An Efficiency of Impedance Matching Approach with Lossy Elements in Wireless Power Transfer System

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Abstract   Impedance matching is one of the most important theory for Wireless Power Transfer(WPT). It is to realize complex conjugate condition at both load and source impedances and lumped elements such as inductors and capacitors are used. Lumped elements have ohmic loss so it causes mismatching when they are not considered. In this paper, exact impedance matching circuits are used for different length of dipole and loop antennas and each efficiency is demonstrated.

Keyword   Impedance Matching, Lumped Elements, Ohmic Loss, Dipole Antenna, Loop Antenna

1. INTRODUCTION

Wireless Power Transfer(WPT) is getting popular because of its effectivity to charge without cables for any electric devices. To make high efficient WPT system, impedance matching is necessary. In WPT system, Impedance matching circuit is used to realize complex conjugate condition at both source and load impedances[1]. However, impedance matching circuits have ohmic loss in lumped reactive components such as inductors and capacitors. It causes impedance mismatching so conventional method cannot solve impedance matching completely. On the other hand, exact matching method has been reported[2]. It solves mismatching problem come from ohmic loss of reactive components using Q-factor. In [2], this method has an effectivity to make impedance matching circuit for load impedance which has small resistance and high reactance.

In this paper, transmission efficiency calculated by conventional method and exact method for dipole and loop antenna and effectivity to consider the ohmic loss are shown.

2. EXACT MATCHING APPROACH

In [1], conventional matching approach (CMA) uses a quadratic equation to calculate two values of each reactance used in L-type matching circuit. Equation (1) is an example of calculation.

$$X = -B_l \pm \sqrt{G_l G_s - G_l{}^2} \ . \qquad (1)$$

In this equation, there is no ohmic loss in matching circuit. So if there is an ohmic loss in matching circuit, that equation cannot calculate perfect value of reactance. In exact matching approach (EMA) reported in [2], the method considers ohmic loss in matching circuit. So the equation changes like equation (2).

$$X = \frac{B_l + B}{(G_l + |B|/Q_B)^2 + (B_l + B)^2} \qquad (2)$$

A parameter Q_B means the Q-factor of lumped element. Q-factor is defined as $Q=|X|/R$, so Q-factor includes its ohmic loss of the lumped element. Using this parameter, exact impedance matching circuit can be calculated.

3. TRANSMISSION EFFICIENCY FOR DIPOLE ANTENNA

Firstly, real and imaginary impedances versus antenna length (l/λ) for dipole antenna are shown in Fig. 2. In this case, antenna material is copper and Q-factor of elements used in L-type matching circuit is set as 50. The impedance of dipole antenna Z_a becomes load impedance when matching circuit is calculated.
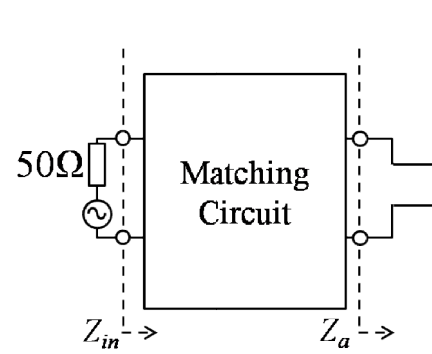

Fig. 1. Dipole antenna and impedance matching circuit

The transmission efficiency from each matching approach versus antenna length is shown in Fig. 3. Equation (3) shows a calculation of transmission efficiency η. η_1 means the efficiency calculated by using impedance mismatching and η_2 is calculated by the loss in impedance matching circuit.

