A PLANAR VERSION OF A SLOTLINE LEAKY WAVE ANTENNA WITH A STACKED SUBSTRATE

J. Macháč, A. Pavliš, M. Houška, J. Zehentner

Abstract *– This paper presents a new version of a leaky wave antenna based on a conductor-backed slotline with a stacked substrate. The advantage of this new structure is its flat top surface, due to the antenna being fed from the rear side via an SMA connector. The antenna radiates into a single main beam above the substrate. A bi-directional antenna radiating symmetrically both forwards and backwards was obtained by mirroring the structure.*

I. INTRODUCTION

Leaky wave antennas have been known for nearly 50 years [1]. The first microstrip line leaky wave antenna was described in [2] and its behaviour was analyzed in detail in [3]. The first slotline leaky wave antenna was reported in [4]. Based on studies of a slotline (SL) [5] and a conductor backed slotline (CBSL) [6] we have designed, fabricated, and measured several leaky wave antennas, e. g., the slotline leaky wave antenna in [7]. The drawback of this antenna is that it radiates into two main beams, one above and one below the substrate. For this reason we turned to the CBSL. Various designed and fabricated antennas utilizing this line [8,9] radiate only into a single main beam. This beam is rather wide, and the side lobe level (SLL) is high. The antenna substrate has to be thick enough for effective radiation. From the fabrication point of view it is more convenient to use a stacked substrate. One slab is a thin commercially-available substrate, while the second slab, known as the spacer, is filled with air [10]. The slotline leaky wave antenna based on a flat slotted waveguide reduces radiation to the sides and therefore has a lower SLL and a narrower main lobe [11].

This paper presents a conductor-backed slotline leaky wave antenna with a stacked substrate and a completely flat top surface. This antenna feeding connector is mounted on the grounding conducting layer. The antenna radiates a space leaky wave of the first order. The CBSL with a wide slot and a substrate consisting of two layers was analyzed by the APTL Program [12], based on the spectral domain method. The CST Microwave Studio performed an optimization of the antenna structure. The antenna is fed through an SMA connector from the rear side. The shape of the radiation pattern of the antenna was improved by a simple reflector in the shape of a semi-cylinder inserted between the upper substrate and the ground conductor. This makes the main radiation lobe narrower, and reduces the level of the side lobes. The parameters of this antenna are comparable with the original antenna. The antenna radiating symmetrically both forwards and backwards was obtained by a simple mirror translation of the layout of the original antenna with the flat top.

II. ANTENNA WITH THE STACKED SUBSTRATE

Fig. 1 Cross-section of the CBSL with a stacked substrate.

The cross-section of the CBSL with a stacked substrate is shown in Fig. 1. The upper layer is substrate GIL1000, 1.52 mm in thickness with permittivity ε_{r2}=3.05, loss factor tgδ=0.004 and metallization thickness t=0.03 mm. The bottom layer is air, so ε_{r1}=1. Assuming that the slot is wide enough, this transmission line can support propagation of a space leaky wave of the first order with odd symmetry of the transversal component of the electric field parallel to the substrate. The dispersion characteristics of this wave calculated by the APTL Program [12] are plotted in Fig. 2. The phase constant β and the attenuation constant α are normalized to the propagation constant in free space k_0. The upper dielectric layer, in Fig. 1, has the parameters stated above, the slot width is 30 mm and three different heights of the air layer h_2=10, 15, and 20 mm were used. The simulation in the Microwave Studio showed that for h_2 lower than 10 mm unwanted modes excite between the parallel plates, and the radiation efficiency is low. The parasitic radiation into the space below the backed metallization increases for values of h_2 higher than 20 mm. The value h_2=20 mm was therefore chosen as a compromise between these two limits. The dispersion characteristic of the leaky mode on the CBSL with h_2=20 mm, Fig. 2, shows that this mode can be effectively excited from 5 to 10 GHz, as its phase constant is lower than k_0 and the attenuation constant has a reasonably low value. The final antenna setup is shown in Fig. 3. The antenna is fed from a coaxial cable via a CPW terminated by a patch, to transform the incident energy effectively into a space leaky wave of the first order. CBSL open end termination in the form of a wedge was

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used. The feeder geometry was optimized in the CST Microwave Studio for minimum return losses in the widest possible frequency band when the space leaky wave is effectively excited. The resulting frequency dependence of S_{11} measured and calculated by the CST Microwave Studio is plotted in Fig. 4. The antenna is matched from 5 GHz up to 7 GHz, when $|S_{11}|$<-10 dB. The antenna radiation pattern was improved effectively by shaping the background metal into a reflector [10], not shown in Fig. 3. The measured and calculated radiation patterns of this antenna are plotted in Fig. 5 at the frequency 6.75 GHz corresponding to the best antenna matching. Angle Θ is read according to the inset of Fig. 3. The SLL, the full width of the radiation pattern at half power (FWHP) and the angle of maximum radiation are plotted in Fig. 6a.

