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LEAKY WAVE RADIATION OF A PRINTED SLOTLINE ANTENNA

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This paper presents a theoretical prediction of the field radiated from a uniplanar slotline antenna operating with the leaky wave. Discussion on a possible spectrum of space leaky waves is opened. Several antennas and their feeding structures are designed. The return loss and radiation pattern of the antennas are calculated and experimentally verified.

1 Introduction

Low profile and entirely planar antennas have been investigated and utilized for more than thirty years. They save up space and can be located on the external surface of a body, according to its shape. In order to produce radiation in the narrow or wide frequency band, either the standing wave in the resonant structure or the traveling wave on the transmission line is utilized [1,2]. The latter case is treated in this paper.

We have investigated the space leaky waves on the slotline in the wide frequency band and determined their dispersion characteristics. It has turned out that a slotline with a sufficiently wide slot can radiate in space. A new view has been introduced on the propagation constants obtained from the dispersion equation referring to space leakage. The aim of this paper is to discuss the new mode spectrum of the space leaky waves on the slotline, to evaluate the ability of the slotline to radiate, to examine the far field, to design and compare antennae feeding through the microstrip line and the coplanar waveguide, to design the antenna, to compare its calculated and measured return loss and radiation pattern.

2 A set of space leaky modes on the slotline

In calculating of the dispersion characteristics of the slotline, a cross-section of which is shown in Fig. 1, we used the method of moments in the spectral domain. In [3] we gave an overview and classification of the dominant and higher order bound waves, and of the space leaky waves with odd and even electric field symmetry within the slot. In order to verify them experimentally at frequencies up to 12.5 GHz, where measuring equipment is easily accessible, we recalculated the dispersion characteristics on a thin and low permittivity substrate. We will inquire into only the 1st space leaky wave, on the slotline with w=60 mm, h=1.2 mm, ε_r=2.6, having odd symmetry of the E_x field component within the slot. Recent research into solutions of the dispersion equation has resulted in a reclassification of space leaky waves, the propagation constants of which are shown in Fig. 2. Sequential numbers in this figure denote successive solutions of the dispersion equation representing possible constituent space leaky waves related to the only one fixed odd basis function within the slot. However, their space field distribution, shown in Figs. 3 and 4, differs considerably. The waves are physical, provided that their phase constants β are lower than the wave number of free space k_0. With the exception of the basic space leaky wave

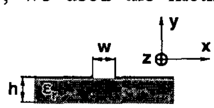

Fig. 1 Cross-section of the slotline.

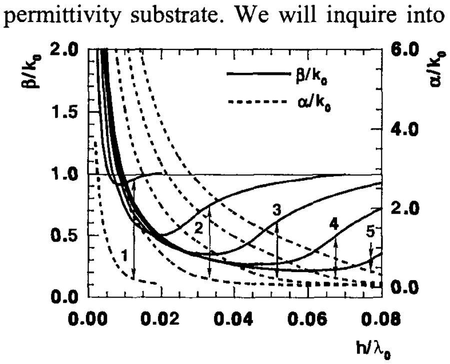

Fig. 2 Normalized phase β/k_0 and leakage α/k_0 constant of the slotline with w=60 mm, h=1.2 mm, ε_r=2.6 depending on the normalized frequency h/λ_0 as the multivalue solution of the dispersion equation.

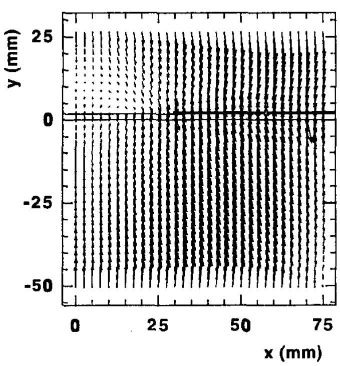

Fig. 3 Field distribution of the 1st space leaky wave at the cross-section plane for h/λ_0=0.015 and for the first leftmost solution in Fig. 2.

