Enabling Simultaneous Near-Field Focusing and Far-Field Radiation Using Multiple Lenses

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Enabling Simultaneous Near-Field Focusing and Far-Field Radiation Using Multiple Lenses

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***Abstract*—This paper introduces a methodology to design a scheme enabling simultaneous near-field focusing and far-field radiation by using multiple lenses. A large-size lens is designed to convert the spherical wave emanating from the feed source to a quasi-plane wave. A small-size lens is located at a parallel plane away from the large-size lens. By imposing proper phase shifts on the small-size lens, it can capture part of the electromagnetic waves from the large-size lens to achieve a focal spot in the near-field region of the small-size lens. The gain of the radiation beam and the intensity of the focal spot can be controlled by either adjusting the area ratio of, or the separation between the large- and small-size lenses. The simulations validate the effectiveness of the proposed methodology. The proposed scheme offers an alternative solution to achieve simultaneous near-field focusing and far-field radiation.**

Keywords—Millimeter-wave, near-field focusing, far-field radiation, lenses.

I. Introduction

Compared to the near-field focusing, the far-field radiation is much more prevalent as the intended targets usually locate in the far-field region of an antenna. As a result, far-field radiation can support long-distance wireless communications such as satellite [1] and mobile communications [2], etc. By contrast, near-field focusing is a kind of behavior that an antenna can focus the electromagnetic waves from an external source (either a feed antenna or free space) into a focal spot with high energy in the near-field region. The technologies of near-field focusing have been widely utilized in short-distance wireless communications such as RFID applications [3]. Due to the high energy of the focal spot, the near-field focusing is also employed to perform wireless energy transfer [4], [5].

If a device can provide simultaneous near-field focusing and far-field radiation, it would be greatly attractive and efficient as it can take into account both the near-field and far-field wireless communications at the same time. However, it is found that most of the previously-reported literature only focuses on a single characteristic that is either near-field focusing or far-field radiation. As the near-field focusing and far-field radiation require significantly distinct phases of the radiating elements, the simultaneous near-field focusing and far-field radiation can be enabled by optimizing the phase distributions [6] or amplitudes [7] of radiating elements. The optimization procedure, however, is usually time-consuming and the performance of near-field focusing and far-field radiation is highly correlated to each other.

In this paper, a scheme is proposed to enable simultaneous near-field focusing and far-field radiation using multiple lenses. By properly imposing the phase shifts of the large- and small-size lenses, the scheme forms a focal spot in the near-field region of the small-size lens and high gain radiation in the far-field region of the large-size lens. The proposed scheme offers an alternative option to enable a device with simultaneous near-field focusing and far-field radiation.

II. Concept and Methodology

Fig.1 presents the schematic diagram of the scheme to achieve simultaneous near-field focusing and far-field radiation using multiple lenses. The entire scheme consists of a feed source, a large-size lens, and a small-size lens. The large-size lens is mainly responsible for converting the spherical wave emanating from the feed source to a quasi-plane wave, while the small-size lens is located away from the large-size lens, capturing part of the electromagnetic waves from the large-size lens to achieve a focal spot in the near-field region of the small-size lens.

According to the schematic diagram shown in Fig. 1, it is expected that the gain of the far-field radiation beam and the intensity of the focal spot can be controlled by either adjusting the area ratio of the large- and small-size lenses or the separation between the large- and small-size lenses, which will be verified in the following.

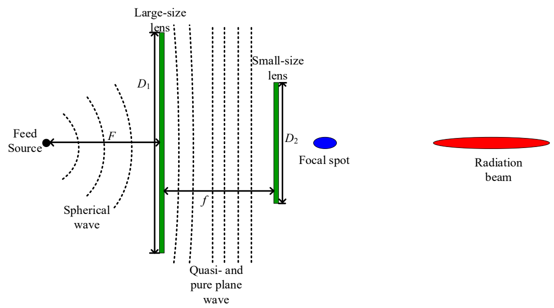

Fig. 1. Schematic diagram of the enabling simultaneous near-field focusing and far-field radiation using multiple lenses.

III. Implementations and Simulations

Here, we study the performance of the near-field focusing and far-field radiation of the proposed scheme when the small-size lens is placed at different planes away from the large-size lens, e.g., $f = 50$ mm, 100 mm, and 200 mm. Fig. 2. shows the model of the proposed scheme with CST Microwave Simulation Studio. Dielectric-based unit cells with a periodicity of 5 mm, a dielectric constant of 2.55, and a loss tangent of 0.02 are employed to build the large- and small-size lenses due to their simplicity. A horn antenna with a type of “PASTERNACK PE9851/2F-10” is adopted as the feed source to illuminate the large-size lens, which operates from 22 GHz to 33 GHz. The horn antenna can provide a nominal 10 dBi gain. The distance between the large-size lens and the feed source is selected as 120 mm to offer a good aperture illumination on the large-size lens.

Figs. 3 and 4 present the 3D far-field radiation pattern and 2D electric-field distribution at 26 GHz when f is 50 mm, 100 mm, and 200 mm, where the locations of the focal spots are all the same with respect to the small-size lens. As seen in Fig. 3, the gain of the proposed scheme is becoming lower with a large *f*. By contrast, the electric-field intensity is stronger with a large *f* as can be observed in Fig. 4. The relations between the gain of the far-field radiation and the electric field intensity of the near-field focusing are reasonable and consistent with the conservation of energy. When the small-size lens is close to the large-size lens, e.g., *f* = 50 mm, the focal spot splits into two spots that are mainly due to the electromagnetic interferences between the large- and small-size lenses.

