SLOTS AS NEW CIRCUIT-ELEMENTS IN DIELECTRIC IMAGE LINE

Klaus Solbach, Ingo Wolff
Dep. of Electr. Eng.
University Duisburg
Bismarckstr. 81
4100 Duisburg 1
Germany

ABSTRACT

Slots in the ground plane of dielectric image lines are investigated as new circuit elements. This configuration has attrated attention for two applications: The dielectric image line above the slot can be designed to act as a shielding, thus reducing radiation losses if a diode is mounted above the slot e.g. in a detector- or mixer-circuit. On the other hand, similar to slots in metal waveguides, slots in the ground plane of dielectric image lines can be designed for antenna applications and even for nonradiating filter-structures.

Introduction

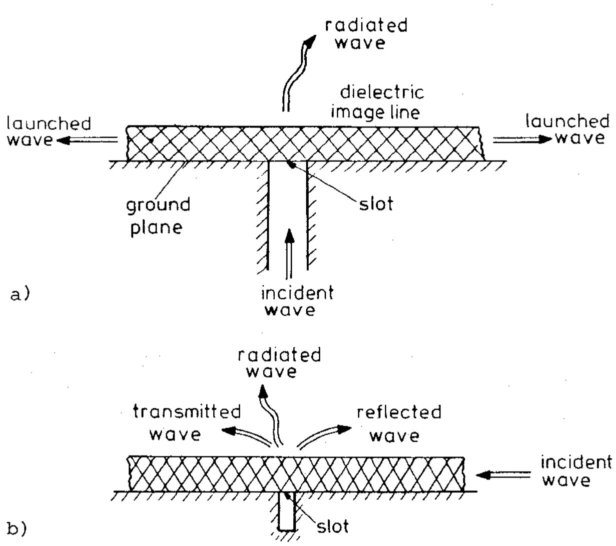
In recent years several components for use in dielectric image line integrated circuits have been developed[1,2,3]. It is now clear that radiation losses play a major role in the performance of dielectric waveguide circuit-elements[4,5]. To reduce the radiation losses in oscillator- and mixer circuits, as a consequence, modified metal waveguide mounts have been proposed with horn-sections to couple to the dielectric waveguide[1]. On the other hand it has been found that antenna structures are particularly easy to realize using discontinuities in the dielectric waveguides[6,7].

In this contribution slots in the ground plane of dielectric image lines are investigated as a new type of circuit elements. These configurations have attracted attention since the dielectric layer above the slot can be designed to act as a shielding, thus reducing radiation losses e.g. in detector- or mixer-circuits.

Nevertheless, similar to slots in metal waveguides, slots in the ground plane of dielectric image lines can be designed for antenna applications and even nonradiating filter-structures.

Slots as Circuit-Elements

In Fig.1 three different applications of slots in the ground plane of dielectric image lines are sketched.



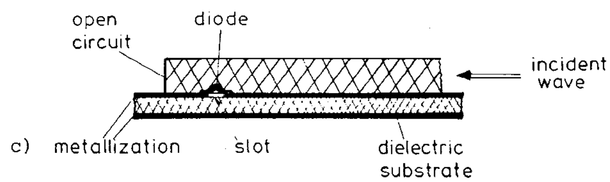


Fig.1: Slots in the ground plane of dielectric image lines employed as mode launcher (a), discontinuity element (b) and for the integration of a semiconductor device (c).

In Fig.1(a) a slot is shown acting as a mode launcher. In Fig.1(b) the configuration used in filter- and antenna-circuits is shown and in Fig.1(c) a slot in the image plane of the dielectric waveguide is used to integrate a semiconductor device.

Two basic types of slots have been investigated, namely the transverse and the circular slot. These slots may either be machined in a solid metal ground plane or may be etched in the metallization layer, if a metallized dielectric substrate is used as the ground plane.

The transverse slot has been investigated analytically employing a planar resonator model, i.e. the finite width of the slot and the dielectric image line have been neglected. The circular slots have been investigated experimentally only, since the basically two-dimensional slots do not lend themselves to a planar model.

It has been found that the narrow transverse slot in a first approximation can be described as a junction of the dielectric image line and a waveguide extending from the slot into the ground plane, Fig.2. This wave-

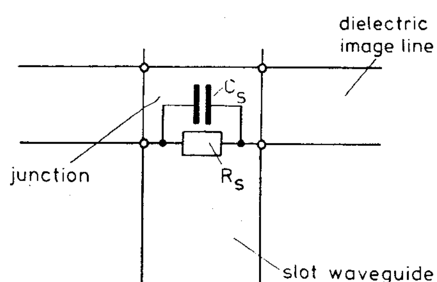


Fig.2: Approximate equivalent circuit representation of a slot in the ground plane.

