# OPEN GUIDED WAVE STRUCTURES FOR MILLIMETER-WAVE CIRCUITS

(Invited Paper)

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## ABSTRACT

Open guided wave structures for millimeter-wave integrated circuit applications are reviewed. Analytical and design techniques for various functional circuits are discussed. Some of the important problems to be solved are identified.

### Introduction

Presently, the majority of millimeter-wave circuits is in the form of waveguides and integrated circuits based on printed transmission lines such as the suspended microstrip line[1] and fin-lines.[2] There are, however, two alternative approaches which would be more attractive at higher operating frequencies. One of them is the quasi-optical structure and another is the dielectric waveguide structures. Both of them are derived from techniques in optics. The former is the millimeter-wave version of beam optics whereas the latter is that of integrated optics. In this paper, we concentrate on the dielectric waveguide techniques.

In the past several years, a growing interest has been shown on dielectric waveguide techniques.[3] Works performed on this subject may be classified into: (1) Analysis of the dielectric waveguide, (2) Passive components, (3) Antennas, (4) Active components and (5) Nonreciprocal devices. Some of the representative works will be described in the paper.

### Analysis of the Dielectric Waveguide

There are two kinds of dielectric waveguides, strongly guiding and weakly guiding ones. The former includes the rectangular rod waveguide, the image guide and its variants, while the latter is represented by the inverted strip dielectric waveguide.[4] For the former, Marcatili's method is still the simplest and yet accurate for many practical applications[5] as long as the operating frequency is in the well-guided regions. To improve the accuracy of the solution near the cutoff, a number of techniques have been introduced. The simplest of these is the effective dielectric constant (EDC) approach.[6]

For the weakly guiding structure, the EDC is the simplest method providing a practically reasonable accuracy. Again, several methods for improvement have been suggested.[7] A very interesting leakage phenomenon was predicted in this class of waveguides and its cause explained.[8]

### Passive Components

Based on the distributed coupling principle, a number of works on 3 dB hybrid couplers have been performed.[9] This component is useful for developing a balanced mixer. On the other hand, resonators can be used for channel dropping or bandpass filters.[10] More than one ring may be needed to reject spurious response at the adjacent resonance. A grating structure may be used for bandstop filters.[11] Some design considerations for these components will be included in this paper.

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### Antennas

Perhaps one of the most useful features of dielectric waveguide techniques is a possibility of realizing high-performance antennas being integrated with the RF front end. Both surface wave antennas[12] and leaky wave antennas[11,13] have been developed and tested. An electronic scanning capability of the leaky wave antennas is a convenient feature for certain applications. The main beam direction can be accurately predicted once the propagation constant is obtained for the dielectric waveguide from which the leaky wave antenna is created by providing periodic perturbations (grating). Analyses of actual radiation characteristics are much more involved.

### Active Components

Development of active components is more difficult than other components. This is due mainly to the open nature of the dielectric waveguide. Any discontinuity arising out of implementation of solid state devices causes radiation, and hence the impedance looking from the device terminal consists of three parts; the resistive part due to radiation, the resistive part due to termination and the reactive part. These junction problems are important topics to be solved in the future. In the mean time, many researchers avoided direct confrontation with these problems by providing a mechanical shield to the device. Often, such a structure looks like a component made inside the metal waveguide with a dielectric waveguide output port.

Some of the accomplishments include the Gunn oscillators[14,15], self oscillating mixers[16] and mixers.[9]

### Nonreciprocal Devices

Relatively few works have been performed in this area. A field displacement type isolator was tested in which a resistive card is placed near a ferrite loaded dielectric waveguide and absorbs the wave energy traveling in the direction for which the field is displaced toward the resistive card.[17] Recently, two different types have been suggested. Both of them depend on the differences of the forward and backward phase constants in a nonsymmetric dielectric waveguide containing a ferrite layer. One of these two makes use of the nonreciprocal leakage created by adding a grating[18] and another depends on nonreciprocal mode coupling principle.[19] The

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loss in the ferrite is a very critical problem and a further research on the material is desired. The use of a surface plasmon in a magnetized semiconductor plasma was investigated in terms of its feasibility.[20]

## Conclusions

Dielectric waveguide techniques are still in infancy and much more works are needed. Presently, these components do not in many cases compete well with those made of printed line techniques in terms of performance. However, at much higher operating frequencies than the ones presently used, the dielectric waveguide technique is believed to be a strong candidate.

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