Conductor-Backed Slotline Antenna

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Abstract — **A conductor-backed slotline leaky wave antenna and its modifications were designed, produced and measured. The modified antennas are characterized by one or two additional dielectric layers placed on the top surface of the original structure. These layers adjust the form of the dispersion characteristics of the line, influence the width of the frequency band, reduce/enhance the scanning sensitivity of the main beam, and change its shape.**

I. Introduction

All open planar transmission lines are capable of producing leaky waves. Consequently, any of them can be used for constructing a leaky wave antenna. A slotline (SL) leaky wave antenna radiates due to excitation of the 1st order space leaky wave with odd symmetry of the transversal component of the electric field within the slot [1,2]. The radiation is directed above and below the substrate, which is not convenient in some applications. The conductor-backed slotline (CBSL), sketched in Fig. 1a, has therefore been investigated [3,4]. The power from the CBSL antenna goes into the space above the antenna. Top additional layer/s enhance the flexibility of the antenna design, resulting in the modified conductor-backed slotline (MCBSL) [4,5], shown in Fig. 1b, 1c, 1d. The antenna design utilizes the 1st order space leaky mode dispersion characteristics and their dependence on the line parameters. We optimized the layout and the cross-sectional size of particular antennas by the CST Microwave Studio field simulator, then produced and measured them.

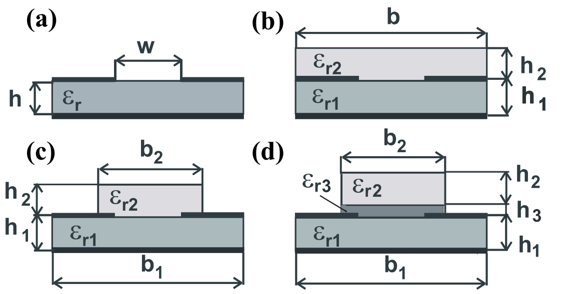

Fig.1 Cross-section of the CBSL (a), the MCBSL (b), the MCBSL with reduced upper layer width (c), the MCBSL with the additional inter-layer (d).

II. Conductor-Backed Slotline Antenna

The substrate of the antenna must have a low permittivity on account of the effective radiation. Consequently, cheap plexiglass with permittivity 2.6 is a suitable candidate for the experiments. The substrate thickness must be chosen with respect to the effective excitation of the space leaky wave. This happens when α, the attenuation constant of the space leaky mode, is sufficiently low. The dependence of α at the frequency f_{max} on substrate thickness is shown in Fig. 2, where the corresponding f_{max} is also plotted. Frequency f_{max} is the upper frequency of the band in which this mode is physical. Attenuation constant α decreases almost linearly in the shown range of h. Consequently, to get low α we have to use a thick substrate. Excessively thick substrates, however, are not desirable in many applications. We therefore used in our experiments plexiglass 15 mm in thickness, which gives the maximum frequency 6.2 GHz supposing that w=30 mm.

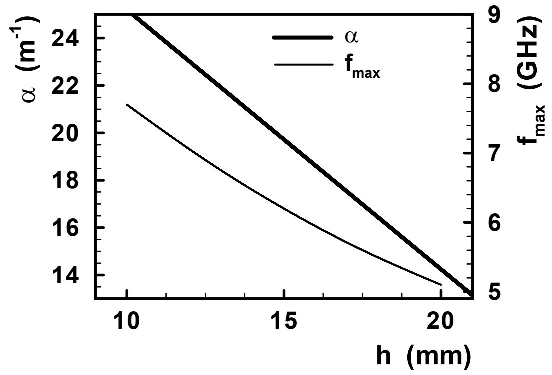

Fig. 2 The attenuation constant at f_{max} and the upper boundary frequency of the 1st space leaky mode on the CBSL with w=30 mm, ε_r=2.6, in dependence on the substrate thickness.

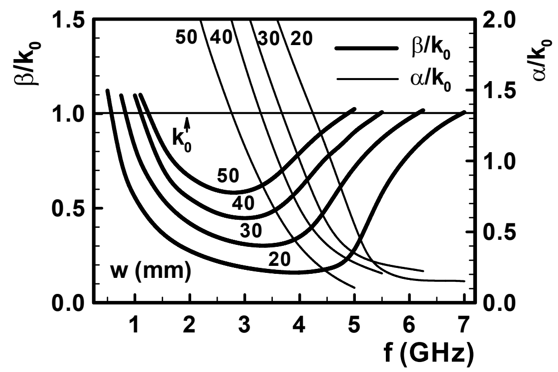

Fig. 3 Normalized dispersion characteristics of the CBSL with h=15 mm, ε_r=2.6 for slot widths w=20, 30, 40, 50 mm.