149-645X/81/0000-0008$00.75

guide can be short-circuited, as in the case of the configuration in Fig.1(b), or it can be terminated by a matched source, Fig.1(a), or it represents the possible propagating waves in the substrate material. The stored energy in the slot is represented by the capacitor C_s and the power radiated into the space above the dielectric image line is represented by the resistance R_s.

Although for circular slots the employed theoretical method is inadequate, the derived basic representation of the discontinuity in Fig.2 seems to be valid for this case too. Only the slot waveguide is of circular cross-section in this case and thus it is operated below cut-off for the fundamental circular waveguide mode, if only narrow circular slots are employed.

Practical Slot-Circuits

Mode Launcher. As sketched in Fig.1(a) slots can be used to launch waves on the dielectric image line. It is clear from Fig.2 that the launching efficiency depends on the magnitude of the slot radiation resistance R_s, since this circuit-element represents the radiation losses.

The results of the numerical calculations for the planar slot model show that R_s is a function both of the dielectric constant ε_r and of the height h of the dielectric waveguide. The launching efficiency increases with the dielectric constant and exhibits a maximum for $h(\varepsilon_r)^{1/2}/\lambda_0 \approx 0.4$, as shown in Fig.3.

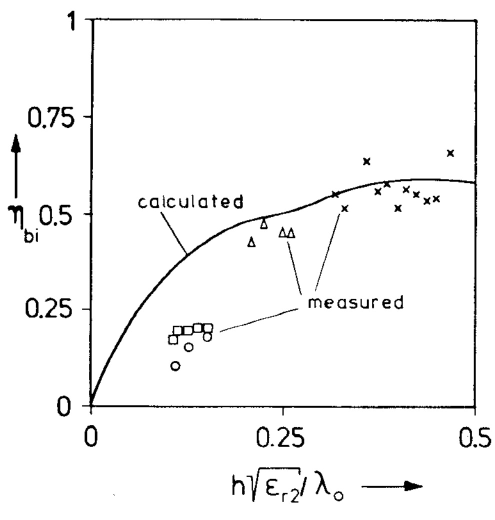


Fig.3: Measured and calculated launching efficiency of a slot in the ground plane of a dielectric image-line.

In an experiment the bidirectional launching efficiency was measured for low permittivity dielectric image lines (ε_r = 2.22) and the results were compared with the theoretical predictions from the numerical calculations in Fig.3. It can be seen that the agreement is reasonable considering the approximate nature of the employed theoretical model.

Antenna. As indicated in Fig.1(b) the slot structure can be used as a discontinuity in the dielectric image line to produce e.g. filter properties or controlled radiation if several elements are combined in a suitable way.

As an example, in Fig.4, a travelling wave antenna structure employing a matrix of 5x20 circular slots is shown. The antenna was designed to yield a low-sidelobe

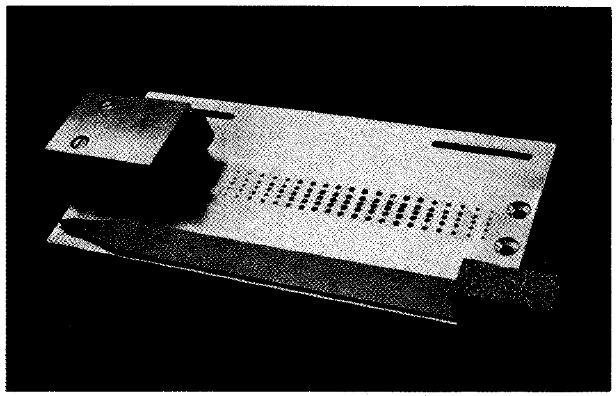


Fig.4: Photograph of a 5x20-element circular slot travelling wave antenna.

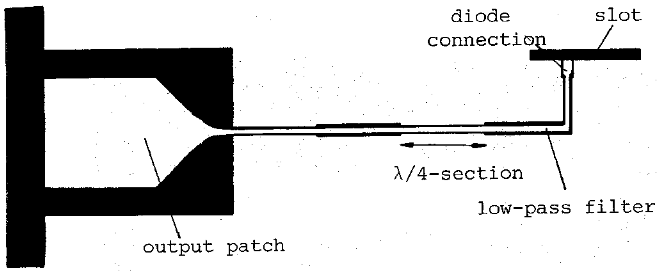
pattern at a frequency of 33 GHz. The dielectric image line was chosen very broad to excite all the five rows of slots in parallel, which is a condition for high directivity in the transverse plane of the antenna (H-plane). The necessary aperture distribution was realized by controlling the resistance R_s of the slots. This was achieved by tapering the diameters of the slots, while the depths of the holes were chosen large enough so that the influence of the bottom of the holes could be neglected (below cut-off waveguide).

