A DUAL POLARIZATION SLOTTED WAVEGUIDE ANTENNA DESIGN FOR LOW COST MANUFACTURABILITY

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Introduction

The subject of this paper is the employment of orthogonal $TE_{m,0}$ mode waveguides[1], *m* being an integer significantly greater than 1, to create mechanically simple dual polarization slotted waveguide antennas. With an appropriate network external to the antenna, any sense circular, any slant linear, or any elliptical polarization is easily selected.

Dual polarization arrays are readily designed and inexpensively fabricated in microstrip. Patch radiators and the associated dual polarization feed lines can be etched on copper clad substrates. However, microstrip antenna arrays will not satisfy system requirements when exceedingly high microwave power is to be transmitted, or when the utmost reduction of the antenna's noise temperature is required. Slotted waveguide planar arrays do handle high power, as well as produce low antenna noise temperatures.

Wide Rectangular Waveguides and Orthogonal $TE_{m,0}$ Modes

The cutoff wavelength for an air filled $TE_{m,0}$ rectangular waveguide is $\lambda_c = 2a/(m\lambda_0)$, where m is the mode index, a = rectangular waveguide width, and λ_0 is the wavelength in air for the microwave frequency of interest. Consider a $TE_{m,0}$ rectangular waveguide that supports the $TE_{m,0}$ mode and is as long as it is wide. The design engineer can then excite an ${}_XTE_{m,0}$ mode traveling in the x direction as well as a ${}_YTE_{m,0}$ mode traveling in the y direction. The top and bottom walls of our waveguide are separated by the dimension b, b being well under $\lambda_0/2$ in the z direction so that there is no z dependent field variations in the waveguide.

Next, impose the condition that at the design frequency the width and length of this wide waveguide is $a = m\lambda_0/2^{0.5}$, making $\lambda_g = 2^{0.5}\lambda_0$. By placing m exciting slots in each of the b height walls enclosing the square volume, and by properly phasing the m exciter slots in each those four walls, the cavity is excited in a standing wave ${}_XTE_{m,0}$ mode and an orthogonal ${}_YTE_{m,0}$ standing wave mode. Some of the slot exciters for the two orthogonal modes can be seen in Figure 1, a photo of an experimental unit built for a demonstration of the principles of this design. Slots can be seen in the left and far narrow walls of the cavity.

Figure 1. A view of some of the $TE_{10,0}$ mode exciter slots in the narrow wall.

Also visible are some of the threaded studs used to secure the slotted top wall plate to the $TE_{10,0}$ mode square cavity.

The mode exciting slots are all of equal amplitude, but phased 0, π, 0, π, 0, π, 0, π, 0, π to match the $TE_{10,0}$ mode characteristics. Looking at the electric fields in a general plane perpendicular to the direction propagation, one sees a sine wave envelope to the E-field amplitudes. The zero crossings are the positions of the nine virtual walls making ten regions in which the fields are identical to the $TE_{1,0}$ mode. There is a π phase difference between adjacent $TE_{1,0}$ regions, hence the phasing of adjacent exciter slots. All of this description applies identically to the mode propagating in the x direction and the other mode in the y direction. *The planes of the* ***virtual*** *conducting walls within the open wide waveguide will be very important in the later discussion of placing radiating slots.*

The ten exciter slots in the x = 0 plane are driven in concert with the exciter slots in the x = a plane. The relative phase of the set of x = 0 mode exciter slots and the x = a slots depends on whether m is odd or even. These same comments apply to the exciter slots at y = 0 and at y = a. There is, however, absolutely no requirement for any particular phase relationship between the exciters for the ${}_XTE_{m,0}$ and for the ${}_YTE_{m,0}$ mode. It is that freedom that will be later seen to enable the arbitrary polarization of the antenna beam to be formed by the radiating slots that will be cut through the top cover of the waveguide.

