Planar Lens Using Embedded Quasi-Lumped-Element Stripline Filters

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***Abstract* — Lenses are an alternative antenna type for narrow beam antennas. Dielectric lenses, however, typically are relatively thick, heavy, and complicated to fabricate due to their specific contour. A possible solution for this problem are planar printed antennas which are thin, lightweight, and can be fabricated easily. This paper describes the design of a planar lens based on an array of slot-coupled planar filter structures; the required phase delay is adjusted by different center frequencies of the respective filters. An example lens at 35 GHz has been designed, fabricated, and tested.**

***Index Terms* — Antennas, filters, frequency selective surfaces, planar lens antenna.**

I. Introduction

Frequency selective surfaces (FSS) are widely used as spatial filter layers; efforts have been made to improve the selectivity by including filter structures known from discrete filter design [1 – 3]. Such filters, on the one hand, can act either as frequency or angular selective devices [1], or their transmission phase behavior can be explored. (A filter characteristic as used within this work is shown later in Fig. 6). A strong, nearly linear phase angle progression can be observed within the passband. In [4], the phase angle performance of a chain of filters has been exploited to realize an antenna which scans over frequency. If filters within an FSS are designed with different center frequencies in different cells, these exhibit different transmission phase angles at a constant frequency. If phase angle is properly adjusted, such an inhomogeneous FSS can act as a planar lens antenna (Fig. 1). In [5], filters are realized by resonating patches on the outer sides of a dual-layer substrate connected by electromagnetically coupled coplanar lines in between the two layers. In the present work, a similar planar lens has been realized using quasi-lumped stripline filters similar to [6] coupled by slots in the outer metallization layers (Fig. 2).

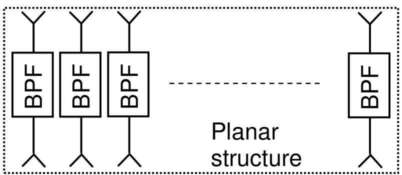

Fig. 1: General structure of a planar lens using filters designed for different center frequencies to achieve the necessary phase angle distribution.

II. Planar Lens Structure

The planar lens presented in this paper consists of an array of "unit cells" comprising a dual layer substrate metallized on the outer sides with coupling slots to a filter in the inner layer of the structure. Fig. 2 shows the principle setup of such a unit cell. Ideally, the cell is closed at the sides by perfectly conducting walls; in practice, a sufficient number of vias will take this task. The filters are realized as stripline filters with different center frequencies according to the required transmission phase angle. An incident wave (assumed as a plane wave for the design process) is incident from one side. The power is coupled to the filter input and re-radiated from the filter output via the slot on the opposite side. Ideally, the signal is phase-shifted according to the position of the operating frequency with respect to the center frequency of the bandpass filter. For the complete lens array, the respective phase angles of the cells are adjusted such that the path length differences from a focal point (feed) to the lens surface are compensated. To avoid grating lobes, cell size should be in the order (or not much bigger) of half a free-space wavelength. In this work, cell size was selected to 5.1 mm × 5.1 mm, equivalent to 0.6 λ_0. Substrate material is Rogers RO 4003 with a dielectric constant of 3.38 and a thickness of 0.51 mm per layer. The two layers were bonded together using a RO 3001 bonding foil.

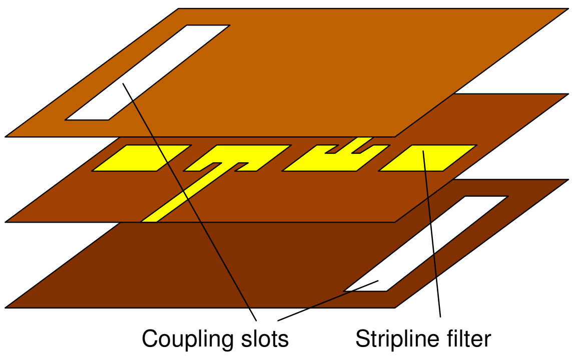

Fig. 2: Principle structure of a unit cell of the planar lens.

III. Slot Coupled Transition

Typically, a slot coupled transition to stripline is composed of a half-wavelength slot with a quarter wavelength stripline stub. Due to the tight space requirements in this application, the stripline stub is separated in two parallel stubs bent towards the direction of the slot (Fig. 3). Vias at the cell edges and close to the transition prevent the excitation of parallel-plate waves between the two ground planes. The complete arrangement is optimized [7] for operation in the 35 GHz frequency range (Fig. 4).

