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An Equivalent Circuit Model for Meander-line Monopole Antenna Attached to Metallic Plate

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1. Introduction

Equivalent circuit models are useful for antenna design because exact electromagnetic simulation generally needs complicated settings and heavy computation. Especially the equivalent circuit modelling with consideration of the antenna installation on devices is very helpful from practical point of view. Several antennas are modelled by equivalent circuit models with fitted parameters. A lumped circuit model is constructed for a dipole antenna by considering length and losses of the dipole as precise as possible and the circuit parameters are determined by using an optimization theory of genetic algorithm (GA) [1]. A lumped circuit model is also constructed for a rectangular and E-shaped microstrip antenna by minimizing an error function which consists of simulated and measured input impedances [2]. Circuit parameters of a lumped circuit and a transmission line are determined for a planar slot antenna by fitting the EM simulated results [3]. However, task of the fitting circuit parameters is very laborious. To overcome this disadvantage, antennas are also modelled by resulting circuit parameters from the geometry of antennas. For example, a lumped equivalent circuit model is applied to a microstrip meander-line antenna by which the frequency characteristics of the input reactance are estimated [4], and the resonant frequencies of a composite left and right Handed (CLRH) dipole antenna are precisely calculated by a lumped equivalent circuit model where inductances and capacitances are determined from the shape of the meander-line and inter-digital line of the radiation element [5]. However, these models have not taken the antenna installation on devices such as dielectric or metallic objects into consideration.

In this paper, a small planar meander-line monopole antenna whose radiation element is backed by a metallic plate is modelled by a simple lumped circuit. Parameters of the circuit elements are calculated from the geometry of the antenna element and a new approximation is proposed for the modelling. Simulated and measured resonant frequencies agree well with each other. This model will be very useful for the design of antennas installed into mobile devices covered by metallic cases.

2. Antenna Modelling

The geometry of a meander-line monopole antenna attached to a metallic plate is shown in Fig. 1 (a). The antenna is put on the metallic plate with a dielectric spacer. The meander-line element and ground plane are patterned on a very thin dielectric sheet. The lumped circuit element model of the antenna is shown in Fig. 1 (b). In this model, the meander-line is regarded as a parallel LC circuit and the top of the radiation element is modelled by a series capacitance caused by the end effect [6]. The metallic plate is regarded as a coupled line whose current is the image component of that on the radiation element. This model becomes available when the distance between the antenna and metallic plate is less than 0.5 mm. In calculating the inductance of the antenna, the self-inductance is doubled due to the addition of that for the image current and the mutual-inductance between the radiation element and metallic plate is applied. The self and mutual inductances of multiple elements are calculated by using the simple formulae for current filaments given in [7]

$$L = \frac{\mu_0}{2\pi}\left[l \ln\left(2l/(w+t)\right) + l/2 + 0.2235\ (w+t)\right] \quad (1)$$

$$M = \frac{\mu_0 l}{2\pi}\left[\ln(2l/d) - 1 + d/l\right] \quad (2)$$

where l denotes the length of the corresponding arm of the meander-line and w and t are the width and thickness of the conductor. In calculating the mutual inductance, a new approximation is proposed and applied. Figure 2 shows the image of the approximation. Mutual inductance is only calculated by considering the effect between the pivot arm or bridge and the parallel arm or bridge induced by pivot arm but others are neglected. The total inductance can be calculated by summing the self and mutual inductances for all the arms and bridges of the meander-lines.

The capacitance C_p in Fig. 1 is the sum of two types of the capacitances per unit length of C_u and C_g multiplied by the length of the arm or bridge of the antenna and the turn of meander-line. The capacitance C_u can be calculated the following formula for a parallel plate capacitor with a surface S and a distance d:

$$C_u = (\varepsilon_0 S)/d \quad (3)$$

The capacitance C_g models parallel arms with coupled line for the odd-mode excitation depicted in [5]. In addition, fringing effect on the capacitor is ignored due to the narrow distance between the arms and plate. An end-capacitance $C_{\rm end}$ is calculated by the formula given in [6]:

