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NEW PROPAGATION EFFECTS FOR THE INVERTED STRIP DIELECTRIC WAVEGUIDE FOR MILLIMETER WAVES

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ABSTRACT

The existing theory for the inverted strip dielectric waveguide neglects the presence of additional constituent modes and the coupling between them at the strip sides. An improved theory which accounts for these features reveals interesting unanticipated physical effects, including leakage, resonances, mode coupling and modifications in transverse field distributions.

The approximate theoretical analysis mentioned above utilizes the so-called "equivalent dielectric constant" (edc) method, which is essentially a simplified transverse resonance procedure that assumes the presence of only one mode, the lowest TM mode, in each of the constituent transverse regions comprising the guide cross section. Furthermore, in the transverse resonance taken under these conditions in the horizontal direction, the geometrical discontinuities present at the strip sides are completely neglected since each constituent region is viewed as possessing an "equivalent dielectric constant."

The first thing that a more accurate analysis reveals is that in each constituent region in the guide's cross section at least two propagating modes, one TM and the other TE, must be present simultaneously under almost all conditions. In fact, if the dielectric sheet or dielectric strip thickness were increased, then the number of modes present simultaneously would increase to four or to six, etc. When we examine the three structures actually analyzed and measured by Itoh, we find that four simultaneous modes are present in two of them, and that six simultaneous modes are present in part of the third guiding structure.

The second key point that a more accurate analysis indicates is that the TE and TM modes which are present necessarily couple to each other at the geometrical discontinuities corresponding to the sides of the strip. This coupling requirement is readily proven by an examination of the field components that must be present at these strip sides.

As will be shown, the simultaneous presence of these other modes in the constituent regions, and their coupling at the strip sides, produce a number of interesting and sometimes important physical effects not observed earlier. Among these effects are the following:

a) Under appropriate conditions, leakage from the strip sides can occur, changing the dominant bound mode into a leaky mode.

b) Under appropriate conditions, for certain frequencies or strip widths, resonance effects can occur.

c) The transverse field behavior, both vertically and horizontally, can differ significantly from what one expects on the basis of the dominant mode alone.

d) If discrete modes higher than the lowest TE and TM ones are present in the individual constituent regions, the guided modes associated with them will...
These previously unexpected propagation effects could produce unwanted performance difficulties under some circumstances, or else advantage could be taken of them if it is known in advance what the effects are and when they occur. Furthermore, by a proper choice of dimensions or dielectric constants these effects can either be made to appear or be eliminated.

We present in Fig. 2 calculations for the basic surface wave characteristics of the constituent regions comprising the inverted strip guide cross section. The calculations are in the form of the "effective dielectric constant" values as a function of strip height for all of the discrete modes existing at that frequency (81.7 GHz).

The curves in Fig. 2 are used in a simple way to determine when these leakage and resonance effects will appear. It will be shown in the talk how these curves are used for this purpose, and a simple criterion in this connection will be presented. As mentioned earlier, the leakage and resonance effects arise because of the TE-TM coupling which occurs at the strip sides. The TM wave inside the strip region, which is incident at an angle on the strip side, excites a reflected propagating TM wave inside, an evanescent TM wave outside, and (due to the coupling) TE waves both inside and outside the strip region. If the TE wave excited outside is propagating rather than evanescent, it carries away a small amount of energy at each reflection, resulting in a leaky mode rather than a purely bound mode. If the TE wave inside the strip region is closer to the normal than the TM wave, then resonance effects occur at certain strip widths. (Similar leakage and resonance behaviors have been reported for strip waveguides for integrated optics, but certain differences are present in this millimeter wave structure.)

One or the other of these special effects can be present (or absent) depending on the precise dimensions of the structure. Table I summarizes the resonance and leakage behavior for three sets of dimensions for the inverted strip waveguide, using the dielectric constant values employed by Itoh.

<table>
<thead>
<tr>
<th>Case</th>
<th>d/λ</th>
<th>b/λ</th>
<th>Resonance</th>
<th>Leakage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.10</td>
<td>0.20</td>
<td>no</td>
<td>yes, if W/λ &lt; 0.3</td>
</tr>
<tr>
<td>2</td>
<td>0.20</td>
<td>0.15</td>
<td>yes</td>
<td>yes, if W/λ &lt; 1.5</td>
</tr>
<tr>
<td>3</td>
<td>0.10</td>
<td>0.10</td>
<td>no</td>
<td>no</td>
</tr>
</tbody>
</table>

One of the cases examined by Itoh (the third case) had a strip width of 0.794 mm, whereas the other two were 1.588 mm and 3.175 mm. Both inside and outside of the strip region, at least 4 modes are present simultaneously, 2 TE modes and 2 TM modes. In his analysis, Itoh assumed that only the lowest TM mode was present.

For case 1, we see that leakage can occur without resonance effects. However, the leakage may be eliminated if the strip width is increased beyond about 0.3λ, which is not difficult to accomplish. On the other hand, in case 2 we observe both resonance and leakage, where the leakage would be present over a rather wide range of values of W/λ. In case 3, neither effect is present, showing that it is certainly possible to design the waveguide without encountering these problems.

A detailed theoretical analysis including all of the constituent modes present and their coupling to each other at the strip sides has been performed for a number of different waveguide parameters. In the talk, comparisons will be shown between the results.
of these theoretical calculations and the data presented
by Itoh for both the longitudinal propagation constant
and the transverse field distributions.

References