Slot width w determines the antenna frequency band, as documented in Fig. 3, where the set of dispersion characteristics of the space leaky mode of the first order on the CBSL is plotted. The theoretical antenna operation frequency band, at which $\beta/k_0<1$, is limited at low frequencies due to the impossibility of leaky wave excitation when its attenuation constant is too high. Therefore, this frequency band starts at about the frequency of the minimum of the phase constant.

The frequency band of the antenna is further reduced by the antenna feeder. The layout and the dimensions of the feeder, sketched in Fig. 4, were optimized in order to get the widest possible frequency band. The CBSL and its modifications can be short or open terminated, as shown in Fig. 4. The shape of these terminations emerges from optimizing the layout in order to suppress the side lobes. The slotline in all antennas presented in this paper is terminated by the short.

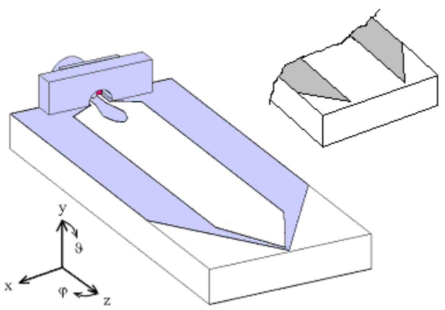

Fig. 4 The CBSL leaky wave antenna, a sketch of the open-end termination.

The calculated and measured return losses of the antenna are plotted in Fig. 5. The antenna radiates effectively when $|S_{11}|$<-10 dB, i.e., from 4.75 to 6 GHz. The corresponding frequency band is about 23%.

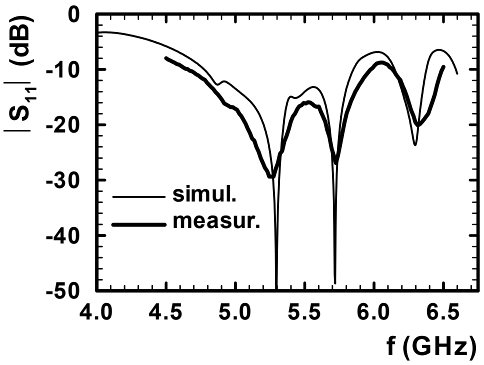

Fig. 5 Measured and calculated return loss of the antenna from Fig. 4 with w=30 mm, h=15 mm, ε_r=2.6, b=70 mm.

The radiation pattern is plotted in Fig. 6, where angles θ=0° and 90° correspond to broad-side and fire-end radiation, respectively, see Fig. 4. The antenna radiates into one lobe, which inclines with frequency. The maximum of the radiation intensity tilts with increasing frequency to the substrate surface from θ=37° to 70° at 4.75 and 6 GHz, respectively, as shown in Fig. 7, where the measured radiation patterns are plotted for three different frequencies. The corresponding scanning sensitivity is about 26 deg/GHz. The measured -3dB widths of the main beam are 46.7° at 4.75 GHz, 36.7° at 5.25 GHz and 32.8° at 6 GHz. Radiation below the substrate also occurs due to the finite dimensions of the substrate with back metallization. Its level increases with frequency from -35 dB to -30 dB and -25 dB below the main beam level at 4.75, 5.25 and 6 GHz, respectively.

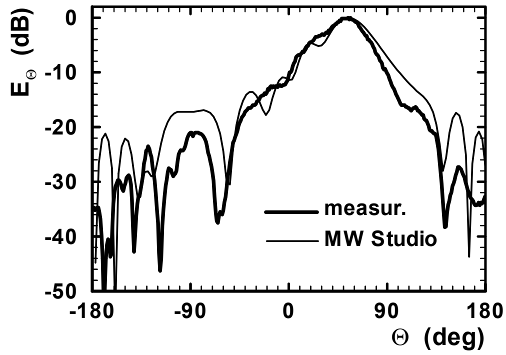

Fig. 6 The measured and calculated radiation pattern of the antenna from Fig. 4 in the elevation plane and at the azimuth φ=0° when w=30 mm, h=15 mm, ε_r=2.6, b=70 mm and f=5.25 GHz.

