the capacitance modification dominates and for that reason the resonant frequency will increase. In Fig. 8 and Fig. 10, it is evident that the change in resonant frequency is larger for MLDA-2 compared to MLDA-1.

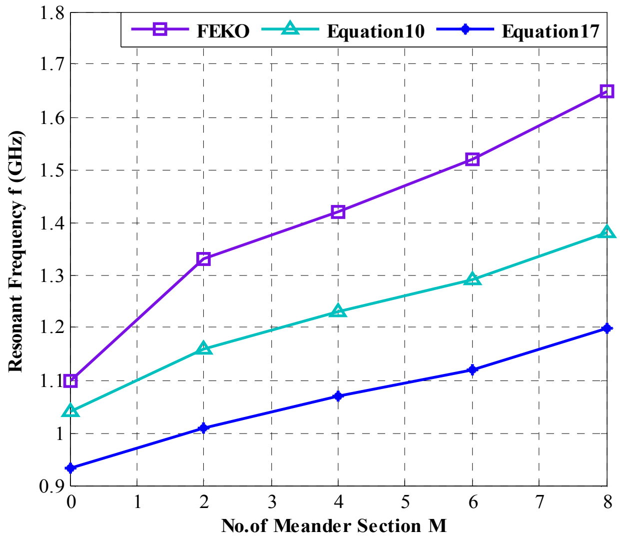

Fig. 6. Resonant frequency versus no. of meander line M for the straight line dipole antenna (M = 0) and the MLDA (M = 2 to 8) when the total length of the wire *L* remains constant.

TABLE III. INDUCTANCE AND CAPACITANCE AS A FUNCTION OF NUMBER OF MEANDERS M

Meanders M	Total wire length L(mm)	Total Physical H(mm)	Inductance L(µH)	Capacitance C(pF)
2	153	129	0.215	0.164
4	177	129	0.246	0.181
6	201	129	0.272	0.195
8	225	129	0.296	0.206

TABLE IV. INDUCTANCE AND CAPACITANCE AS A FUNCTION OF NUMBER OF MEANDERS M

Meanders M	Total wire length L(mm)	Total Physical H(mm)	Inductance L(µH)	Capacitance C(pF)
2	129	129	0.174	0.142
4	129	78	0.162	0.136
6	129	75	0.153	0.131
8	129	72	0.142	0.123

Therefore, it is observed that no mathematical expression can be developed for this effect in MLDA antennas.

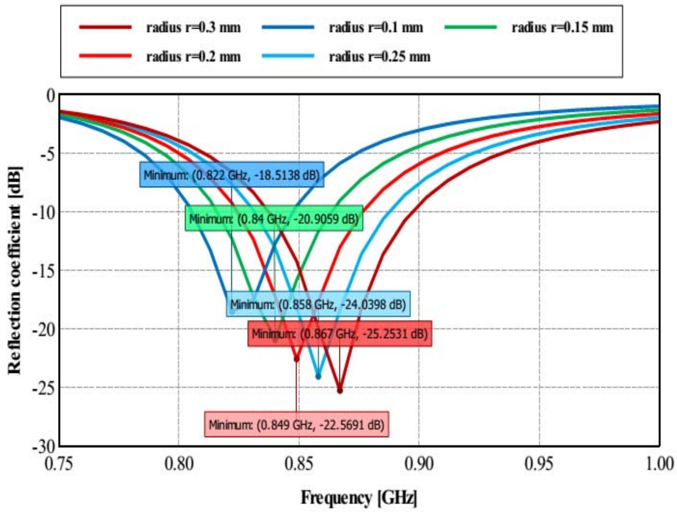

Fig. 7. Simulation result of resonant frequency (wire radius were varied from 0.1 mm to 0.3 mm) for MLDA-1 antenna when M = 8.

