Design of the Transmission and Reception Antennas for Beamed Power Transfer

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Abstract— **This paper proposes the design method of the antennas for beamed power transfer via radio wave. The transmission antenna is composed of arrayed radiating elements of which the phase is designed to form a concave phase front. The simulation analysis clarifies the characteristics of the transmitted beam. Accordingly, the focusing capability is dependent on the size of the transmission antenna, frequency, and the distance. The reception antenna is determined according to the obtained beam profile.**

Keywords— ***power transfer; radio wave; beam; array antenna; phase; focus; concave phase front ; range***

I. INTRODUCTION

Recently, radio waves are used for power transmission [1] in addition to communications or radars. Especially, for a large transmission distance, e.g. longer than 1 m, a beamed power method is preferred to coupling methods [2]. In this application, the most part of the transmitted power should be received by the receiving antenna [3]. However, radio waves inherently spread in propagation due to diffraction.

In this paper, we study the possibility of downsizing the transmission and reception antennas by generating a radio wave beam for wireless power transmission using a phased array antenna (PAA). Especially, we try to focus the beam. Focusing characteristics by a PAA have not been studied in detail. The beam propagation characteristics are revealed by simulation.

Application systems are divided by the distance between the transmission and reception points into short-range (several meters), medium-range (several hundreds meters), and long-range (several tens of thousands km). The features of beam propagation in each range category are clarified.

II. CONSTITUTION OF THE BEAMED POWER TRANSFER SYSTEM

The general configuration of a wireless power transmission system is shown in Fig. 1. On the left side, the input power from a power source is converted to a high frequency radio wave, and input to a transmission antenna. The radio wave is transmitted and propagates in the shape of a beam to the reception antenna on the right side. The received power is rectified, and output to a user.

The transmission antenna is a PAA that is composed of many radiating elements with phasing capability. We try not to spread the radiated field due to the diffraction effect, but to focus the field. Therefore, the key device is a transmission antenna, which is analyzed in this paper.

III. ANTENNA DESIGN PROCEDURE

The design procedure is shown in Fig. 2. For simplicity, the radiating elements are arrayed in one-dimension with the spacing of approximately a half wavelength. The antenna includes a reflector behind the radiating elements to suppress the backward radiation and interference vulnerability.

Actually, each element is fed by a single oscillator via power dividers and the feeding circuit with a high-power amplifier and a phase shifter, though omitted in this figure. The excitation of each element can be changed by the amplification and the circuit loss. And the connection between the element and the feeding circuit should be determined according to the relative power levels [4]. Therefore, we do not need to pay much attention to the circuit and element excitation loss.

For simplicity, the radiating elements are assumed to be isotropic radiators later on. However, the theory including non-isotropic radiator, e.g. half-wavelength dipoles or patch antennas, is easily extended as the radiation pattern width of each element is much wider than the pattern width of the total antenna.

Now we conceive to gather all radiated fields at the hypothetical focus F which is z_{f0} apart from the plane of the transmission antenna. In order to derive the phase relation, we suppose a hypothetical circle with the center at F and the radius of R. To give the same phase at F to all radiated fields, the n-th element should be supplemented with the following phase Δ_n [5]:

$$\Delta_n = -kR\left(1 - \frac{\sin\theta_N}{\sin\theta_n}\right) \qquad (1)$$

IV. Antennas for Various Applications

We analyzed the model antenna by simulation changing the location of the hypothetical focus. The frequency is 2.45 GHz. The simulation results are summarized for each range category.

A. Short-Range Applications

The typical example in this category is feeding an electric vehicle via microwave [6]. The range from a transmission platform to a client car is less than 1 m. The transmission antenna should be of small size, 1 m as an example, so that elements are 17 in number.

The calculated radiation patterns are shown in Fig. 3 for several values of z_{f0}. The pattern with z_{f0} = 1.0 m is the narrowest, and looks like a far field pattern.

Changing the z_{f0} value to 0.5 m, the pattern shows the feature of a near field radiation. The beam width is close to the transmission antenna aperture. With z_{f0} = 1.5 m, the pattern is deteriorated from the far field pattern with z_{f0} = 1.0 m.

If the field intensity at z_{f0} = 1.0 m is too high for the rectifier capability, we can relax the intensity by choosing the z_{f0} value between 0.5 and 1.0 m or between 1.0 and 1.5 m. Fig. 4 extending the simulation range. The reception antenna diameter D_r is equal to the beam width which is temporally defined by two points with field decrease of 1/e (e=2.72), as is analogous to Gaussian beam.

B. Medium-Range Applications

Typical application in a medium range is a wireless power transmission from an electric power generator to a commercial grid [7]. The distance is assumed 1 km. The transmission antenna can be large, 10 m diameter, so that the elements are 163 in number.

When z_{f0} = 1 km, the field distribution on the receiving plane looks like a far field pattern as is the same as the short range case. The reception antenna diameter D_r is about 16 m.

C. Long-Range Applications

The typical application is to transmit the generated power of microwave from satellite in orbit to the earth [8]. In this case, the distance is 36,000 km.