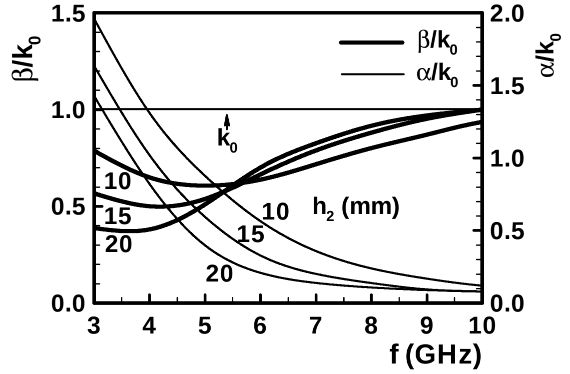


Fig. 2 Normalized dispersion characteristic of the CBSL with a stacked substrate defined in the text.

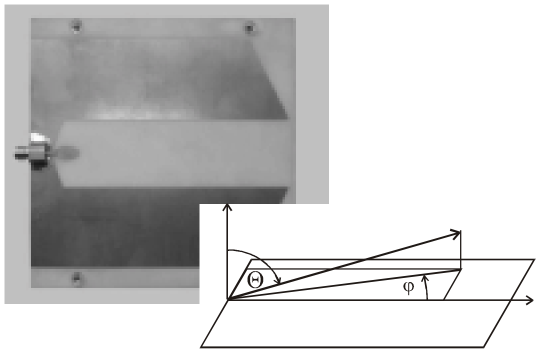


Fig. 3 Layout of the original antenna.

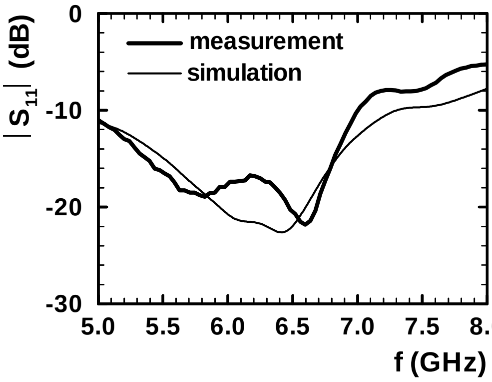


Fig. 4 S_{11} of the original antenna.

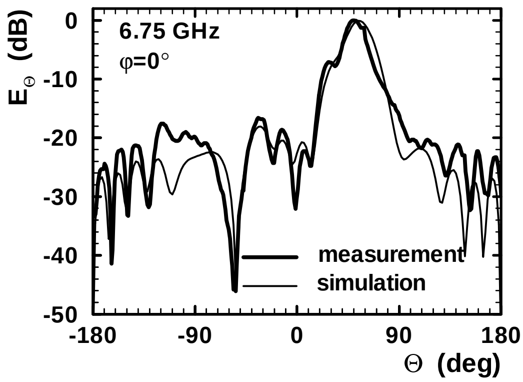
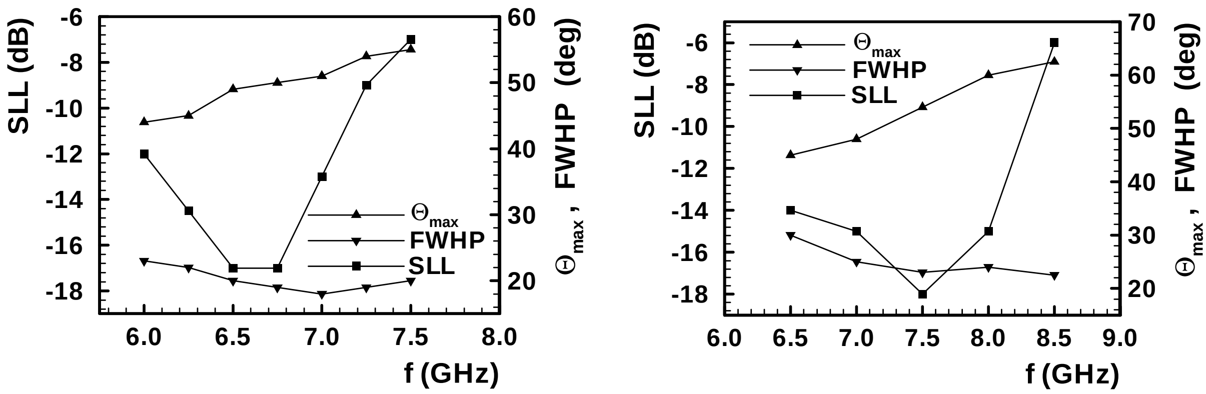


Fig. 5 Radiation pattern of the antenna from Fig. 12 at 6.75 GHz.



