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The Wide/Multi Band Leaky Wave Lens Antenna

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Introduction

Leaky waves antennas have been investigated for a long time and are typically an inexpensive solution for beam scanning antennas. Indeed, since most type of leaky propagation mechanisms are very dispersive, the beam direction can be scanned with frequency provided one accepts a narrow bandwidth available for each scanning angle. Recently [1] the Green's Function of a slot printed between two infinite dielectrics has been investigated. The propagation constant for this structure, β , is roughly the average of the ones associated to each of the homogeneous media separately. Accordingly, β is a slow wave for the less dense medium and a fast wave (leaky) wave for the denser medium. If the two media are free space and a dense dielectric, radiation occurs in the dielectric. This type of propagation does not involve multiple reflections due to a finite thickness slab, or to a waveguide type of cross section; which typically render dispersive all previously proposed leaky wave radiation mechanisms.

The main idea of this work is to exploit this property for the first time and to realize wide-band and multi-band leaky wave lens antennas. In particular we will concentrate on the design of directive feeds for sub-mm wave applications.

The key reason that renders the present leaky wave slot very suited for sub-mm sensing is that most of the THz sensors already use lenses [2]. In most instances integrated receiver are located in the lower focus of a rotational symmetric elliptical dielectric lens antenna. These lenses are typically chosen because they do not suffer from loss of power in guided modes and moreover, since they are shaped elliptically with the eccentricity properly related to the dielectric constant, they also providing high-directivity. Finally, very often also the dielectric losses are not an issue because the entire receiving chains are cooled to few Kelvin degrees. The most widely known ESA-NASA mission that makes use of these receivers is the Herschel-Planck mission. It makes use of a large reflector for focusing the incoming signal to a series of different single pixel receivers each one of them operating at a different central frequency. The spectrum from 180 GHz to 2 THz is actually sampled. As a result, an entire array of lenses, each with its integrated receiver, is located in a relatively large zone in correspondence of the focal plane of the reflector. For the next generation instruments of similar kind, it would be extremely convenient to be able to compact the system realizing a smaller number of lenses, each one operating over multiple frequencies.

Antenna Design and Measurement

In the frame of a contract with the ESA, performed together with Satimo and Saab-Ericsson Space, TNO has concentrated in the design of a double-frequency slot and lens based antenna (Fig. 1).

Fig.1. Two prototypes of leaky lens antennas

In particular the higher frequency is chosen roughly twice higher than the first one. The restriction to two operation frequencies is just for the sake of simplicity in the design of the filtering structure that is needed to isolate the two feeding points. The geometry of the lens antennas are visible in fig. 1. An elliptical cross section is enforced for each incremental radiation from the slot. The rays launched by the slot form an angle γ with the slot axis. γ is only function of the dielectric

discontinuity ϵ_{r1} , ϵ_{r2} and can be expressed by $\gamma = \cos^{-1} \sqrt{\frac{\epsilon_{r1} + \epsilon_{r2}}{2\epsilon_{r2}}}$.

The elliptical cross sections maximize the directivity in the E plane and also renders applicable the analysis results pertinent to slots etched between two infinite dielectrics thanks to the fact that the rays reflected the dielectric-air interface once undergo at least a second reflection before coming back to the original focus.

The directivity in the H-plane is instead achieved only thanks to the leakage effects. Given that the wave mechanisms in the slot and in the lens are essentially frequency independent, the basic lens and slot design is a very simple and straight forward tasks. To summarize, the most unique feature of this leaky wave antenna is that its main beam of radiation remains substantially the same at the different frequencies. This is due to the peculiar radiation mechanism [1] used that has found application for the first time in the present antenna. The agreement between measurements and calculations, as far as *S*-parameters are concerned, is outstanding (Fig. 2). Also the measured properties of the radiation patterns are outstanding (Fig. 3). One should note that these features were demonstrated despite there are no commercial codes able to help in the analysis and the lens system was essentially designed from basic, frequency independent, physical concepts.

Fig.2. S parameters of dual band antenna: measured (solid lines) and simulated (dashed lines). 43% and 19% relative bandwidth at -13 dB level can be observed.

Fig.3. Comparison between the radiated field at 10.5 GHz and 22.5 GHz a) on the E-Plane; b) on the H-Plane.

Conclusion

The properties of these new leaky wave lens antennas can be synthesized as follows

1. They are directive and broad band antennas whose performances are very similar to those of long tapered slot (LTS) antennas [3].
 2. With respect to LTS antennas they present broader bandwidths and similar cross polarization levels. However they require a dielectric lens which makes them more bulky at low frequencies but also more directive in the E-plane.
- A joint TNO-ESTEC patent is pending on this type of antenna.

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