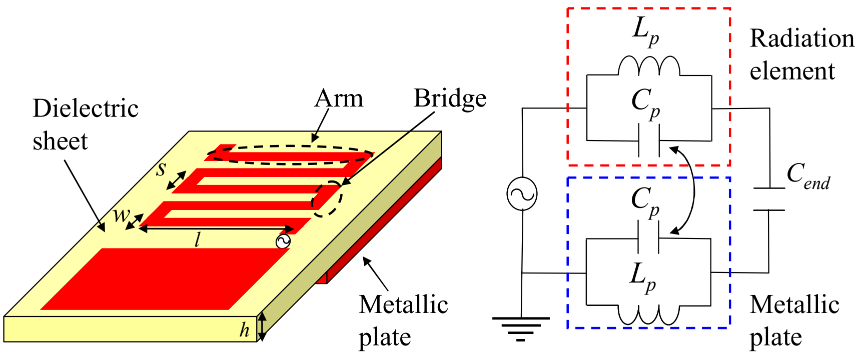
$$C_{end} = 8\varepsilon_0 \pi a \quad (4)$$

where a denotes the radius of the radiation element which is transformed from the rectangular cross section of the antenna by using a plot shown in [8].

Resonant frequency is then calculated by the simple formula:

$$f_{res} = 1/\left(2\pi\sqrt{L_t C_t}\right) \quad (5)$$

where L_t is the total inductance and C_t the total capacitance.



(a) Antenna geometry (b) Lumped element model

Figure 1: Antenna geometry and equivalent circuit model.

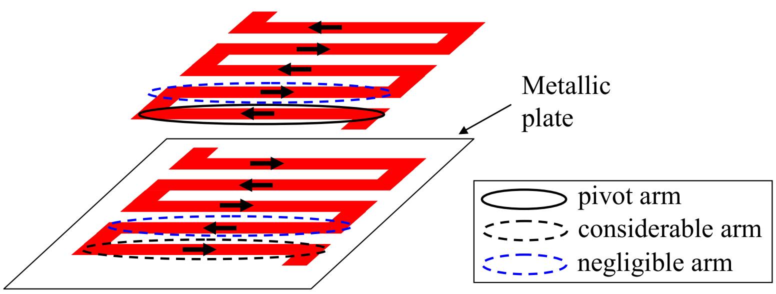


Figure 2: Image of proposed approximation for calculating mutual inductance of meander-line attached to metallic plate.

3. Numerical Results

To show the validity of the model, calculated and measured results for a fabricated antenna shown in Fig. 3 are compared with each other where the antenna configuration is as follows: N=5, l=5 mm, w=0.5 mm, s=0.5 mm, h=0.15 mm where N is the number of turn of meander-line. The antenna is made on a dielectric substrate with a thickness of 35 μm and dielectric constant of 3. Figure 4 compares the calculated and measured resonant frequencies by changing the arm length with N=5 and the number of turns with l=5 mm. In the measurement, the resonant frequency is chosen as the frequency at the zero input reactance. Reasonable agreement is obtained for certain ranges of the two parameters. Measured input characteristics and radiation patterns at 1.36 GHz are shown in Figs. 5 and 6, respectively. Good matching is observed at the calculated resonant frequency and omni-directional radiations are obtained at the resonance.

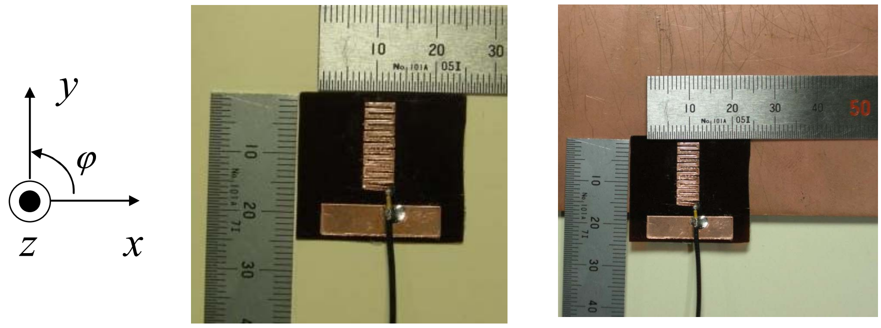


Figure 3: Fabricated antenna.

