DIELECTRIC IMAGE LINE GROOVE ANTENNAS FOR MILLIMETERWAVES

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Abstract

Dielectric image line groove antennas are very useful for application in the millimeterwave region. Three different types of groove discontinuities under a dielectric image line have been investiated theoretically and experimentally: 1) a slot discontinuity in a metallic ground plane, 2) a slot discontinuity in the metallization of a substrate material under the dielectric image line and 3) cylindrical holes in a metallic ground plane under a dielectric image line. The theoretical approach of the analysis uses an orthogonal series expansion of the electromagnetic fields; the theoretical results have been prooved experimentally. The results of the theory are used to design dielectric image line millimeterwave antenna arrays. The antennas are described and their radiation pattern will be discussed.

Introduction

The application of slot structures under a dielectric image line for the excitation of electromagnetic radiation was already used by Cooper /1/ as early as 1958. The slots are excited by the surface currents in the ground plane of the dielectric image line similarly as in the case of waveguide slot radiators.

One disadvantage of the image line antennas proposed by Cooper is, that electromagnetic energy is radiated into the substrate material carrying the slot structures; these losses were evaluated only very inaccurately by Cooper. The dependences of the losses on the dielectric constant and on the height of the substrate material as well as on the slot geometry were not investigated.

In this paper a twodimensional model is derived for the slotstructure in a solid ground plane and in the metallization of a substrate material under a dielectric image line. Using the results of these models, the optimal parameters for dielectric image line slot-antennas are approximately calculated. Additionally the radiation from cylindrical grooves in a metallic ground plane of a dielectric image line is investigated experimentally and various antennas for the application in the millimeterwave region (25 GHz - 100 GHz) on the basis of the slot- and groove radiators are presented and discussed.

The Resonator Model for the Slot Discontinuities

Fig.1a) shows a longitudinal dielectric image line cross section with a slot in the metallic ground plane under the image line. For the purpose of our investigations it is assumed that the transversal cross section of the line is infinitely wide, i.e. the dielectric image guide in this case is assumed to be a grounded slab guide with a slot of infinite width in the ground plane under the dielectric guide.

For the sake of simplicity additionally an approximation is made by assuming that the influence of the slot on the dielectric image guide and the radiation of electromagnetic energy from the slot can be computed from the onedimensionally open resonator shown in Fig.1b). This resonator having the length 2ℓ and two infinitely large reflecting walls will be used to calculate the equivalent circuit of the slot discontinuity with respect to the radiation perpendicular to the ground plane of the resonator.

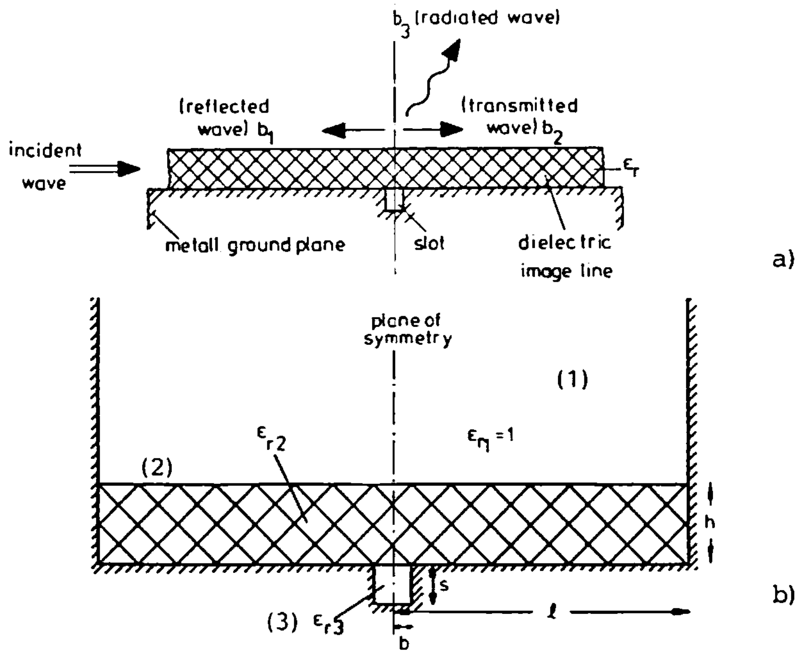

Fig.1: The slot discontinuity under a dielectric image guide (a) and the resonator model used in the theoretical investigations (b).