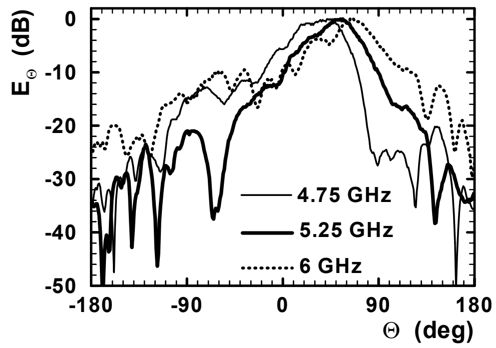

Fig. 7 The radiation patterns as in Fig. 6 measured at 4.75, 5.25 and 6 GHz.

III. ANTENNA MODIFICATIONS

Unlike a CBSL antenna, the upper dielectric layer of the MCBSL offers two additional parameters controlling the dispersion characteristics. Fig. 8 shows the dependence of the dispersion characteristics of the 1st space leaky mode on the MCBSL, Fig. 1b, on the thickness of the upper dielectric layer h_2. The permittivity of the substrate and the layer is 2.6. These characteristics resemble the characteristics from Fig. 3 when h_2 is small. For a thicker upper layer, e.g., h_2=5 mm in Fig. 8, the dispersion characteristic is steeper and provides a narrower usable frequency band. This MCBSL is therefore suitable for an antenna design with higher scanning sensitivity. The dispersion characteristics in Fig. 8 become relatively flat at higher frequencies and greater h_2, e.g., for h_2=10 mm. Such a line is a candidate for a wide band antenna with a radiation pattern less sensitive to frequency variation. For an even thicker upper layer the frequency band shrinks again. The increase in the upper dielectric layer permittivity shifts the dispersion characteristic to lower frequencies and makes it steeper, resulting in a narrower usable frequency band strongly influenced by the antenna feeder.

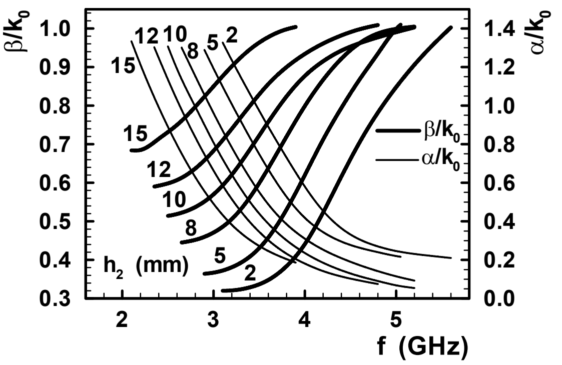

Fig. 8 Dispersion characteristics of the 1st space leaky mode on the MCBSL from Fig. 1b with w=30 mm, h_1=15 mm, $\varepsilon_{r1}=\varepsilon_{r2}$=2.6 calculated for various h_2.

A MCBSL antenna with reduced width of the upper dielectric layer, Fig. 1c, possesses a smoother radiation pattern than an antenna with the same width of the two dielectric layers, Fig. 1b. The measured radiation of the MCBSL antenna from Fig. 1c with h_2=10 mm is shown in Fig. 9. The main lobe moves slightly with the frequency from θ=41° at 4 GHz to 54° at 5 GHz, so its scanning sensitivity is 13 deg/GHz. The -3 dB width of the radiation pattern remains 54° from 4 to 5 GHz.

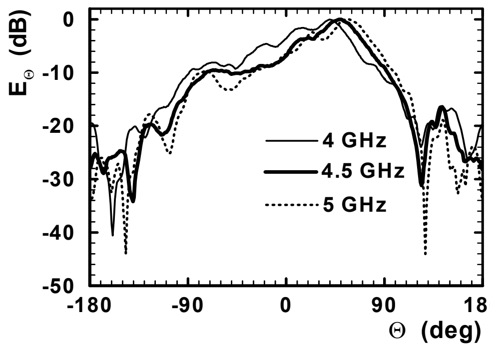

Fig. 9 Measured radiation patterns of the MCBSL antenna, Fig. 1c, with w=30 mm, h_1=15 mm, h_2=10 mm, $\varepsilon_{r1}=\varepsilon_{r2}$=2.6, b_1=70 mm, b_2=31 mm, when φ=0°.