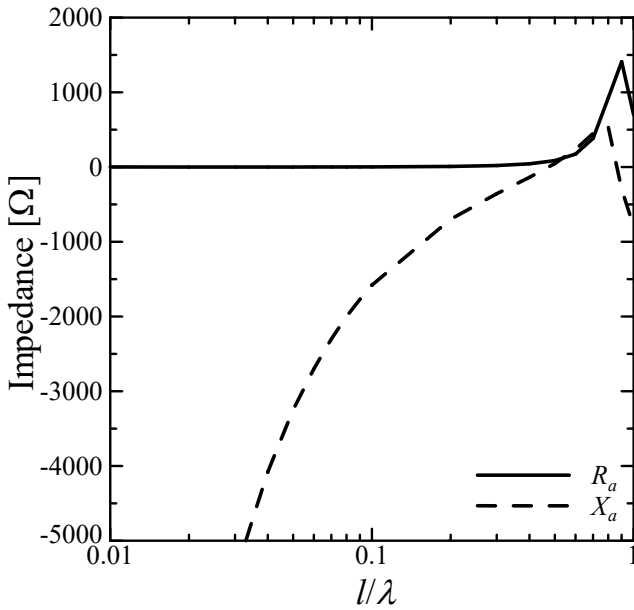$$\eta = \eta_1 \eta_2 \ . \qquad (3)$$

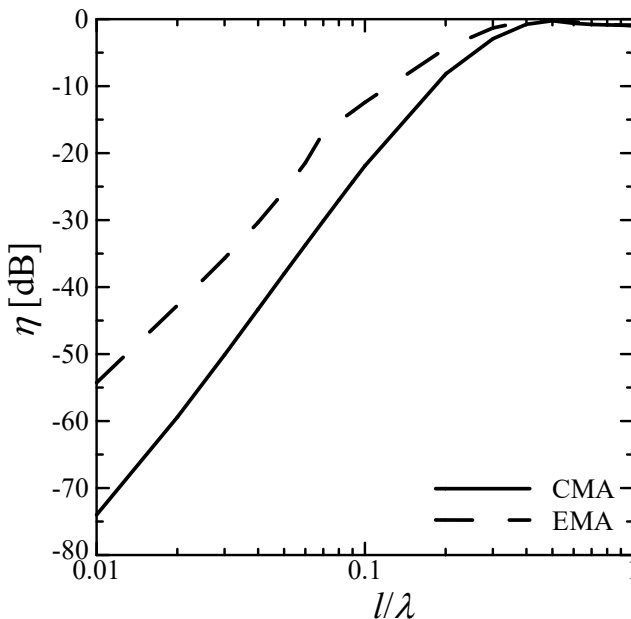Fig. 2. Impedance of dipole antenna at each length

Fig. 3. Transmission efficiency vs. Length of dipole antenna

In Fig. 3, it is clear that EMA is better than CMA for dipole antenna, especially at $l/\lambda<0.5$. It is because Z_a has large reactance at those lengths. Large reactance causes impedance mismatching in the case of CMA. However, at $l/\lambda > 0.5$, η_2 becomes much more critical than the case of η_1. It takes over the effectivity of considering ohmic loss of lumped elements and results that the efficiency of CMA is better than EMA.

Fig. 4 shows that EMA does not have the mismatch loss at any length and it is the advantage for CMA at $l/\lambda<0.5$. As a result, to make the exact

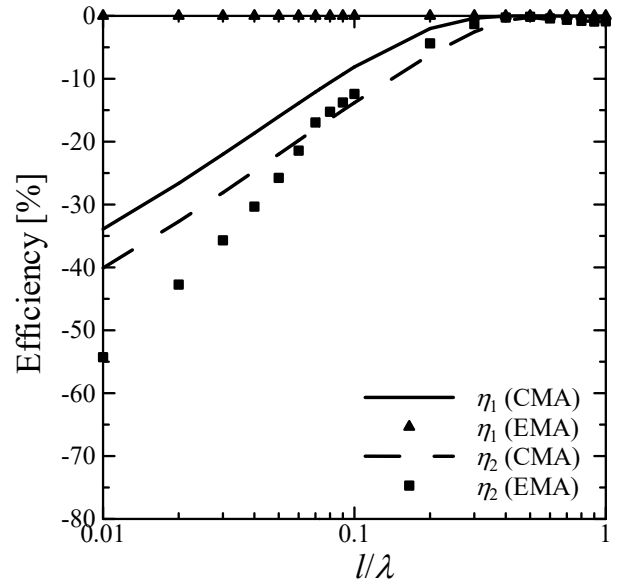impedance matching circuit is effective for small dipole antenna.

Fig. 4. Efficiency η_1 and η_2 vs. Length of dipole antenna

4. TRANSMISSION EFFICIENCY FOR LOOP ANTENNA

Furthermore, real and imaginary impedance versus antenna length (l/λ) for loop antenna is shown in Fig. 6. Frequency f and the material are same as the case of dipole antenna.
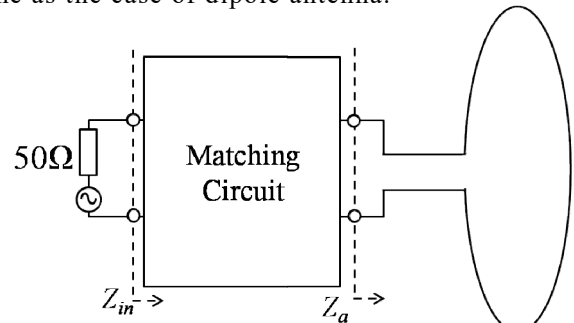

Fig. 5. Loop antenna and impedance matching circuit

From Fig. 6, loop antenna has very small resistance and large reactance at small length. The effectivity of considering ohmic loss of lumped elements in matching circuit is increased due to these small value.