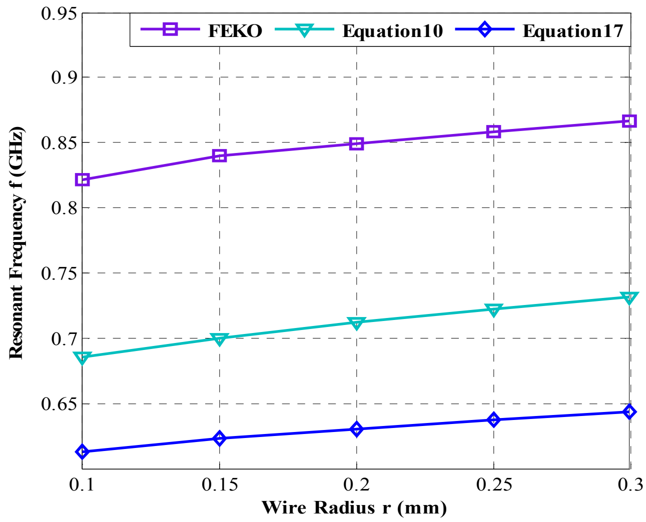

Fig. 8. Resonant frequency versus radius of wire for MLDA-1 when M=8.

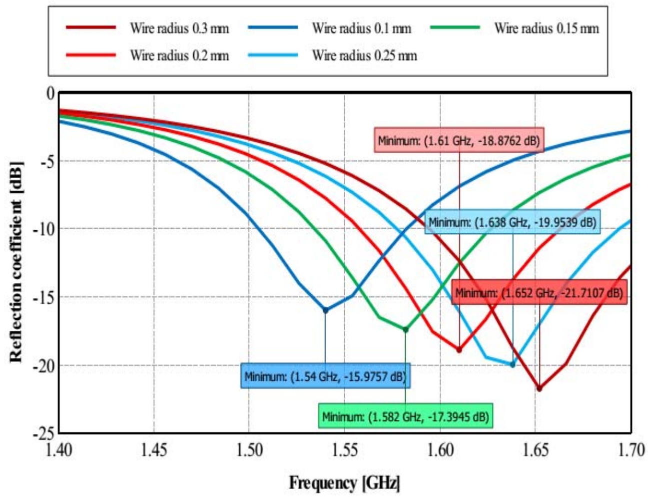

Fig. 9. Simulation result of resonant frequency (wire radius were varied from 0.1 mm to 0.3 mm) for MLDA-2 when M = 8.

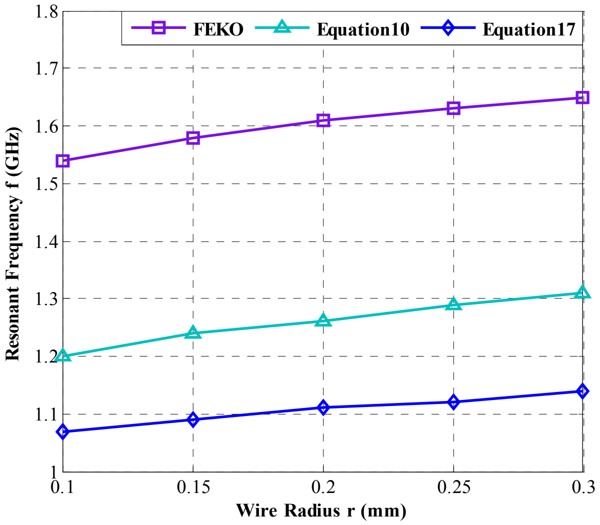

Fig. 10. Resonant frequency versus radius of wire for MLDA-2 when M = 8.

IV. Conclusion

Proposed two meander line antennas model configuration have been designed by FEKO software. Simulation results showed that by increasing meander line on to a half wave dipole the resonant frequency can be decreased when the physical length of the antenna remains constant and can be increased when the total wire length of the antenna remains constant. The resonant frequency has been found by two inductance methods are compared to the result from simulation software FEKO. The result showed a good agreement with the simulation. The overall capacitance and inductance effect has been discussed. The change in resonant frequency due to wire radius has been also discussed. It was demonstrated that the resonant frequency of both antennas increased as the radius increased. Therefore, the proposed two antennas have the ability to work as an RFID tag antenna in the frequency range of 860MHz to 960MHz.

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