The University of Manitoba

FILTERING AND RADIATION CHARACTERISTICS OF ANNULAR SLOT ARRAY STRUCTURES

By

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A Thesis
Submitted To The Faculty Of Graduate Studies
In Partial Fulfillment Of The Requirements For The
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To the memory of

MONEER NAGHAVI KAMAL

for all her love and devotion

ABSTRACT

A method is established which gives field solutions inside two radial waveguides coupled by an array of annular slots on the common boundary. The cases of electromagnetic penetration into half space as well as cylindrical cavity regions are also treated. For the half space problem, the thickness of one of the waveguide regions is allowed to approach infinity. Whereas, for the cylindrical cavity case, the radial waveguide is terminated at an appropriate place by a cylindrical short circuit. Since the analysis is based on the response of the system to azimuthal current rings, the appropriate Green's functions for electric current rings are obtained in a similar manner as those of magnetic type. Therefore, the method can be extended to the geometries involving annular or cylindrical type conducting bodies as well as aperture-type geometrical discontinuities.

The solution is obtained by constructing the impulse response of the system and expressing the induced current distribution over the slots and the conducting bodies in terms of a suitable set of basis functions with complex coefficients. These constants are then obtained by an application of the boundary conditions on the discontinuity surfaces. The method is applied to three different geometries, namely, two radial waveguides coupled by an array of annular slots on the common boundary, an annular slot array antenna fed by a radial waveguide and the cavity backed annular slot antenna. Graphical results for selected cases are presented to substantiate the applicability of the models in the design of microwave filtering devices as well as highly directive antenna systems.

It is also shown that, in general, higher order modes excited by the discontinuities can have significant effect on the solution and for a precise evaluation of the fields in the respective regions, their contribution must also be included. A method of generating the desired incident mode or modes is suggested which uses simple vertically oriented arrays of thin probes.

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LIST OF SYMBOLS

Unless otherwise stated, the symbols most commonly used in this thesis have the following meaning:

GREEK ALPHABET:

ε	Dielectric constant of a medium.
ε_o	Dielectric constant of free space.
μ_o	Permeability of free space.
(ρ, ϕ, z) , (ρ', ϕ', z')	Cylindrical coordinate variables, prime denotes source coordinates.
(r, ϕ, θ)	Spherical coordinate variables.
ρ_i	Average radius of the ith slot.
η_o	Intrinsic wave impedance of free space.
τ	Ratio of the radii of the edges of an annular slot.
λ	Intrinsic wavelength of a region.
λ_o	Free space wavelength.
(ρ_s, ϕ_s)	Coordinates of the feeding probe.
ε_r	Relative dielectric constant of a medium with respect to free space.
δ_m	Width of the mth slot.
$\hat{\rho}, \hat{\phi}, \hat{\theta}$	Unit coordinate vectors of the respective variables.
ε_n	Neumann constant.
ω	Angular frequency.
ψ^e, ψ^h	Green's functions or wave functions of TM and TE types, respectively.
Φ_n^e, Φ_n^h	Angular dependent part of the nth mode functions of TM and TE types, respectively.

GREEK ALPHABET:

ψ_a^e, ψ_a^h	Auxiliary Green's functions of TM and TE types, respectively.
$\delta(\cdot)$	Delta function.
$\psi_{pq}^{e\ inc}$	Incident pq mode of TM type.
$\overset{+}{\rho}_m, \overset{-}{\rho}_m$	Radii of the outer and the inner edges of the mth annular slot.
$\bar{\psi}^{e}, \bar{\psi}^{h}$	Hankel transforms of ψ^e and ψ^h, respectively.
γ	Complex propagation constant in the z direction for the spacial frequency domain.
α	Complex variable of the spacial frequency domain.

LATIN ALPHABET:

a, b	Height of radial waveguides.
a_n, b_n	Fourier coefficients in the expansions of the angular dependent part of the current rings and the aperture fields.
c	Radius of a cylindrical cavity.
$C_n^{J,H,N}(\alpha\rho')$	Integrals of the respective Bessel functions with respect to ρ'.
dB, db	Decibel.
E_{in}	Electric field strength of the nth mode over the ith cell.
E_a, H_a, J_a	Auxiliary fields and their source.
$H_n^{(2)}(\cdot), H_n^{(2)\prime}(\cdot)$	Second kind Hankel function of order n and its derivative.
$\lvert H\rvert_n(\cdot)$	Struve function of order n.
I^e, I^h	Infinite integrals associated with half-space Green's functions of TM and TE types, respectively.
$I_m(\cdot)$	Imaginary part of a complex number.