Both efficiencies are plotted in Fig. 7. The efficiency of EMA is greater than CMA at $l/\lambda<0.4$. The reason is the same with the case of dipole antenna. Fig. 8 shows two parameters η_1 and η_2 for loop antenna. From Fig. 8, η_2 calculated by both methods are very close at $l/\lambda<0.4$. In those lengths, to improve impedance mismatching becomes the advantage directly. However, EMA made less efficiency matching circuit than CMA at $l/\lambda > 0.4$. The reason is because Z_a has much more resistance than smaller one and it improves η_1 in the case of CMA.
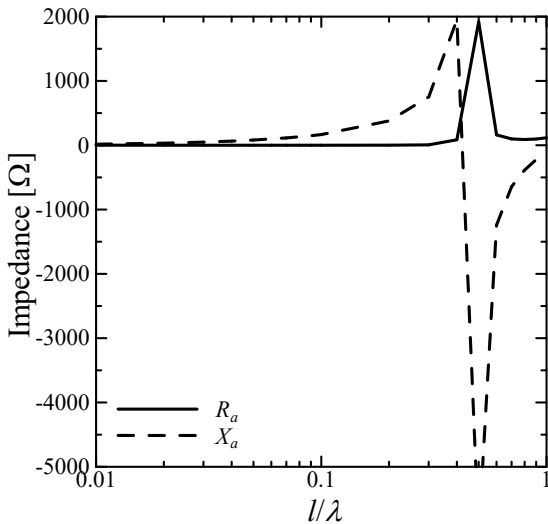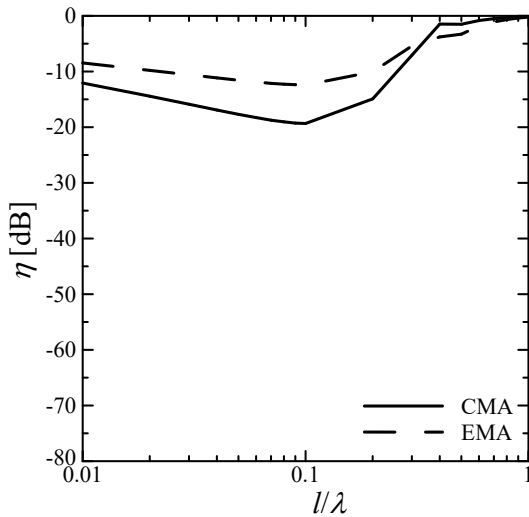
Fig. 6. Impedance of dipole antenna at each length
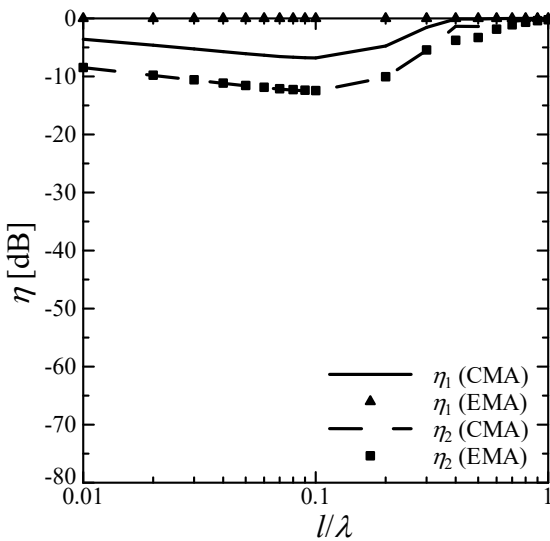

Fig. 7. Transmission efficiency vs. Length of loop antenna

Fig. 8. Efficiency η_1 and η_2 vs. Length of dipole antenna

5. CONCLUSION

In this paper, the effectivity of considering exact matching approach for dipole and loop antennas is reported. As a result, for both antennas which has small resistance and large reactance, exact impedance matching is effective to improve transmission efficiency especially its length is short. However, CMA can make matching circuit as effective as EMA when antenna length is long. In conclusion, to realize perfect impedance matching is not effective for all lengths of antennas.

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7. CONTACT

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8. References

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