The scanning sensitivity of the main beam of the MCBSL antenna, Fig. 1b, with the parameters defined in Fig. 8 and h_2=5 mm predicted by the calculation is 40 deg/GHz, but its radiation pattern is not suitable for practical applications due to its strong ripple. Fig. 10 shows the radiation patterns of the MCBSL antenna with the cross-section in Fig. 1c, where h_2=5 mm and b_2=31mm. The main lobe scanning sensitivity is now only 24 deg/GHz from 4 to 5 GHz, as the main beam inclines from 37° at 4 GHz to 61° at 5 GHz. The -3 dB width of the radiation patterns varies from 56° at 4 GHz to 37° at 5 GHz.

The measured patterns plotted in Figs. 9 and 10 fit well the calculated patterns not shown here in order not to make the plots overweighted.

The calculated and measured return losses of the antenna with h_2=10 mm are plotted in Fig. 11. The frequency band determined by $|S_{11}|$<-10 dB is from 4 to 5.4 GHz, which is 30 %.

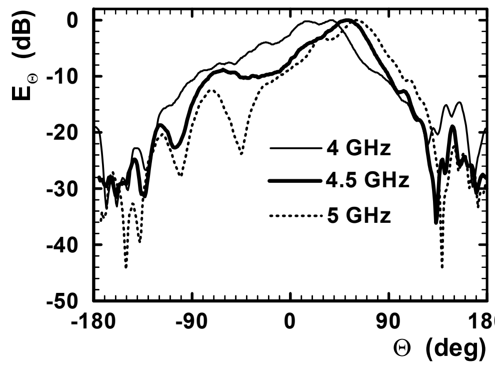

Fig. 10 Measured radiation patterns of the MCBSL antenna, Fig. 1c, with w=30 mm, h_1=15 mm, h_2=5 mm, $\varepsilon_{r1}=\varepsilon_{r2}$=2.6, b_1=70 mm, b_2=31 mm, when φ=0°.

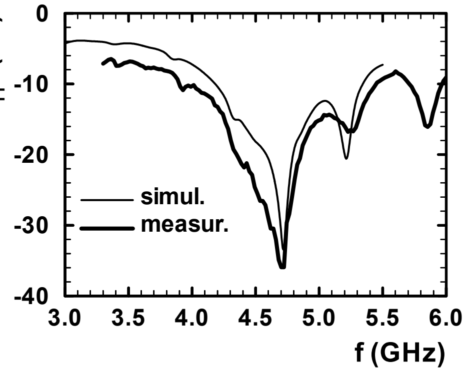

Fig. 11 Measured and calculated return loss of the MCBSL antenna defined in Fig. 9.

The additional inter-layer placed between the substrate and the top layer of the MCBSL, Fig. 1d, offers two additional parameters controlling the dispersion characteristics and the radiation pattern. The air inter-layer narrows the antenna radiation pattern. A similar effect was observed on a microstrip antenna in [6]. This is apparent from the comparison of Fig. 9 with the radiation pattern plotted in Fig. 12 and valid for the MCBSL antenna with the air inter-layer, Fig. 1d.

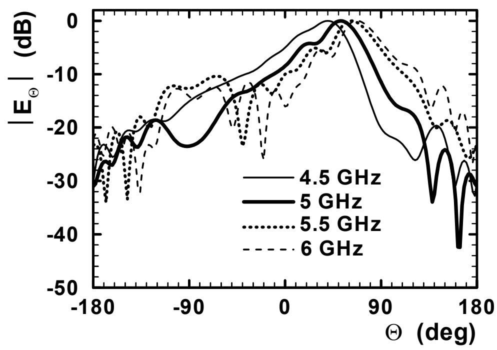

Fig. 12 Calculated radiation pattern of the MCBSL antenna with the inter-layer, Fig. 1d, when w=30 mm, h_1=15 mm, h_2=10 mm, h_3=3 mm, $\varepsilon_{r1}=\varepsilon_{r2}$=2.6, ε_{r3}=1, b_1=70 mm, b_2=8 mm, in the plane φ=0°, at 6.5 GHz.

The -3 dB width of the radiation patterns varies from 39° at 4.5 GHz to 33° at 6 GHz, while the main beam direction inclines from 40° at 4.5 GHz to 67° at 6 GHz, which gives the scanning sensitivity 18 deg/GHz. The calculated return loss of the MCBSL antenna with the additional inter-layer defined in Fig. 12 is plotted in Fig. 13. The frequency band determined by $|S_{11}|$<-10 dB is from 4.65 to 5.85 GHz, which is 22%.