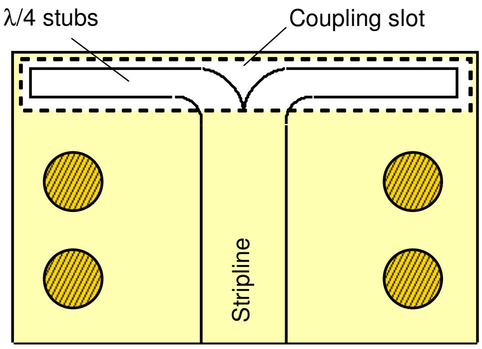

Fig. 3: Configuration of the slot coupling to stripline.

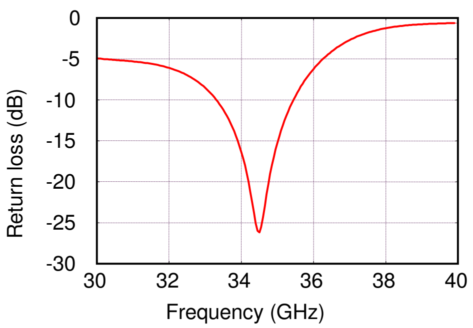

Fig. 4: Simulated return loss (stripline port) of the slot coupled transition to stripline.

IV. Filter Design

To allow a small filter size, quasi-lumped filters, similar to those in [6] were designed, consisting of capacitively coupled shunt resonators (Fig. 5). The resonators are formed by patch-like structures, the inductances are formed by strips to ground (vias to ground). The design and simulation procedure is identical to [6] and based on a 2½D simulator [8]. Due to the high frequency, the resonators result in structures close to quarter wavelength stubs. Fig. 5 shows the inner metallization layer including the stubs for the slot transitions. The holes for the vias are drilled and electroplated only after joining the two substrates together by a bonding foil. The resulting simulated response of a filter (stripline ports) designed for a center frequency of 35 GHz is shown in Fig. 6.

The combination of the two slots with a filter finally exhibited a somewhat deteriorated performance, but was nevertheless sufficient for the first planar lens design.

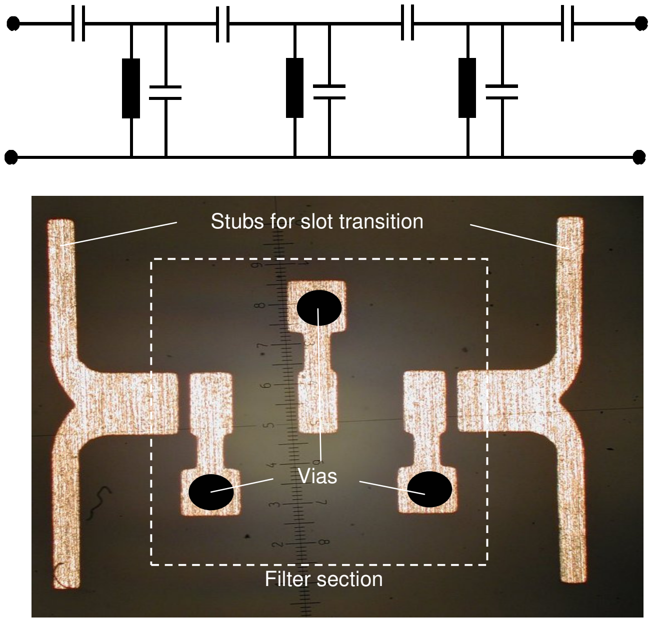

Fig. 5: Equivalent circuit of the bandpass filter and inner metallization layer of a unit cell including the stubs for the slot transitions.

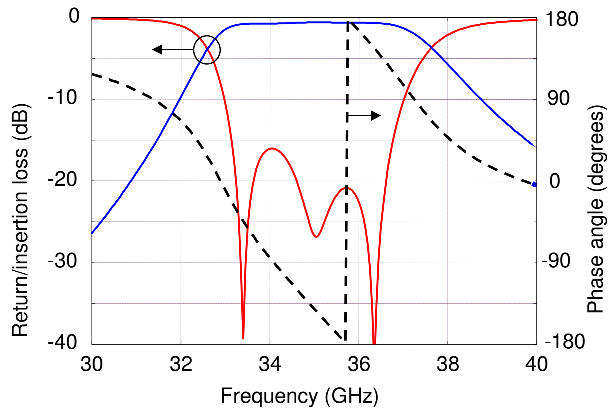

Fig. 6: Simulated performance of the filter (stripline ports).