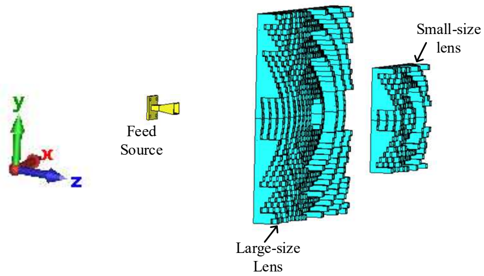

Fig. 2. One CST model of the proposed scheme enabling simultaneous near-field focusing and far-field radiation using multiple lenses. (The dimensions of the large- and small-size lenses are 200 mm × 200 mm and 100 mm × 100 mm, respectively)

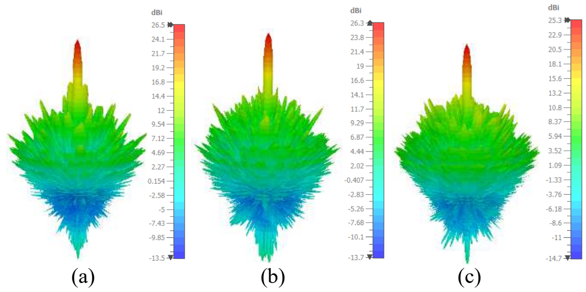

Fig. 3. The simulated far-field radiation pattern of the proposed scheme at 26GHz with different values of *f* (the separation between the large- and small-size lenses). (a). *f* = 50mm. (b). *f* = 100mm. (c). *f* = 200mm.

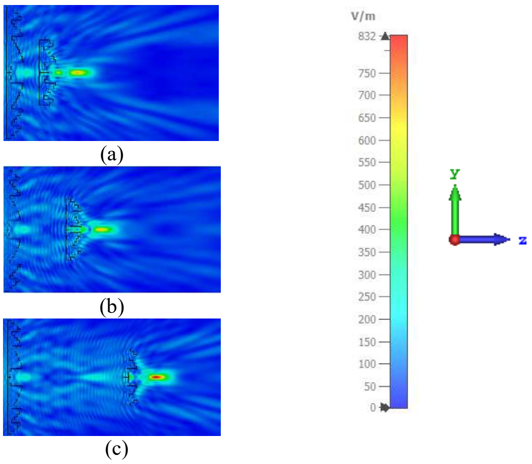

Fig. 4. The simulated near-field electric-field intensity of the proposed scheme at 26GHz with different values of *f* (the separation between the large- and small-size lenses). (a). *f* = 50 mm. (b). *f* = 100 mm. (c). *f* = 200 mm.

We also check the performance of the near-field focusing and far-field radiation of the proposed scheme when the size of the small-size lens is larger. Fig. 5 gives the far-field radiation pattern and near-field electric-field intensity of the proposed scheme at 26 GHz when the small-size lens is 150 mm × 150 mm and *f* is 200 mm, where the location of the focal spot is still the same as the small-size lens with a dimension of 100 mm × 100 mm. As seen in Fig. 5, the gain of the proposed scheme is 23.1 dBi which is smaller than 25.3 dBi observed in Fig. 3(c). However, the near-field electric-field intensity is 1019 V/m which is much higher than the value of 832 V/m in Fig. 4(c). When the size of the small-size lens is bigger, it can capture more electromagnetic waves from the large-size lens to form a focal spot with higher electric-field intensities, resulting in a reduced gain of the far-field radiation. The results are still consistent with the conservation of energy. From the results shown in Figs. 3, 4, and 5, the strategies to control the gain of the far-field radiation and the near-field electric-field intensity can be concluded, which are highly consistent with the predictions stated in Section II.

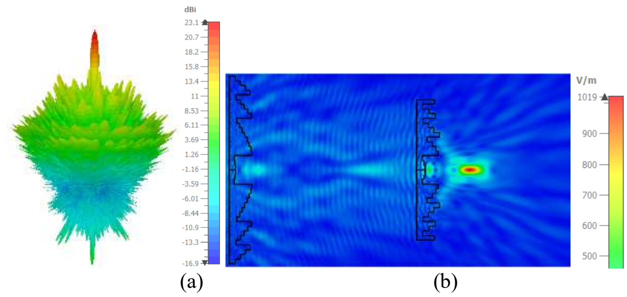

Fig. 5. The simulated far-field radiation beam and near-field electric-field intensity of the proposed scheme at 26GHz with a larger small-size lens. (a). 3D far-field radiation pattern. (b). 2D near-field electric field intensity.

IV. Conclusion

This paper introduces a methodology to design an antenna scheme enabling simultaneous near-field focusing and far-field radiation. The large-size lens converts the spherical waves from the feed source to quasi-plane waves while the small-size lens locates away from the large-size lens. The small-size lens can capture part of the electromagnetic waves from the large-size lens to achieve a focal spot in the near-field region of the small-size lens. The simulations sufficiently verify the effectiveness of the proposed scheme. The proposed methodology offers an alternation solution to enable a device with simultaneous near-field focusing and far-field radiation.

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