The field distribution on the receiving plane is shown in Fig. 5. The reception antenna diameter D_r is read as about 6000 m. Even changing the hypothetical focal length, we could not derive a focused beam.

V. Conclusion

The design method of a PAA for power transmission to generate a narrow beam was proposed. The technique is shown to be effective to investigate the focusing behavior of an array antenna for beamed power transfer.

The focused beam size was dependent on the transmitting antenna size, frequency and transmission distance. In the short range, focusing capability is strongest among three ranges. In the long range, the beam cannot be focused but only expands due to diffraction effect.

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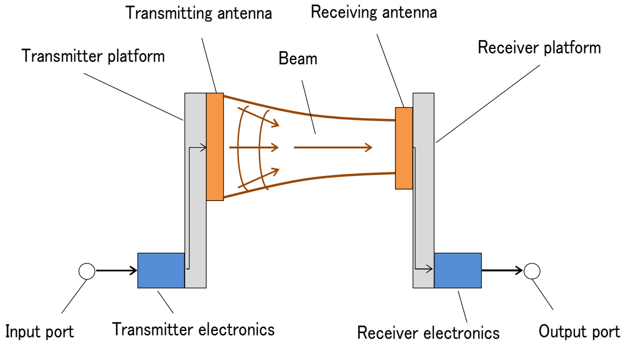

Fig. 1 System configuration of beamed power transfer.

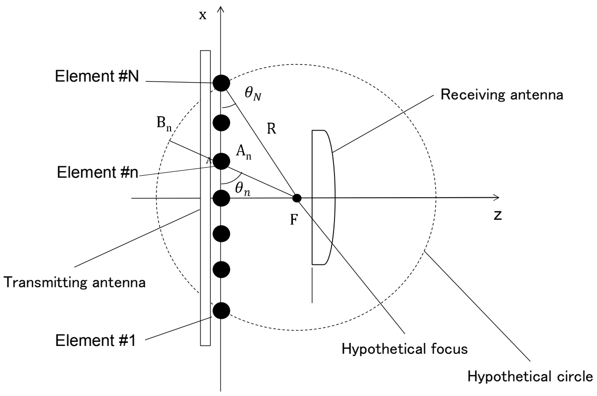

Fig. 2 Design of transmission antenna in relation to a reception antenna.

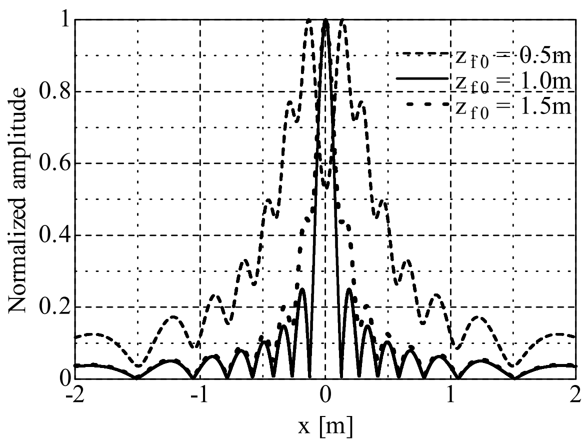

Fig. 3 Field distribution at a plane of 1 m distance from the transmission antenna. The parameter is the hypothetical focal length.

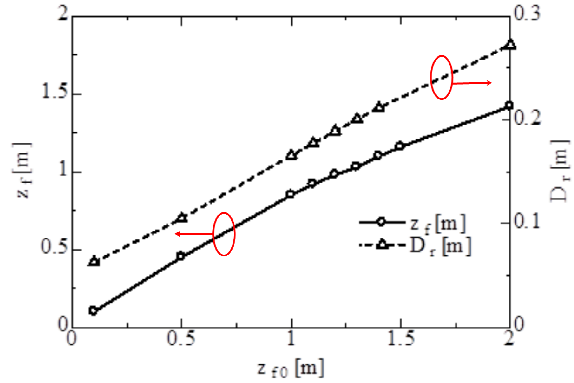

Fig. 4 The samallest reception antenna diameter D_r and its location z_r in relation to the hypothetical focal length z_{f0}.

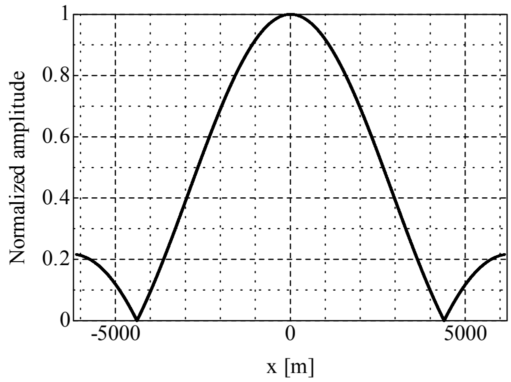

Fig. 5 Field distribution at a plane of 36,000 km distance from the transmission antenna. The hypothetical focal length is 36,000 km.