Wideband Radial-Line Slot Array Antenna Technology for Near-Field Meta-Steering Systems

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***Abstract*— The paper reviews wideband radial-line slot array design and its suitability to develop wideband beam-steering antenna through near-field meta-steering (NFSM). A low-profile and highly efficient beam-steering antenna system can be realized using the wideband RLSA and pair of metasurfaces, which are placed in the near-field region of the RLSA. In NFMSs the base antenna remains fixed while the metasurfaces are rotated to steer the beam in both azimuth and elevation directions. The concept was first demonstrated with narrowband medium-gain antenna, and since then, it has been extended to design high-power systems, dual-band high throughout systems, and wideband steering systems.**

Keywords—antenna array, beam scanning, beam steering, COTM, CubeSat, high-gain, IoT, LEO, MEO, metasurface, near-field, phase transformation

I. Introduction

Radial-line slot array antennas, because of their planar profiles and the ability to achieve high gain without using feed network, are attractive for fixed and mobile satellite-based wireless services [1,2]. These antennas are excellent to be used as a base antenna in the Near-Field Meta-Steering (NFMS) systems. NFMS involves steering beam of a fixed base antenna in a large conical region by rotating a pair of specially designed metasurfaces, which are placed in the near-field region of a planar high-gain base antenna [3,4]. When demonstrated for the first time, a linearly polarized medium-gain antenna was used as a base antenna [3]. The suitability of RLSAs for NFMSs has been investigated in the past [5]. This research revealed that RLSAs operate in an extremely narrow frequency band.

The classic RLSAs are made of a radial waveguide formed between two parallel metal plates. The bottom plate is solid and is the ground plane of the antenna. The top plate has radiating slots that are arranged appropriately for the desired antenna polarization. As an example, in CP RLSAs, radiating slots are arranged on a spiral. The inter-element spacing between two adjacent rings of the spiral is set to one guided wavelength to make the antenna radiate constructively in the broadside direction. The antenna thus strictly operates within an extremely narrow band around the center operating frequency [6,7].

Recent research introduced the concept of using non-uniform waveguides to considerably enhance the bandwidth of the RLSAs [8]. This paper review wideband RLSA technology and explains its suitability to develop a wideband frond-end beam-steering antenna for satellite-based wireless systems. The rest of the paper is organized such that the configuration of wideband RLSA technology is discussed in Section II. Conceptual details of wideband NFMSs are given in Section III, and the paper is concluded at the end.

II. Wideband Radial Line Slot Arrays

As mentioned previously, the classical narrowband RLSAs have radial-waveguide with a single feed point. The radiating slots, which are on the top metal plate, are arranged in concentric circles for the linearly polarized RLSAs and in a spiral for the CP RLSAs. The phase variation within the waveguide depends on the material used inside the waveguide. Mostly, these waveguides are filled with the dielectric or slow-wave structure to ensure that the guided wavelength (λ_g) is smaller than the free-space wavelength (λ_0). The slots spacing along the radial direction is kept fixed to λ_g, and, therefore, these slots radiate synchronously at the guided wavelength and making a broadside beam.

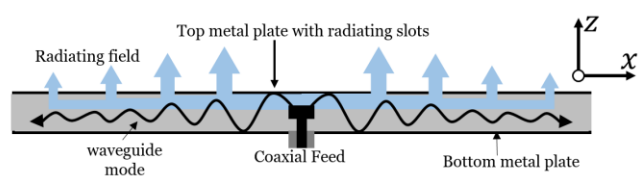

Fig. 1: Configuration of the classical narrowband RLSA.

In the wideband RLSA, the waveguide is split into more than one circular concentric section, as shown in Fig. 2. While the radiating slots have fixed radial spacing, similar to the narrow band RLSAs, the wavelength in the waveguide is varied. The wavelength is varied such that the guided wavelength in each section matches the radial spacing at a different frequency; thus, effectively, each distinct section generates a broadside beam at a separate frequency. For explanation, only a three-sectioned waveguide is shown in Fig. 2 where each of the three sections effectively radiates frequency f1, f2, and f3, respectively. The number of sections and the separation between frequencies can be adjusted to meet the design specification.