For calculating the resonant frequencies of the resonator which is disturbed by the slot in the ground plane, the adjoint electromagnetic eigenvalue problem is solved. Because the slot-impedance is only interesting with respect to the TM- fundamental mode, only E^y-potentials are assumed in the different field regions of the resonator. The fields are expanded into orthogonal series and additionally the boundary conditions are fullfilled on the metallic boundary as well as on the common planes between the three different field regions (1), (2) and (3) (Fig.1b). Field region (1) is assumed to be open in z-direction so that the radiation into this direction can be taken into account.

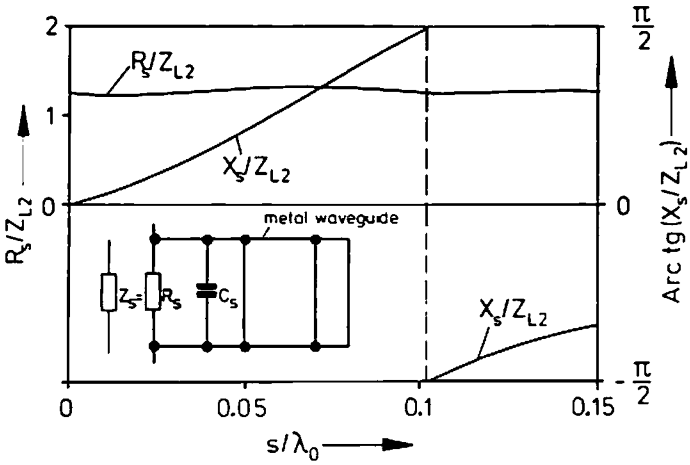

Fig.2: The equivalent circuit of the slot discontinuity and the real and imaginary part of the slot impedance Z_S.

From the field computation based on this simple model an equivalent circuit can be derived for the description of the slot under the image guide; it is shown in Fig.2. It contains the resistance R_s which is a measure for the radiation from the discontinuity, the capacitance C_s which describes the eletromagentic energy stored near the discontinuity and the metallic waveguide which stands for the slotstructure under the image guide. Fig.2 shows the real part and the imaginary part of the slot impedance Z_s in dependence on the slot width s.

From Fig.3 the influence of the height and the dielectric constant of the image line on the radiation resistance R_s can be determined: There exists a maximum of the radiation resistance (i.e. a minimum of radiation) which nearly independent of the dielectric constant occurs for a value of the normalized height h (see Fig.3) of the dielectric image line near 0.4. The curves shown in Fig.3 can be used to design the slots under the image line for a wanted radition resistance.

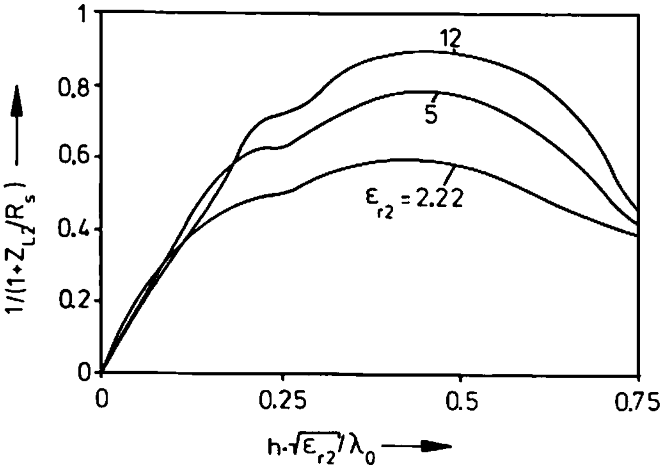

Fig.3: The dependence of the radiation resistance on the normalized height h and the dielectric constant of the dielectric image line.

In a similar way as shortly described for the slot structure shown in Fig.1, the slot structure shown in Fig.4a) can be analysed; only one additional field region in the substrate material must be considered. Fig.4b) shows the real and imaginary part of the slot impedance Z_s of this structure again in dependence on the slotwidth s.