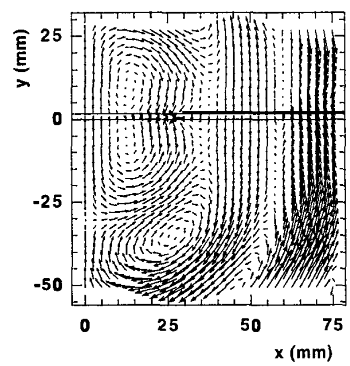

Fig. 4 Field distribution of the 1st space leaky wave at the cross-section plane for h/λ_0=0.015 and the second solution in Fig. 2.

related to the leftmost propagation constant, numbered one, the others are physically meaningful only in the close neighbourhood of the source, due to the great leaky constant α. In all probability this indicates enhanced leakage of power into the substrate, not high radiation efficiency. Nevertheless, a number of modes originate from the same E_x in the slot and have a different space distribution. Since they occur at the same frequency there is multiple degeneration of the propagation constant. This results from a movement of the branch point and a branch cut at the complex plane of the Fourier transform variable where integration is carried out in accordance with the change of the propagation constant. This finding confirms the short notification regarding the number of solutions made in [2] with respect to the suspended microstrip. All the work so far published considers the leftmost solution, number one in Fig. 2, as the first space leaky wave propagation constant. For practical reasons, only this wave is utilized for operating a slotline leaky wave antenna.

3 The antenna and its feeder design

The antenna design was based on the background presented above. A microstrip patch placed along the slotline axis on the opposite side of the substrate excites the first space leaky wave as in [4]. Fig. 5 shows the orientation of the antenna and the co-ordinates. The feeder is unable to excite the 2nd and 3rd space leaky wave, since their fields and the feeder field are not in conformity with each other. However, the field of the 1st higher order bound wave resembles the field of the 1st space leaky wave in and close to the slot, and can excite simultaneously. The feeder dimensions were designed by the Zeland IE3D simulator. The length of the slotline was determined by the distance at which the amplitude of the 1st space leaky wave decreased to zero.

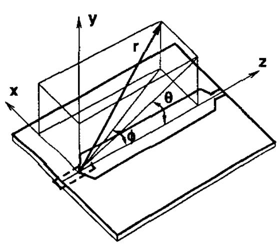

Fig. 5 Co-ordinates and the microstrip patch fed slotline antenna arrangement.

Primary design of the line termination took account of a short section of a narrow slotline on which the 1st space leaky wave is not allowed to propagate. An endeavour to suppress the ripples in the radiation pattern and the backward antenna radiation resulted in the short-circuit slotline termination shown in Fig. 6. To take complete advantage of the uniplanar technology the CPW patch antenna feeder was designed, again by the IE3D simulator. The upper notes on the field configuration excited by the microstrip patch still remain valid. The primary design of the new antenna was at 3 GHz. The transition from the coaxial connector to the CPW input of the antenna raised the need to insert between them a short piece of the CPW. Due to this additional CPW section the antenna operation frequency was shifted to 2.66 GHz. A further consequence of this was that the scanning sensitivity was enhanced.

The last modification of the antenna followed from a study of the undesired standing waves occurring along the slot. Their successful suppression ensured a matched load at the end of the slot in which the first higher order bound wave is absorbed. A conductor-backed slotline antenna enables radiation only in the half-space.

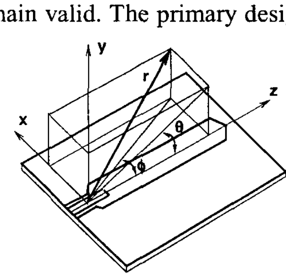

Fig. 6 Co-ordinates and the new CPW fed slotline antenna arrangement.