The measured sidelobe level near the main beam was -25 dB and the half-power beam-widths were measured as 6° (E-plane) and 36° (H-plane).

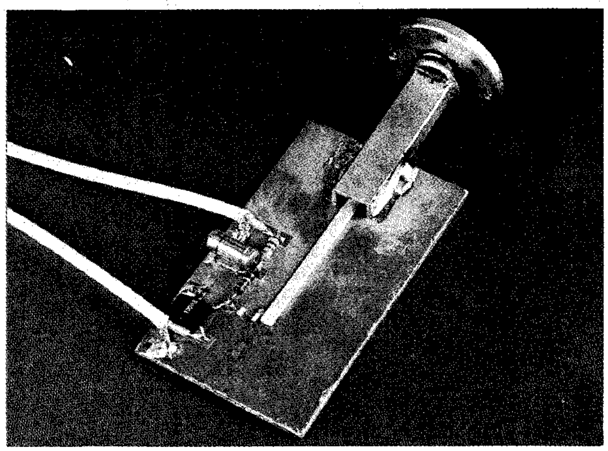
Detector-Circuit. In Fig.1(c) a cross-sectional view of a detector- or mixer-circuit is shown, where a slot in the metallization of a dielectric substrate is employed to couple the diode to the dielectric image line. The dielectric waveguide is open-circuited at a quarter-wavelength distance from the slot so that the current across the slot is a maximum. The diode is connected across the slot so that its impedance appears parallel to the slot impedance. Thus, a perfect match of the diode impedance assumed, the coupling efficiency of the circuit is determined by the slot radiation resistance, the substrate wave impedance and the reflexion loss at the dielectric waveguide termination.

The results of numerical calculations for the planar slot model show that for a highly efficient circuit a high permittivity dielectric image line with a low permittivity substrate as ground plane has to be employed. For the experimental detector-circuit shown in Fig.5, using an Epsilam-10 (ε_r = 10) dielectric guide over an RT/Duroid 5880 (ε_r = 2.2) substrate, the efficiency was calculated in the order of -1 dB.

In the shown experimental detector-circuit (Fig.5) for the frequency range 26 to 40 GHz a beam-lead mixer diode was employed (DMK-6606, Alpha Industries), which required a bias current to achieve highest sensitivity. The detector circuit was tuned to 32 GHz by cutting the dielectric image line termination. The circuit exhibited a maximum sensitivity of 250 mV/mW including the losses in the mode launcher and the dielectric image line. This figure compares quite well with the performance of commercially available metal waveguide detectors.



a)



b)

Fig.5: The metallization structure (a) and a photograph (b) of a detector-circuit employing a slot in the ground plane of a dielectric image line.

References

1. R.Knox, "Dielectric waveguide microwave integrated circuits - an overview", IEEE Trans. MTT, vol. MTT-24, no. 11, 1976, 806-814.

2. J.A.Paul, Yu-Wen Chang, "Millimeter-wave image-guide integrated passive devices", IEEE Trans. MTT, vol. MTT-26, no. 10, 1978, 751-754.

3. T.Itoh, "A distributed feedback dielectric waveguide oscillator with a built-in leaky-wave antenna", IEEE MTT-S 1979 International Microwave Symposium, Digest, Orlando, FL, 1979, April/May, 217-219.

4. K.Solbach, "Grating-tuner in dielectric image line for integrated millimeter wave circuits", 9th European Microwave Conference, Brighton (England), 1979, Sept., 458-462.

5. M.Desai,R.Mittra, "A method for reducing radiation losses at bends in open dielectric structures", IEEE MTT-S International Microwave Symposium Digest, Washington DC, 1980, May, 211-213.

6. K.Solbach, "E-band leaky wave antenna using dielectric image line with etched radiating elements". IEEE MTT-S 1979 International Microwave Symposium Digest, 1979, April/May, Orlando FL, 214-216.

7. R.Horn, H.Jacobs, E.Freibergs, K.Klohn, "Electronic modulated beam-steerable silicon waveguide array antenna", IEEE Trans. MTT, vol. MTT-28, no.6, 1980, 647-653.