An Analytical Investigation of Near-Field Plates

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In the past few years, there has been considerable interest in near-field superlenses that can focus electromagnetic waves to subwavelength resolutions. Following John Pendry's work on the "perfect lens"[1], various superlenses consisting of slabs with negative material parameters have been developed and experimentally verified at microwave, infrared and optical frequencies [2-5]. More recently, an alternative approach to subwavelength focusing using patterned, grating-like surfaces was introduced and developed in [6-7]. The proposed surfaces have been referred to as near-field plates. A near-field plate is a subwavelength-structured, planar device that focuses electromagnetic waves from close or distant sources to subwavelength resolutions. The plate's textured surface (modulated reactance) sets up a highly oscillatory electromagnetic field that converges to a prescribed focus in the plate's near field. Focal patterns of various shapes and symmetries can be achieved by tailoring the design of a near-field plate in different ways. At microwave frequencies, these plates can be realized as non-periodic arrays of reactive elements (inductors and capacitors), while at optical frequencies nanofabricated plates consisting of plasmonic and dielectric materials can be envisioned. Recent experiments at microwave frequencies have experimentally verified a near-field plate's ability to form a subwavelength focus [8]. In [8], an experimental near-field plate consisting of an array of interdigitated capacitors was shown to focus 1.027 GHz microwave radiation emanating from an S-polarized cylindrical source to a focus with FWHM = $\lambda_0/18$.

In this paper, we present an analytical method for modeling near-field plates. The proposed method provides additional insight into the operation and design of these plates, over the numerical approach described in [7]. Separately, we consider near-field plates that can focus plane waves and cylindrical waves to subwavelength resolutions. In the analytical treatment, the plates are assumed to be infinite in width. The current density on the plate is found in the spectral domain and then inverse Fourier transformed to obtain its spatial dependence, as well as the plate's impedance profile. The current density on the plate is shown to consist of two parts: the first part produces the desired focal pattern, while the second part cancels the incident wave (both plane wave and cylindrical wave illuminations are considered) on the focus-side of the plate. The analytically derived expressions are compared and contrasted with those obtained numerically for electrically-wide plates. The analytical results for the current density and impedance profile of the plates are shown to be in good agreement with those obtained numerically. Finally, it is demonstrated that the slight differences that do exist between the two approaches can be attributed to edge diffraction.

References

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