Slotline Leaky Wave Antenna with a Stacked Substrate

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Abstract—This paper presents a new version of a leaky wave antenna based on a conductor-backed slotline with a stacked substrate. The antenna radiates due to the first order space leaky wave excited on a slotline with a wide slot. The antenna radiates into the one main beam above the substrate. The main lobe of the radiation pattern is relatively wide and there is also intensive radiation in the backward direction and below the substrate. Shaping the background metal layer produces a reflector, which reduces the parasitic radiation by 7 dB. When this background layer is larger than the substrate the radiation below the substrate is additionally reduced by 3 dB. The reflector moreover reduces the width of the main beam.

1. Introduction

All kinds of open planar transmission lines are predisposed to excite leaky waves. There are two kinds of leaky waves. Surface leaky waves radiate power into the substrate. These waves are in most cases undesirable as they increase losses, cause distortion of the transmitted signal and cross-talk to other parts of the circuit. Space leaky waves radiate power into a space and mostly also into the substrate. These waves can be utilized in leaky wave antennas.

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]. We have investigated space leaky waves on a slotline (SL) [5] and on a conductor backed slotline (CBSL) [6]. Based on these studies we have designed, fabricated, and measured several leaky wave antennas, as, e. g., the slotline leaky wave antenna in [7]. The drawback of this antenna is radiation 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 the one main beam. This beam is rather wide with a high level of the side lobes (SLL). 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].

This paper presents a slotline leaky wave antenna with a stacked substrate and conductor backing. The antenna radiates the space leaky wave of the first order. The CBSL with a wide slot and substrate consisting of two layers was analyzed by the APTL Program [11] based on the spectral domain method. The CST Microwave Studio performed optimization of an antenna feeder. The shape of the radiation pattern of the antenna has been improved by the background conductor formed into a simple reflector. This makes the main radiation lobe narrower, and considerably reduces the level of the side lobes.

2. Antenna Structure

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 $\varepsilon_{r2} = 3.05$, loss factor tg$\delta = 0.004$ and metallization thickness $t = 0.03$ mm. The bottom layer is air, so $\varepsilon_{r1} = 1$. 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 [11] 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 Microwave Studio showed that for h_2 lower than 10 mm unwanted modes excite between the parallel plates, and the radiation efficiency is low. For values of h_2 higher than 20 mm the parasitic radiation into the space below the backed metallization increases. 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 4 to 10 GHz, as its phase constant is

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

lower than k_0 and the attenuation constant has a reasonably low value. The phase constant slowly increases with frequency. The direction of the main lobe radiation pattern, determined by the phase constant, depends therefore slightly on the frequency.

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 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.

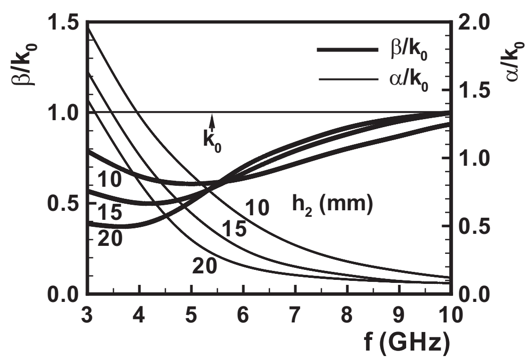

Figure 2: Normalized dispersion characteristic of the CBSL with a stacked substrate defined in the text.

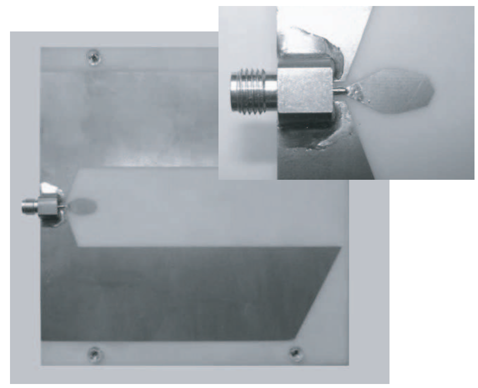

Figure 3: The fabricated antenna with the feeder shown in detail.