V. Lens Array

Based on the slot coupled filter structure as described before, the design of a planar lens was started. The diameter of the lens and the focal distance were selected to 80 mm and 150 mm, respectively. Based on this geometry, a phase angle range of about 180° had to be covered. To reduce the number of filter designs, phase angle was adjusted in increments of 45° degrees, resulting in only 5 different filters (different center frequencies) and a Fresnel zone design of the lens. With phase increments of 45°, however, the loss in gain is relatively low. As feed, a simple pyramidal horn was used. Fig. 7 shows the setup of the complete planar lens antenna for first laboratory tests, Fig. 8 a photograph of the fabricated planar lens. The coupling slots and the vias forming the cell boundaries and suppressing parallel plate modes can be recognized clearly.

Fig. 9 shows the measured radiation diagrams in E- and H-plane at 35 GHz. Beamwidths are 8.2° and 8.5°, respectively. Sidelobe level is about -18dB in the H-plane and -14 dB in the E-plane (where the illumination of the lens was not optimal). Fig. 10 displays the H-plane radiation performance as a function of frequency from 33 GHz to 37 GHz. Angle and frequency are drawn on the horizontal and vertical axis, respectively, while amplitude is color-coded. In spite of the filtering functions of the unit cells, a reasonable large bandwidth could be achieved. Fig. 11 shows H-plane radiation diagrams for lateral feed offsets of ±30 mm, ±60 mm, and ±90 mm, resulting in beam scans up to ±24°. For the outer beams, amplitude is reduced by about 2 dB.

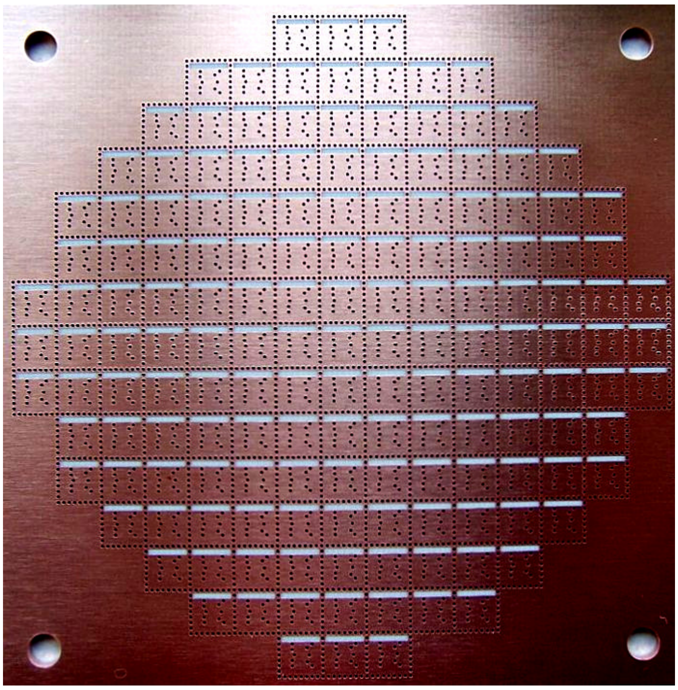

Fig. 8: Photograph of the fabricated planar lens.

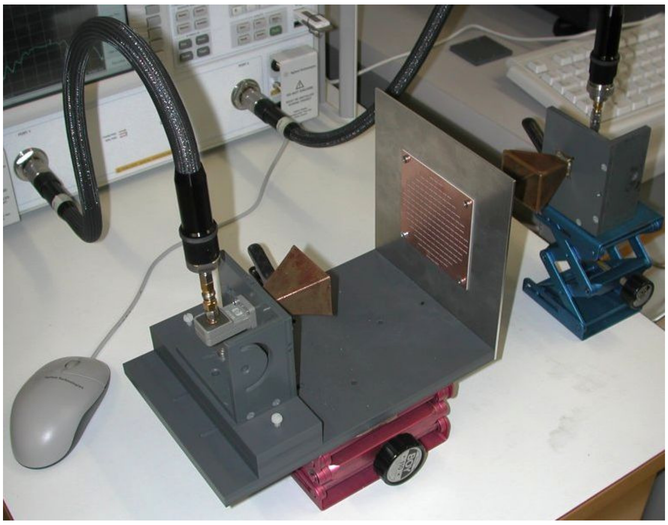

Fig. 7: Setup of the complete planar lens antenna for first laboratory tests.