(a) **(b)**

Fig. 6 Measured side lobe level, full width at half power in the vertical plane, and the angle of maximum radiation of the original antenna [10] (a) and of the new flat top antenna (b).

III. ANTENNA WITH AN ENTIRELY FLAT TOP

The main drawback of the original antenna [10] is that it is fed through the coaxial connector located on the top surface of the antenna, and the backward wall of the reflector overhangs the top substrate surface with the slot. This violates the planarity of the antenna. Therefore, a new version of the antenna was designed, see Fig. 7. This new antenna is fed by the SMA connector mounted on the rear side of the background conducting layer. The central conductor is led from the connector across the spacer inserted in a teflon cylinder, improving the antenna matching in the frequency band at which the leaky mode is effectively excited. This conductor is soldered on to the patch exciting the space leaky wave of the first order in the radiating slot. The upper dielectric substrate, the slot width, and the thickness of the air layer are the same as in the case of the original antenna. The radiation pattern is shaped by a metallic reflector, Fig. 7. This semi-cylindrical reflector is soldered between the grounding layer and the top slotline conductors. The reflector diameter is 68 mm, equal to the total slotline width. The whole structure of the feeder, the radiating patch and the reflector were optimized by the Microwave Studio to obtain the best antenna matching and a radiation pattern compatible with the characteristics of the original antenna.

The antenna reflection S_{11} is plotted in Fig. 8. The measured reflection coefficient differs from the coefficient calculated by the Microwave Studio. The reason probably lies in an imprecisely fabricated feeding circuit. The usable frequency band of the new antenna is shifted by approximately 0.75 GHz to higher frequencies than those of the original antenna. To this end the design of the new antenna version was not fully successful. The antenna radiation pattern measured at the frequency band center 7.5 GHz is compared with the pattern calculated by the Microwave Studio with a perfect fit, see Fig. 9. The radiation patterns measured at several frequencies are plotted in Fig. 10. The radiation below the ground plane varies from about -25 dB to -30 dB depending on frequency. This is at least -5 dB better than for the original antenna. The wave radiated by this antenna is linearly (vertically) polarized, and the level of the cross polar field is lower by -26 dB in the direction of maximum radiation. The radiation characteristics of the new flat top antenna are comparable with the original antenna [10], except the frequency band, as shown in Fig. 6. The antenna gain calculated and measured at several frequencies is listed in Table 1. The measured gain is lower than the calculated gain due to higher losses in the fabricated structure than the losses estimated for the simulation.

f (GHz)	G (dB) simul.	G (dB) meas.
6.5	13.1	11.74
7	14	12.94
7.5	15.1	13.17
8	15.3	12.92
8.5	13.1	12.44

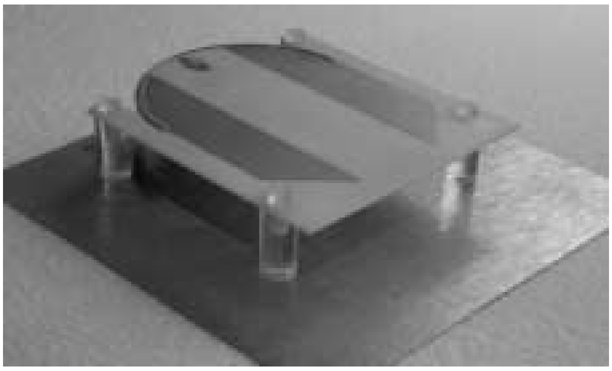


Fig. 7 The fabricated flat top leaky wave antenna.

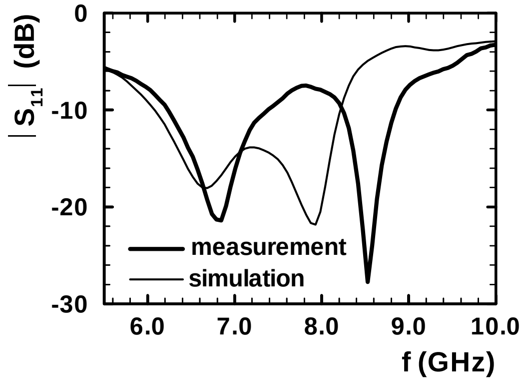


Fig. 8 S_{11} of the fabricated flat top leaky wave antenna.

