Rigorous TE Solution to the Dielectric Wedge Antenna Fed by a Slab Waveguide

Gerald M. Whitman, *Senior Member, IEEE*, Chairat Pinthong, Wan-Yu Chen, and Felix K. Schwering, *Life Fellow, IEEE*

***Abstract*—A rigorous TE solution to the dielectric wedge antenna fed by a slab waveguide of the same material is presented. The method of solution involves modeling the wedge as a sequence of step discontinuities and uses an iterative procedure to track forward and backward partial wave fields, expressed as modal expansions, to obtain the rigorous field solution. Radiation patterns of directive gain are presented. All patterns smoothly decrease from a maximum in the endfire direction and exhibit extremely low side lobe levels. Longer length wedges or smaller dielectric constant materials are shown to produce higher directivity and smaller half-power beamwidths. For slender, gradually tapered wedges, the reflection coefficient of the guided (surface) wave at the input to the wedge is very small indicating a low VSWR for tapered dielectric antennas and there appears to be no gain limitation with antenna length for these antennas.**

***Index Terms*—Dielectric antenna, dielectric wedge antenna, mode-matching, tapered dielectric rod antenna.**

I. Introduction

CURRENT interest in tapered dielectric radiators stems from their compatibility with dielectric waveguides and the availability of both lowloss silicon and solid state energy sources, which permit integration for use in millimeter-wave and integrated optical devices [1]–[4]. Such devices usually involve open structures in which the electromagnetic field is not confined by metal walls on all sides. Hence, energy leakage occurs. For a structure to be a waveguide, the leakage has to be minimized. If the structure is an antenna then efficient coupling to the radiation field must be effected. By tapering the end section of a dielectric guide along it axis, a guided surface wave field gets transformed into a radiation field which is characterized by maximum intensity in the forward direction. Tapering the dielectric guide, as opposed to suddenly truncating it, will significantly reduce the VSWR on the uniform section of the guide and improve the radiation characteristics of the tapered section (increased directivity and lower side lobe levels), thus resulting in an antenna of improved performance over a wide frequency band [5]–[7].

Tapered dielectric rod antennas have been known for many years; see [2] for a comprehensive list of references. It is surprising, therefore, that a good antenna theory for these antennas has not become available in the meantime. A possible reason for the absence of an accurate antenna theory is that the geometry of these tapered dielectric antennas, though strikingly simple, does not lend itself to convenient representation in a separable coordinate system. Rigorous theoretical approaches to analyze these antennas, such as, coupled mode theory or the full wave method [8]–[10] are available. However, they are mathematically very complex and usually require an iterative procedure just to obtain a solution of acceptable accuracy.

To simplify somewhat the analysis while still yielding physical insights, the two dimensional structure of a dielectric wedge antenna fed by a slab waveguide of the same material is examined. A single surface wave mode is assumed to be guided by the dielectric slab that terminates into the wedge antenna. The dielectric wedge is modeled by using the staircase approximation. The field scattered by each step discontinuity is then rigorously formulated as a mode-matching problem and solved numerically. The method of solution is an extension of the step-transition method introduced by Marcuse [10]–[12] and improved upon by Suchoski, Jr. and Ramaswamy [13]. Solution of the step discontinuity problem provides the basis for the solution of the overall wedge antenna problem. Suchoski, Jr. and Ramaswamy have applied their method to transitions between uniform optical waveguides of different cross sections. The antenna problem treated in the present paper requires a higher degree of accuracy; this was achieved by devising an iterative approach to the (overall) problem and by more accurately evaluating certain integrals that resulted from the mode-matching procedure and extend over infinite ranges. Furthermore, by an appropriate renormalization of the modal fields, a conspicuous pattern discontinuity problem occurring in the plane normal to the forward direction was resolved. This problem appeared in the existing theories on dielectric step transitions [10]–[13] as well as in [14], [15]. The need for higher accuracy derives from the objective to demonstrate the very low side lobe capability of tapered dielectric antennas and from the fact that in the tip region of the antenna strong mode coupling occurs, an effect obviously not present in transitions between uniform waveguides of finite cross section.

Many methods have been developed to study taper transitions between different dielectric guides or fibers. Several approaches, including the coupled mode theory, the step-transition method and the propagating-beam method, are reviewed in [13], which also introduces the so called "exact numerical method." This method is based on Marcuse's step-transition method, but applies orthogonality relations to obtain a sparse,

Manuscript received December 7, 2004; revised June 7, 2005. This work was supported in part by the U.S. Army Research Office under Contract DAAL 03-91-C-0034.

G. M. Whitman and C. Pinthong are with the Electrical and Computer Engineering Department, New Jersey Institute of Technology, Newark, NJ 07102 USA (e-mail: whitman@njit.edu).

W.-Y. Chen is with the INTI College Malaysia, Negeri Sembilan, Malaysia.

F. K. Schwering is with the U.S. Army, CECOM, Fort Monmouth, NJ 07702 USA.

Digital Object Identifier 10.1109/TAP.2005.861533