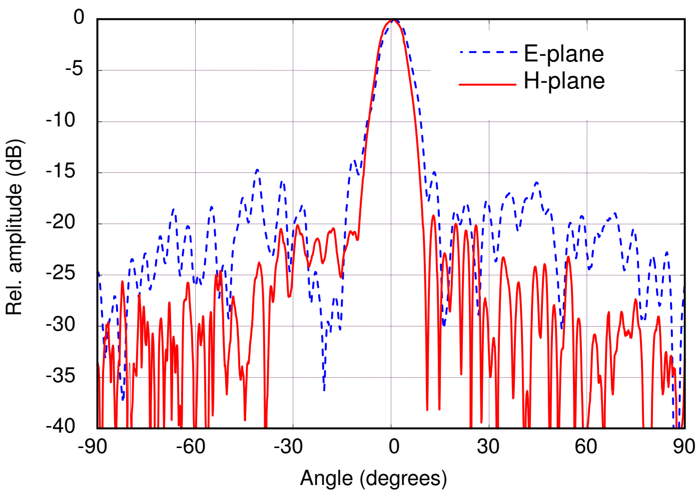

Fig. 9: E- and H-plane radiation diagrams of the planar lens at 35 GHz.

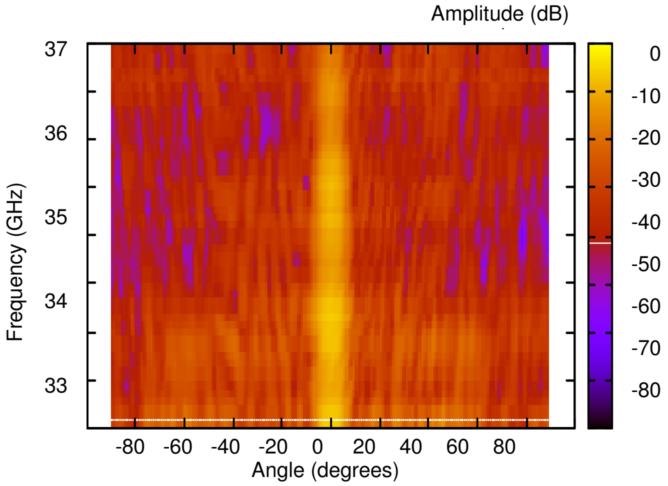

Fig. 10: Plot of the radiation characteristics of the planar lens from 33 GHz to 37 GHz.

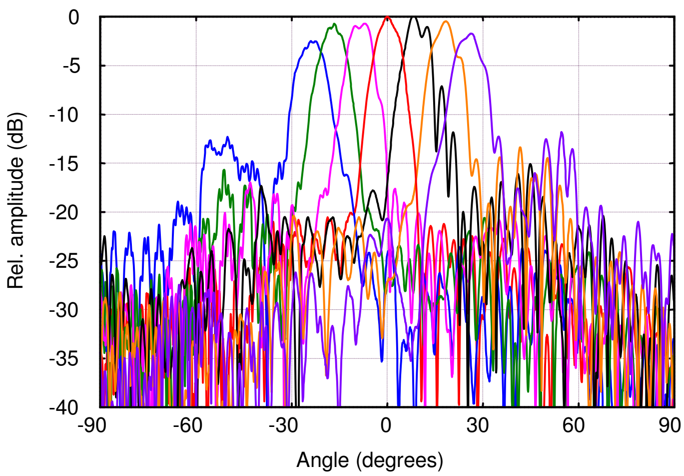

Fig. 11: Radiation diagrams of the planar lens at 35 GHz for different lateral offset positions of the feed (±30 mm, ±60 mm, and ±90 mm).

VI. Conclusion

Slot coupled transitions combined with stripline type, quasi-lumped filters have been applied to the design of a planar lens antenna. A 35 GHz test antenna has been designed, fabricated, and tested. With a diameter of 80 mm, beamwidths of 8.2° and 8.6° have been achieved. A reasonable large bandwidth and a wide angle scanning of ± 24° has been demonstrated.

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