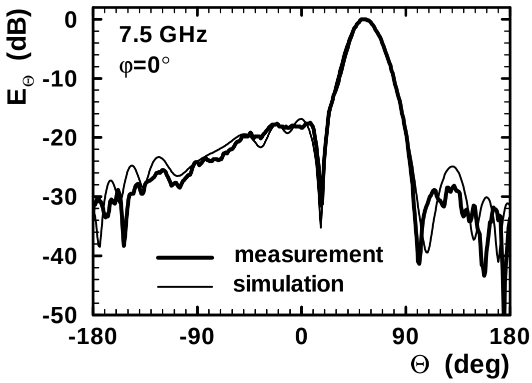


Fig. 9 Radiation patterns of the antenna from Fig. 7 at 7.5 GHz.

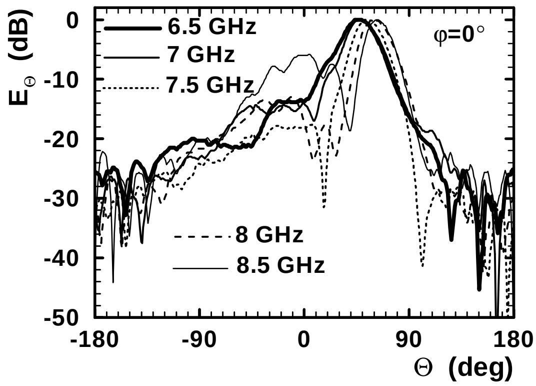


Fig. 10 Radiation patterns of the antenna from Fig. 7 measured at 6.5, 7, 7.5, 8, 8.5 GHz.

The proposed antenna was simply redesigned to a bi-directional antenna radiating symmetrically both forwards and backwards. This antenna is fed through an SMA connector fixed to the background metal, so its top is again completely flat. The fabricated antenna is shown in Fig. 11. The layout of the slotline on the top is just mirrored. The strip like patch is fed at its center and excites the space leaky wave in two directions. The mirrored reflector is divided into two parts to open the space at the antenna center for the feeder. The vertical radiation pattern of the bi-directional antenna is plotted in Fig. 12. Due to interference of the waves radiated in the two directions, the main beam is split. The band at which this antenna is matched is further shifted toward higher frequencies.

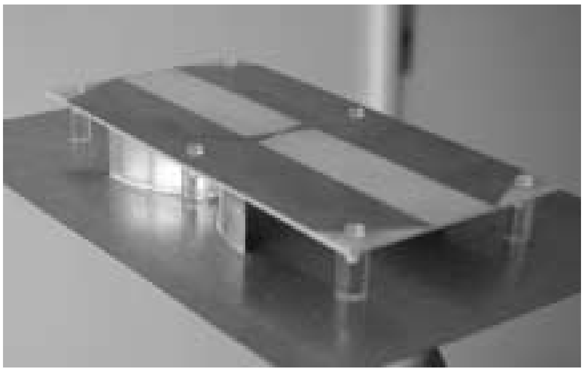


Fig. 11 The fabricated bi-directional antenna.

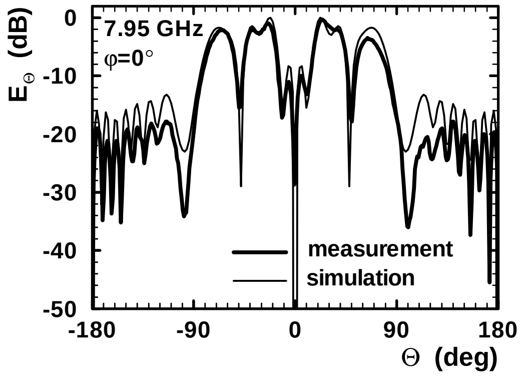


Fig. 12 Radiation pattern of the antenna from Fig. 12 at 7.95 GHz.

4. CONCLUSION

This paper presents the planar version of a leaky wave antenna based on a conductor-backed slotline with a stacked substrate. This substrate consists of a thin dielectric layer and a thick air spacer. The radiated beam is formed by a semi-cylindrical reflector placed between the ground conducting layer and the top substrate. The antenna radiates a first order space leaky wave with odd symmetry into a single main beam above the substrate. This beam is tilted in the forward direction when the frequency increases. The antenna layout was optimized using the CST Microwave Studio. The antenna effectively radiates from 6.5 to 8.5 GHz. Its radiation pattern has a single main beam and the side lobes are at a level not worse than –10 dB below the maximum radiation. The radiation below the substrate varies from -25 dB to -30 dB below the maximum of the main lobe, depending on frequency. The maximum gain of the antenna is 13 dB at 7.5 GHz. The radiation characteristics of this entirely flat top antenna are comparable with the original antenna. The beam is several degrees wider and the direction of the main beam varies faster with frequency. The radiation below the substrate is -5 dB less intensive. This antenna was redesigned to an antenna with bi-directional radiation, retaining the entire flat top. The radiation pattern was split and the applicable frequency band was shifted up, and the radiation below the substrate is now only about -20 dB compared to the main lobe direction.

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