LATIN ALPHABET:

$J_n(\cdot)$, $J_n'(\cdot)$	Bessel function of order n and its derivative.
J, J_m	Electric and magnetic current densities, respectively.
$k_{\rho m}$	Radial propagation constant of the mth mode.
k	Wave number of a region.
k_o	Free space wave number.
$\ell_n(\cdot)$	Natural logarithm.
$P_i(\rho' - \rho'_i)$	Unit pulse function of the ith cell.
$R_n(\rho')$	Radial dependent part of the aperture electric field of the nth mode.
$\mathrm{Re}(\cdot)$	Real part of a complex number.
S_1, S_2	Arbitrary cylindrical surfaces in regions I and II, respectively.
S'	Source plane.
TEM	Transverse electromagnetic field to z axis.
TE(h)	Transverse electric to z (h waves).
TM(e)	Transverse magnetic to z (e waves).
TM_{mn}	Transverse magnetic field of the (mn)th mode.
U^e_{mn}, V^e_{mn}, U^h_{mn}	Coefficients of the (mn)th mode of radial waveguide and cavity Green's functions of TM and TE types, respectively for $\rho > \rho'$
u^e_{mn}, u^h_{mn}	Coefficients of the (mn)th mode of radial waveguide and cavity Green's functions of TM and TE types, respectively for $\rho < \rho'$
$U^e_n(\cdot)$, $U^h_n(\cdot)$	Coefficients of the nth mode of the half-space Green's functions of TM and TE types, respectively.

CHAPTER I

INTRODUCTION

Telecommunication technology has reached the state of maturity which allows reliable contact between terrestrial points to be estabilished within seconds. As a prime contributor to this achievement, communication satellites have been used for a large number of diverse services. The early recognition of their potential use in world-wide communication prompted a rapid growth of international and military satellite communication systems, an industry which is barely ten years old.

One of the significant elements underlying this growth was the prospect of achieving band-widths exceeding those previously available for intercontinental communications. The exploitation of the wide bandwidths now easily available in the use of satellites and the ever increasing demand for higher frequencies requires solution to a series of technical problems in the communication links. As an inherent part of these links, earth station and spacecraft antennas must also conform to the specific needs as they arise. This is why satellite antennas have developed from low-gain, omnidirectional antennas to multifrequency multifunction antenna systems now in use [1,2].

Still higher frequencies are under active consideration, not only because of spectrum crowding at the lower frequency bands, but because of the desire to accommodate higher data rates than are now being sent commercially. So far, there have been a number of different design approaches conforming to satellite stabilization considerations which have been tested for their performance in actual missions [1-9].

Generally speaking, the optimum goal in designing any satellite antenna is to attain a pre-specified high gain radiation pattern by using a low profile antenna with the least complex feed system, with low weight and volume occupied by the antenna assembly, ease of fabrication and, most important of all, lower manufacturing cost factor. The last two goals are becoming more important as the frequency spectrum is broadened constantly and satellite communication is exploited commercially.

The purpose of the present work is to study a new class of low profile radiating element for use in high frequency telecommunication systems. The structure may be used as the basic block in formation of high frequency filtering devices as well as low profile antenna systems for applications in aircrafts, spacecrafts and low cost earth stations. Due to the structural simplicity of the radiating element it looks quite promising for use at high frequencies and the production cost seems to be much lower than conventional types presently in use.

The basic element is essentially a slotted radial waveguide. It is formed by an array of co-centered electrically narrow annular slots etched on one side of a dielectric substrate which is sandwiched by two ground planes, figure 1. For applications as an antenna, depending on the excitation of the slots, the structure is capable of producing radiation patterns with the main lobe in the direction of the z-axis (end fire) or a doughnut type radiation field with a null in that direction (broad-side). Terminology is borrowed from conventional arrays by viewing the antenna as a compressed version of a stack of circular loop radiators.

An important consideration for antenna systems covering large angular regions lies in their polarization state over the coverage zone.

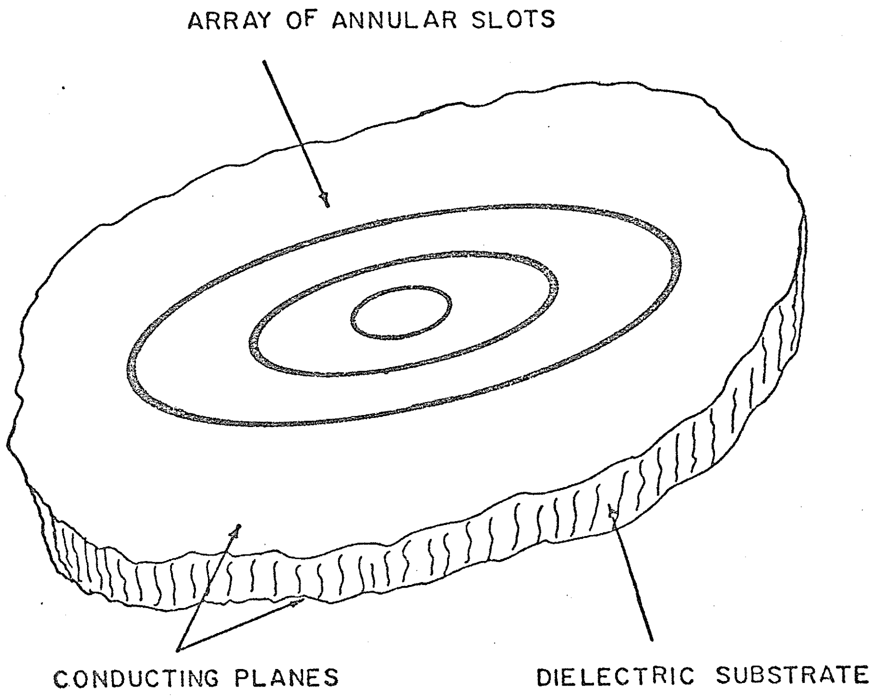

Figure 1.1: Basic radiating element.