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 measured and calculated antenna radiation patterns at 6 and 7 GHz are plotted in Fig. 5 and are in good accord. Angle Θ is read according to Fig. 6. The radiation patterns measured at additional frequencies are plotted in Fig. 6. This antenna has only a small difference between the level of the main lobe and side lobes (side lobe level—SLL), see Fig. 8, and relatively intensive radiation under the substrate. The level of the lobes directed under the substrate is about -13 dB comparing to the main lobe. The main lobe slightly tilts in the forward direction and the full width at half power (FWHP) of the main lobe decreases with frequency, as follows from Fig. 8.

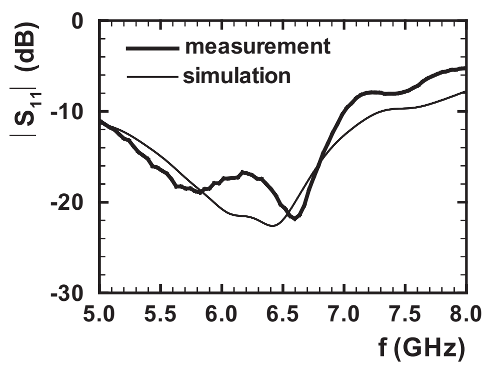

Figure 4: S_{11} of the fabricated antenna.

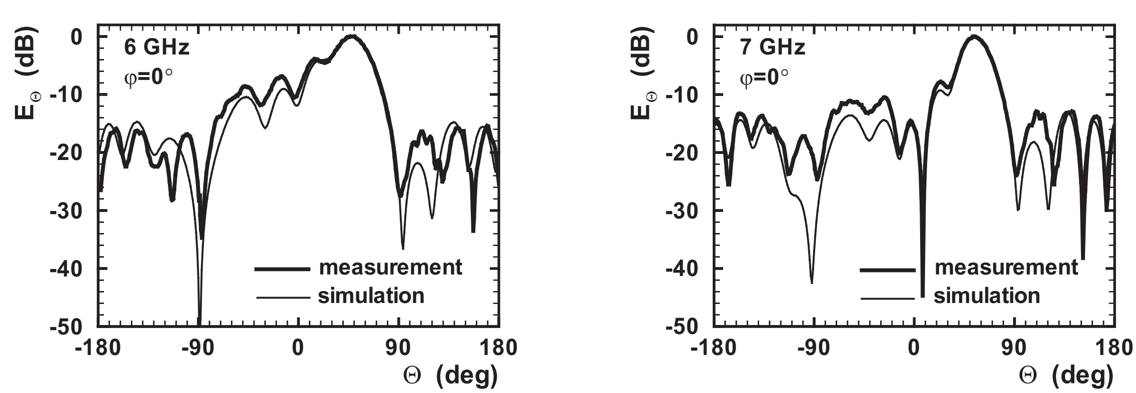

Figure 5: Radiation patterns of the antenna from Fig. 3 at 6 and 7 GHz.

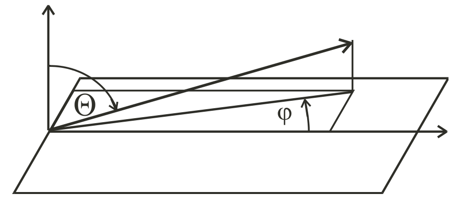

Figure 6: Orientation of angles.

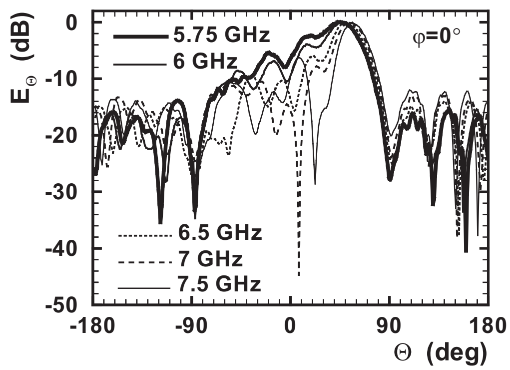

Figure 7: Radiation pattern of the antenna from Fig. 3 measured at 5.75, 6, 6.5, 7, and 7.25 GHz.

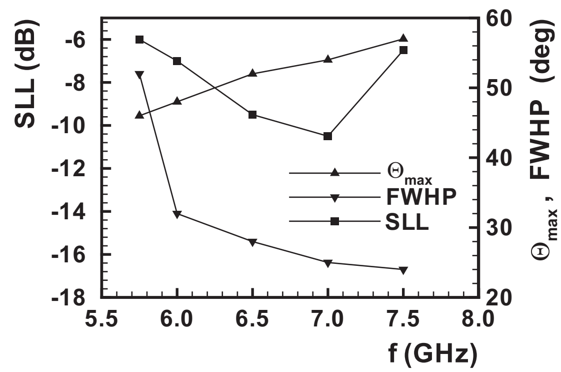

Figure 8: Measured side lobe level, full width at half power, and the angle of maximum radiation of the antenna from Fig. 3.