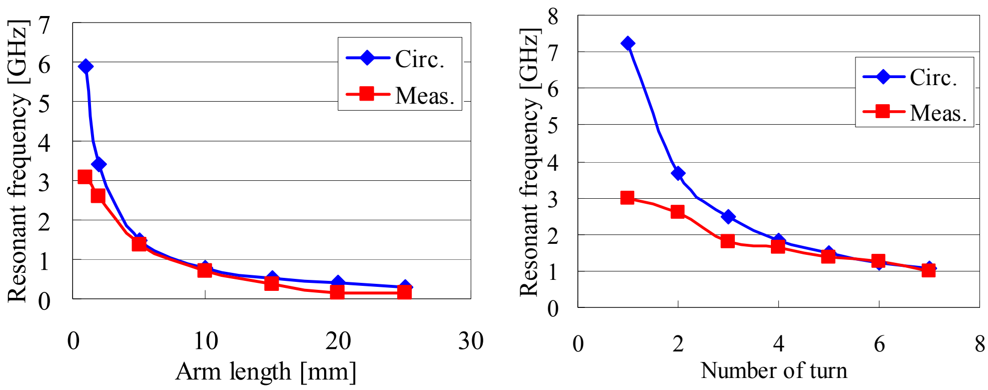


Figure 4: Calculated and measured resonant frequency for arm length and number of turn.

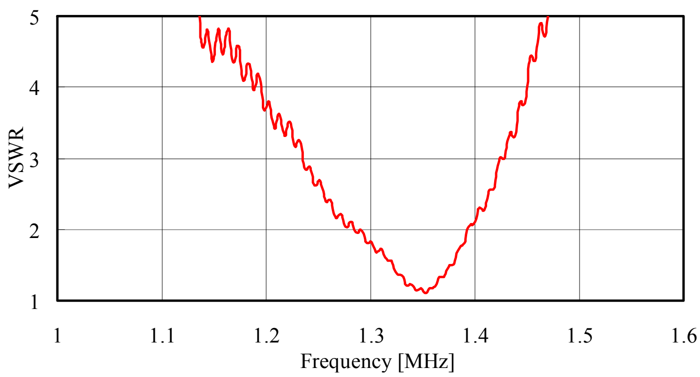


Figure 5: Measured input characteristics for fabricated antenna.

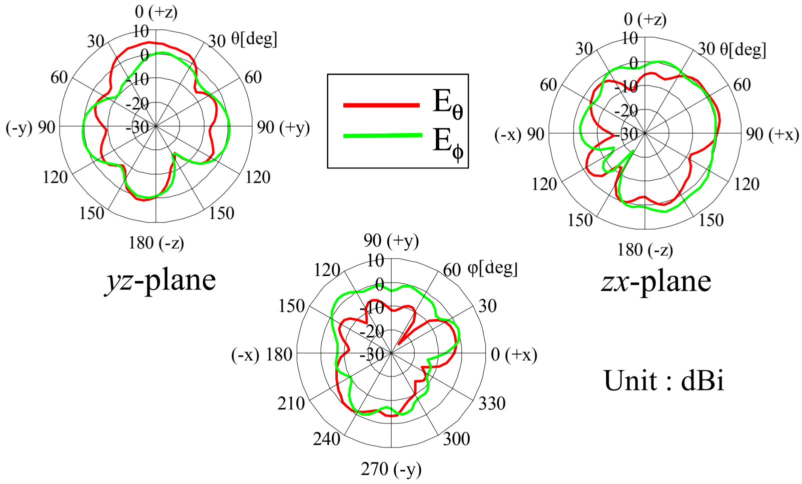


Figure 6: Measured radiation patterns at 1.36 GHz for fabricated antenna.

4. Conclusion

A lumped equivalent circuit model for a meander-line antenna attached to a metallic plate is successfully constructed. An approximation is proposed and the parameters of the circuit elements are derived from the geometry of the antenna. Reasonable agreement is obtained between calculated and measured resonant frequencies and the model can be used for rough estimation of the resonances for meander-line antennas.

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