A CP RLSA design that was demonstrated with measured results of a prototype in [8] has three sections. The guided wavelength in each of the sections is varied by using a different permittivity dielectric material. A higher permittivity dielectric was used in the outermost section meaning the smallest guided wavelength in that section.

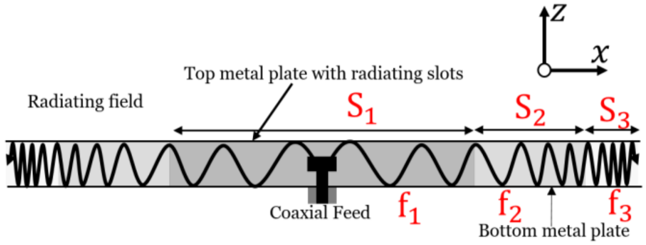

Fig. 2: Configuration of non-uniform waveguide-based wideband RLSA.

The maximum gain of the antenna was 27.3 dBic with a 3dB gain bandwidth of around 27.5%. The axial ratio and return loss bandwidth of the antenna was more than 30%. This wideband RLSA can be used as a base antenna for the wideband NFMS system for wideband applications. This design concept is briefly covered in the following section.

III. Near-Field Meta-Steering System

A classical NFMS has a base antenna and the pair of low profile and thin metasurfaces placed in the near-field region of the antenna, as shown in Fig. 3. The metasurfaces introduce progressive phase shift through phase-shifting cells along a radial axis and effectively tilt the beam along the axis. If the two metasurfaces are aligned, their tilt axis is in the same direction then the beam is tilt to the maximum elevation angle. If the phase progression of the two metasurfaces is in the opposite direction, then the beam is tilt to the broadside direction. Any other rotation combination moves the beam to an arbitrary elevation angle between two extreme values. With co-rotation of the metasurfaces, the beam can be moved to any azimuth angle between 0 and 360°. This concept has now been extended for diverse systems used in high-power microwave and dual-band applications [9-11].

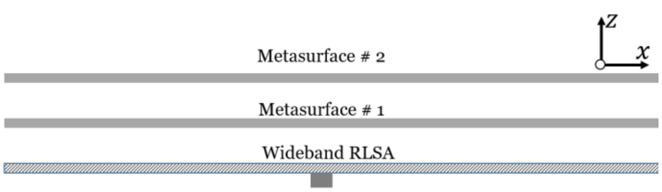

Fig. 2: Configuration of classical NFMS that could be used for wideband NFMS.

The concept can easily be extended to realize a wideband NFMS with wideband RLSA as the base antenna. The advantage of using RLSAs is that it did not excessively increase the height of the antenna, and thus the system maintains its low profile. The wideband metasurface design is still a work in progress, and the development will be reported in subsequent publications. In this regard, a system has been demonstrated using dielectric structures that has more than 40% steering bandwidth [12]. However, the large height of the dielectric structures makes it less attractive for some high-gain applications, including communication-on-the-move (COTM). For these applications, a thinner printed type metasurface with wideband performance will be preferred.

IV. Conclusion

A wideband beam-steering antenna can be designed using recently demonstrated wideband RLSA technology and near-field meta-steering (NFMS). The RLSA is the base antenna and is fixed while the metasurfaces made of printed and dielectric layers are rotated to steer the beam in a wide conical region. Such a beam-steering system can be used at remote locations and operated with small power supplies. Due to the inherent advantages of the NFMS technology, these antennas do not suffer from excessive losses similar to those suffered by electronics beam-steering techniques due to active radio frequency components. Unlike traditional mechanical systems, NFMS technology yields antennas with planar profiles having much smaller maximum height.

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