3. Antenna with a Reflector

The radiation pattern of the CBSL antenna with a stacked substrate has one rather wide main lobe. The antenna also radiates backward and below the backed metallization, Figs. 5, 7 and 8. Its radiation pattern can be shaped effectively by adding the background metal reflector [10], Fig. 9. The layout of the feeder and of the slotwidth was left without any change. This antenna was simulated by CST Microwave Studio with the aim to reduce the side lobes with a reasonably small reflector. Finally the reflector position is 20 mm behind the substrate edge and exceeds the substrate height by 20 mm. This reflector scarcely influences the antenna input impedance. Fig. 10 compares the measured and calculated radiation patterns of the antenna with the reflector at 7 GHz. The radiation patterns measured at three different frequencies are plotted in Fig. 11. Comparing the radiation patterns in Fig. 11 and Fig. 7, we see that the antenna with the reflector has a narrower main beam and the level of both the side lobes and of the lobes directed under the substrate are reduced by 7 dB.

Making the size of the background metal layer larger than the antenna substrate further reduces the radiation below the substrate. In this way we get the antenna shown in Fig. 12. The reflector has the same geometry as in Fig. 9, the bottom conductor is enlarged by 30 mm on the side and front walls of the substrate.

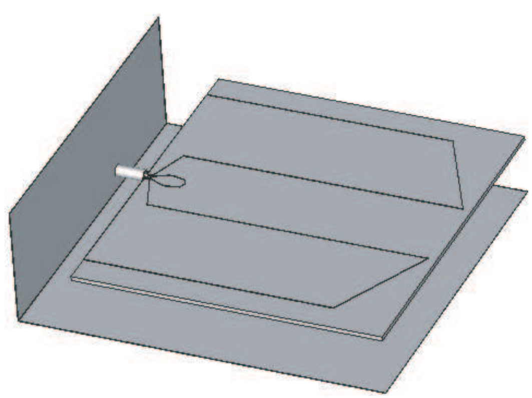

Figure 9: The Microwave Studio model of the antenna with a reflector.

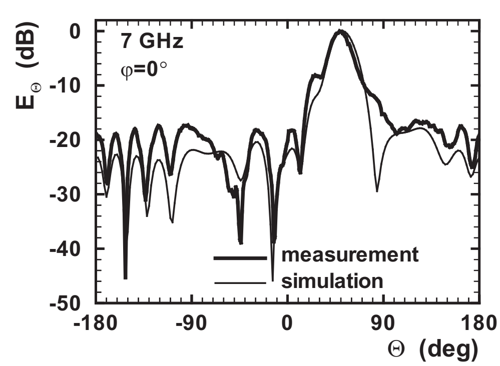

Figure 10: Radiation pattern of the antenna from Fig. 9 at 7 GHz.

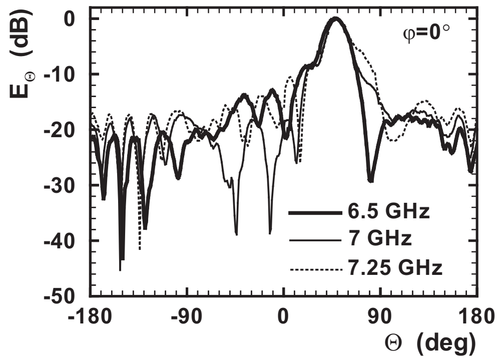

Figure 11: Radiation pattern of the antenna from Fig. 9 measured at 6.5, 7 and 7.25 GHz.

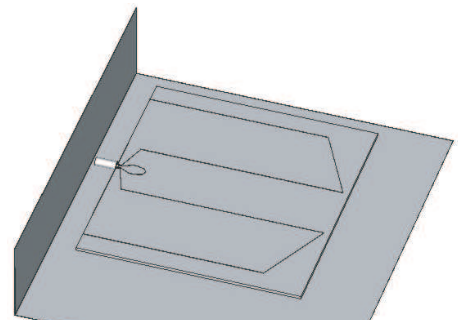

Figure 12: The Microwave Studio model of the antenna with a reflector and the background metal layer larger than the substrate by 30 mm.