4 Antenna parameter measurements

Mapping the field by a small probe movable across, Fig. 7, and along, Fig. 8, the slot confirmed domination of the 1st space leaky wave in the excited spectrum. The fit of the measured field decay only by the 1st space leaky wave was faster and therefore wrong over a distance of 100 mm from the feeder. The dashed line in Fig. 8 is the sum of the 1st space leaky wave and the first higher order bound wave, which remains on the line even after the leaky wave vanishes. The magnitude of the space leaky wave is 16 times greater than the magnitude of the bound wave. The bound wave reflection from the short-circuit line termination leads to periodical ripples in the measured record. The thin solid line in Fig. 8 accounts for this effect and compares well with the measured record. Fig. 9 confirms this conclusion experimentally. The thick line is the field decay along the slotline terminated by an absorber while the thin line belongs to the short-circuit termination.

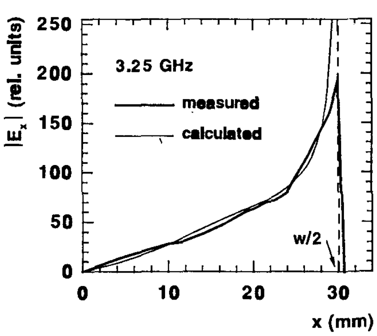

Fig. 7 Measured and calculated transversal electric field component E_x across the slot of the line from Fig. 2 at a frequency of 3.25 GHz and at a distance of 130 mm from the feeding microstrip patch.

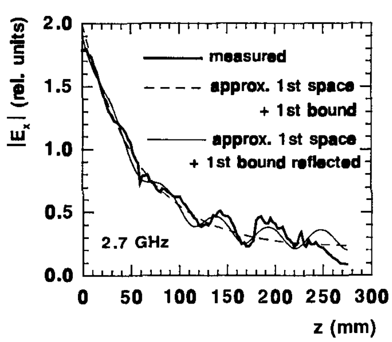

Fig. 8 Measured and calculated decay of the transversal electric field component E_x along the slotline from Fig. 2 when the position of the probe is taken from the edge of the feeding CPW patch and f=2.7 GHz.

The return losses of the antenna fed by the microstrip and by the CPW patch are shown in Fig. 10 and 11, respectively. The junction resistor between the inner conductor of the coaxial connector and the microstrip patch, losses in the substrate, in the aluminium metallization, and in the adhesive, not accounted for in the simulation, produced worse return losses than their predicted values. The CPW feeder has a somewhat wider frequency band. The short-circuit and matched load termination scarcely influenced the return loss.

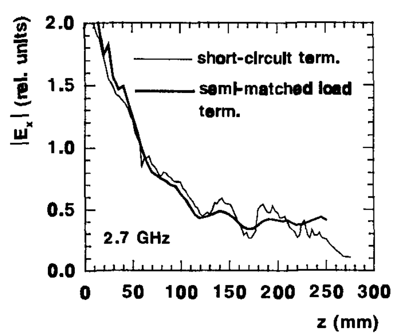

Fig. 9 Measured decay of the E_x field component along the slotline in Fig. 8 terminated by the short-circuit and by the semi-matched load.

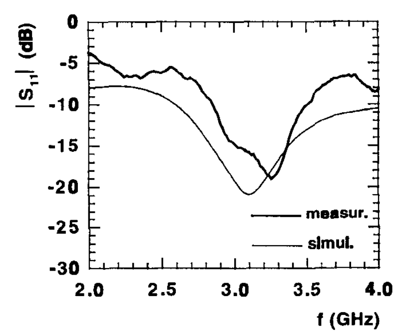

Fig. 10 Measured and calculated return loss of the slotline with with w=60 mm, h=1.2 mm, ε_r=2.6 fed by the microstrip.

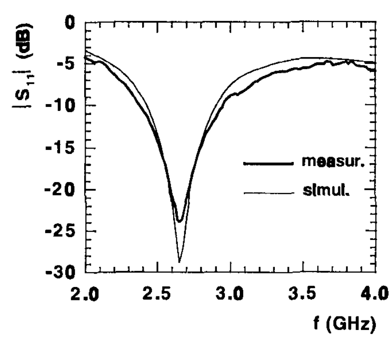

Fig. 11 Measured and calculated return loss of the slotline in Fig. 10 fed by the CPW patch.