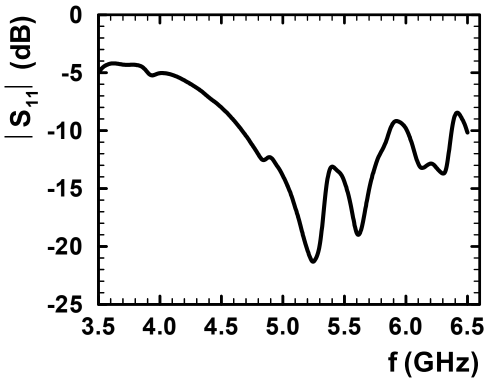

Fig. 13 Calculated return loss of the antenna defined in Fig. 12.

The layout of the metallization and the lower substrate of the MCBSL antennas presented in this third section are the same as in the second section, above. Only the additional dielectric layer has been put on the CBSL structure without any additional optimization of the feeder.

VI. Conclusion

A conductor-backed slotline with a wide slot is a suitable radiating element – a leaky wave antenna which radiates into one main lobe above the substrate. However, radiation below the substrate also occurs, due to the finite size of the antenna. The antenna design is based on the dispersion characteristics of the 1st order space leaky mode. An antenna, fed by the CPW, was designed, fabricated and measured. Short-circuited termination of the slot in the shape of a wedge reduces the radiation pattern ripple and back lobes. Frequency scanning sensitivity 26 deg/GHz was achieved in the 4.75-6 GHz range. The measured and calculated radiation patterns as well as the input return loss compare well. The effective operation frequency band of the antenna, in which $|S_{11}| < -10\,\text{dB}$, spans from 4.75 to 6 GHz, i.e., 23 %.

The modified conductor-backed slotline enables more flexible antenna design. The thickness and permittivity of the upper dielectric layer change the dispersion characteristics of the 1st space leaky mode. The antenna thus possesses on the one hand increased beam scanning sensitivity, and on the other hand a radiation pattern less sensitive to the frequency. To protect the antenna radiation pattern from a strong ripple the width of the upper dielectric layer was reduced. The two antennas were produced and measured. The MCBSL antenna with the upper layer 10 mm in thickness exhibits reduced scanning sensitivity of 13 deg/GHz and its frequency band is 30%. The antenna with this layer 5 mm in thickness exhibits scanning sensitivity of 24 deg/GHz, which corresponds to the aim to design an antenna with increased scanning sensitivity.

A conductor-backed slotline antenna with an additional inter-layer offers two additional parameters for controlling the antenna behaviour. For the air inter-layer, the width of the main lobe of the antenna radiation pattern is narrowed. Scanning sensitivity of 18 deg/GHz and a frequency band of 22% have been predicted for this designed antenna.

Acknowledgement

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References

[1] J. Zehentner, J. Machac, P. Lorenz, J. Mrkvica: „Leaky wave radiation from printed slotline antennas,“ in *Proceeding of the 2001 Asia Pacific Microwave Conference,* Taipei, Taiwan, Dec. 2001, Vol. 3, pp. 1175-1178.

[2] J. Machac, J. Zehentner, P. Lorenz, J. Mrkvica: “Wide slotted printed slotline radiator,” in *Proceeding of the 2002 MIKON – XIV International Conference on Microwaves, Radar and Wireless Communications*, Gdansk, Poland, May 2002, Vol. 1, pp. 226-229.

[3] J. Zehentner, J. Machac, J. Mrkvica: “Novel selected modes on the conductor-backed slotline,” *2002 IEEE MTT-S International Microwave Symposium Digest*, Seattle, June 2002, Vol. 2, pp. 961-964.

[4] J. Zehentner, J. Machac, J. Mrkvica, C. Tuzi: “Modes on the standard and inverted conductor-backed slotline,“ *2003 IEEE MTT-S International Microwave Symposium Digest*, Philadelphia, PA, USA, June 2003, Vol. 2, pp. 677-680.

[5] J. Zehentner, J. Machac, J. Mrkvica, C. Tuzi: “The inverted conductor-backed slotline – a challenge to antenna and circuit design,” in *Proc. of the 33rd European Microwave Conference*, Munich, Germany, October 2003, Vol. 1, pp. 73-76.

[6] L. O. McMillan, N. V. Shuley: “The effect of an air gap on the radiation pattern of a microstrip leaky wave antenna radiating into a half space,” *AP-S International Symposium*, July 1997, Vol. 2, pp. 1134-1137