The measured and calculated radiation patterns of this antenna are plotted in Fig. 13 at the frequency 6.75 GHz. The two lines fit each other well. The radiation patterns of this antenna measured at several frequencies are plotted in Fig. 14. It follows from Figs. 13 and 14 that the radiation below the substrate is reduced by 3 dB comparing to the antenna from Fig. 9 and by 10 dB comparing to the original antenna without the reflector in Fig. 3. The SLL is reduced from 6.5 to 6.75 GHz to -17 dB. The FWHP of the main beam varies around 20 deg when the frequency changes, which is considerably lower than the FWHP of the antenna from Fig. 3. The direction of the main lobe is saved. The SLL, FWHP, and the angle of maximum radiation of the antenna from Fig. 12 are plotted in Fig. 15. The plot in Fig. 15 in comparison with the plot in Fig. 8 shows the improvement of the radiation pattern when the reflector is applied.

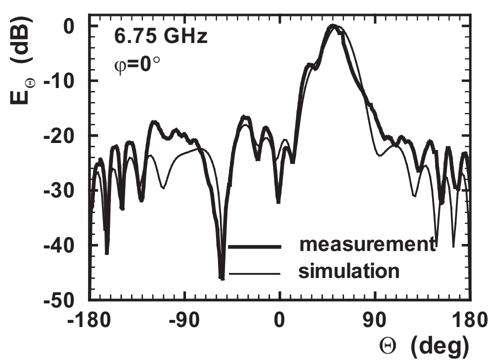

Figure 13: Radiation pattern of the antenna from Fig. 12 at 6.75 GHz.

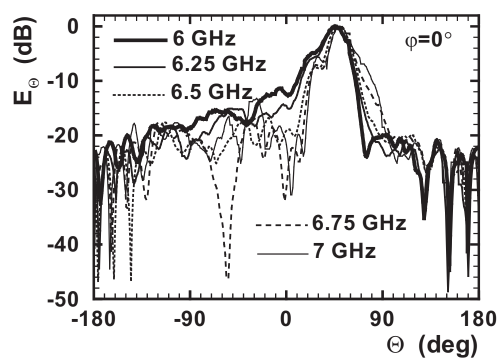

Figure 14: Radiation pattern of the antenna from Fig. 12 measured at 6, 6.25, 6.5, 6.75 and 7 GHz.

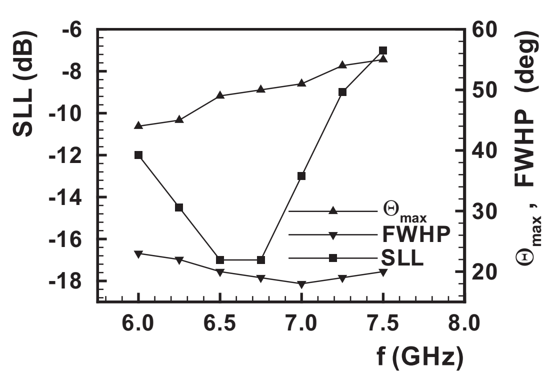

Figure 15: Measured side lobe level, full width at half power, and the angle of maximum radiation of the antenna from Fig. 12.

4. Conclusion

This paper presents a leaky wave antenna based on a conducto-backed slotline with a stacked substrate. This substrate consists of a thin dielectric layer and a thick air spacer. The antenna radiates a first order space leaky wave with odd symmetry only into one 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 5 to 7 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 is not worse than -14 dB below the maximum of the main lobe.

The additional reflector effectively shaped the radiation pattern. Two versions of the antenna with the reflector were designed with the aid of the CST Microwave Studio and then fabricated and measured. The antenna feeder and the slot layout were the same as the antenna without the reflector had. The antenna with the reflector and the ground conductor of the same size as the substrate reduces the level of the side lobes to -17 dB, and the radiation below the substrate to -20 dB. The antenna with the background conductor larger than the substrate has a level of radiation below the substrate lower by an additional 3 dB, i. e., -23 dB. The width of the main lobe is around 20 deg, which is narrower than for the antenna without the reflector. The direction of this lobe is the same for the antenna both with and without the reflector.

Acknowledgement

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