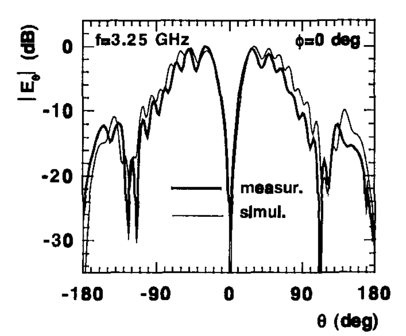

Fig. 12 Measured and calculated $E_\theta(\theta)$ radiation pattern of the antenna in the plane ϕ=0 degrees at 3.25 GHz.

Fig. 12 plots the measured and calculated radiation patterns $E_\theta(\theta)$ in the vertical plane ϕ=0 of the microstrip patch fed antenna. Ripples in the radiation pattern arose due to an undesired standing wave occurring in the metallized area. It has turned out that reflection of the first higher order bound wave from the short-circuit at the end of the antenna was responsible for the ripples. The measured and calculated radiation patterns of the CPW fed antenna without absorber are shown in Fig. 13. For comparison we also plot the measured radiation pattern of the same antenna terminated by a semi-matched load. In the latter case the pattern is clearly without ripples. The antenna beam inclined from 36.3 to 22.7 degrees from the plane ϕ=0 when the frequency changed from 2.5 to 4.0 GHz for the first, and from 58 to 42 degrees when the frequency changed from 2.35 to 3.5 GHz for the second antenna. The measured antenna gain was 7 dB.

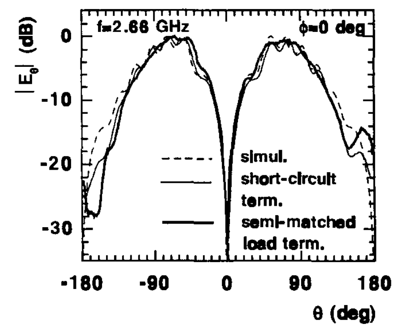

Fig. 13 Measured and calculated $E_\theta(\theta)$ radiation pattern of an antenna 300 mm long, fed by the CPW, in the plane ϕ=0 degrees at 2.66 GHz with short-circuited termination, and measured $E_\theta(\theta)$ when the slot is terminated by the semi-matched load.

5 Conclusions

The slotline with a wide slot on a thin and low permittivity substrate was investigated. Emphasis was put on radiation of power by the space leaky wave. At the same frequency particular space leaky waves have multivalue propagation constants. Each constituent wave has a more complex and more rapidly growing field in space, and a fast decreasing amplitude along the line. The first five consecutive solutions of the slotline dispersion equation belonging to the same category of constituent modes were identified.

Excitation of the desired wave depends considerably on the feeder. Our slotline antenna was fed both by a microstrip patch placed on the metalless side of the substrate and by a CPW patch placed in-line on the metallized plane of the antenna. The latter arrangement is fully planar with respect to the feeder and radiator. Better feeder efficiency, evaluated in terms of return loss, was achieved than in [4]. Field mapping across and along the slot confirmed the presence and domination of the first space leaky wave and revealed a cause of ripples in the radiation pattern.

The slotline antenna radiates two beams, on opposite sides of the substrate. Short circuited termination of the slot reduces backward lobes and, to some extent, radiation pattern ripples. The matched load at the end of the antenna cancels the standing waves along the slot and removes ripples in the far field. Frequency scanning sensitivity 9 deg/GHz was achieved in the 2.5-4.0 GHz range and 14 deg/GHz in the 2.25-3.5 GHz range, respectively. The measured and calculated radiation patterns compare well.

A conductor-backed slotline antenna was also tested. It radiates only to the half-space and could form a counterpart to the microstrip leaky wave antenna [5].

Acknowledgements

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