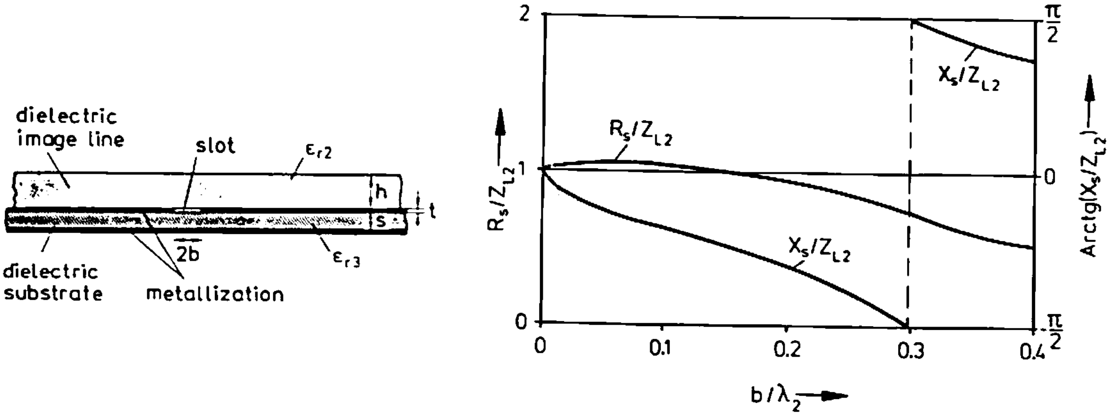

Fig.4: Slot structure in the metallization of a substrate material under the image line (a) and real and imaginary part of the slot impedance (b).

Similar results have been obtained for circular holes in a metallic ground plane under a dielectric image line.

Millimeter Wave Image Line Groove Antennas

In order to verify the calculation method for the slot discontinuities experimentally, measurements have been taken of dielectric image lines in the frequency range between 26 GHz and 40 GHz. The measurement techniques and the experimental result will be demonstrated in the oral presentation.

One dimensional and quasi-twodimensional millimeterwave array antennas on the basis of the groove radiators under a dielectric image line have been designed and measured in the frequency range between 26 GHz and 90 GHz. The following antennas and their radiation characteristics will be presented and discussed: 1) A onedimensional 25-element array antenna with linear slots etched in the metallization of a RT/Duroid substrate material. The slot resistances have been calculated for a Taylor-distribution /2/ providing a 25 dB side lobe attenuation and an efficiency of 7% at 33 GHz. 2) A 31-element array antenna with milled slots in a metallic ground plane under the dielectric image line. It has been designed for the E-band (60 GHz-90 GHz). Again a Taylor distribution of the effective radiation resistance is used. 3) A 20 element array antenna with bored holes in the metallic ground plane at 33 GHz. This is a very simple antenna which can be cheaply produced. It has excellent properties throughout the whole K-band (26 GHz-40 GHz), Fig.5. 4) A quasi-twodimensional array antenna has been designed, which uses a twodimensional arrangement of bored holes in a metallic ground plane. One part of the holes lies under the dielectric image line, the other part is placed besides the image line and is excited by the stray field of the dielectric guide.

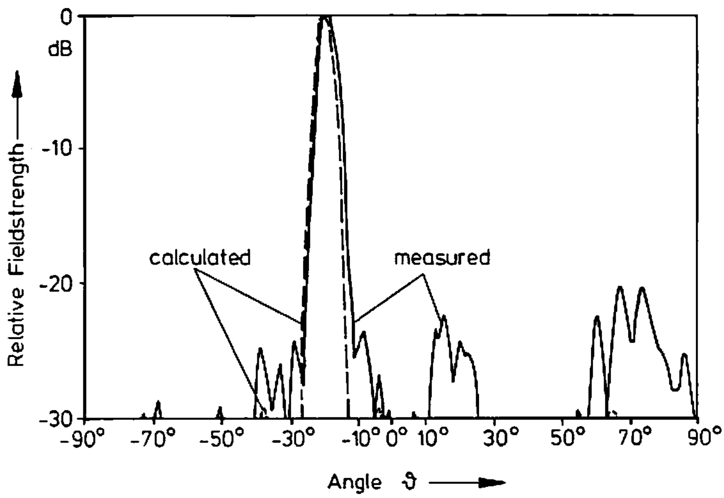

Fig.5: Radiation pattern of the 20-element array antenna with bored holes in the ground plane under the image line.

References

/1/ H:W.Cooper, M.Hoffmann, S.Isaacson: 1958 IRE National Convention Rec., part 1 (1958), pp. 230-239.

/2/ A.Dion: IRE Trans. Antennas and Propagation, AP-6 (1958), No.10, pp. 360-365.