As a final and important comment on the orthogonality of the ${}_XTE_{m,0}$ and the ${}_YTE_{m,0}$ mode, it can be shown that the driving ports for the two modes are isolated from each other. Experimentally, greater than 35 dB isolation was measured.

“Broadwall” Longitudinal Shunt Radiating Slots

Earlier, it was established that the field configuration in the cavity for the ${}_XTE_{m,0}$ mode is made up of m identical regions, each having a field configuration of the standard the $TE_{1,0}$ mode. Similarly for the ${}_YTE_{m,0}$. The longitudinal shunt slot is the most widely used radiating slots for standard slotted waveguide antennas formed from a multiplicity of $TE_{1,0}$ waveguides. That same slot type is successfully used in the dual polarization antenna under discussion. At first glance, the longitudinal shunt slot would seem to be a heavily-coupling *series* slot to the orthogonal mode. In fact, despite being transverse to the propagation direction of the other mode, the longitudinal shunt slots coupling to the first mode do not couple to the other mode if slots are centered on virtual walls of other mode.

Figure 2 shows the slot-width-direction stagger pattern of some of the longitudinal shunt slots on a plate that does not yet have the slots for the other polarization. Persons familiar with conventional single-polarization flat plate waveguide antennas will notice that the stagger pattern of offsets alternates in going from one column to the next. That is forced by the earlier mentioned fact that the phase of the $TE_{1,0}$ in the m^{th} row is π phase different from its neighbors. The stagger pattern gives rise to grating lobes in the 45 degree plane antenna pattern cut planes. A remedy for the grating lobes will be discussed later.

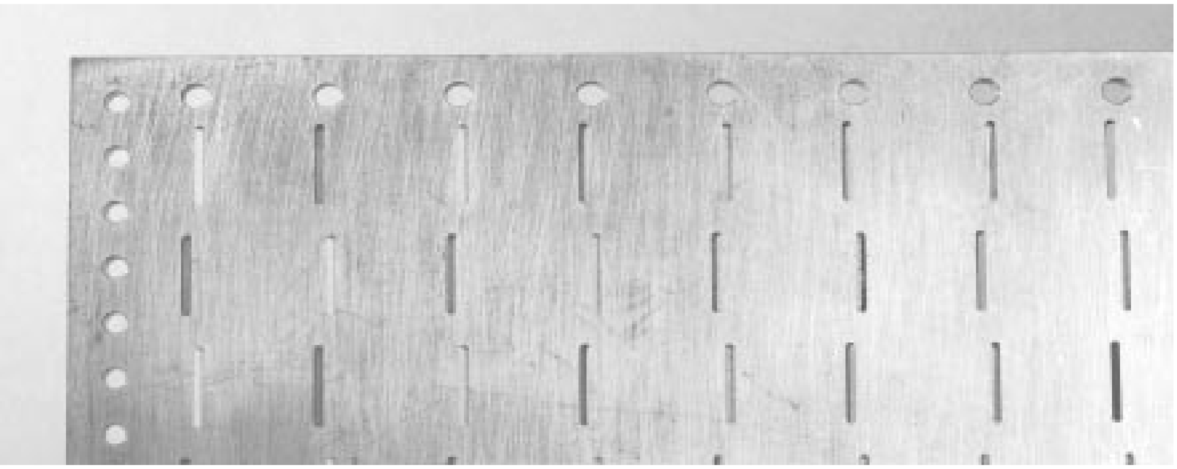

Figure 2. Longitudinal slots' offsets.

“Broadwall” Inclined Series Slots and “Narrow wall” Inclined Shunt Slots

Neither of these slot types, common to standard single polarization slotted waveguide flat plate antennas, can be used with this dual polarization antenna.

Offset Series Slots

This type of coupling is not available to antennas using standard the $TE_{1,0}$ waveguide. In this type of dual polarization antenna, a slot that is transverse to the mode propagation direction will not couple if its length is centered on a virtual wall of that mode. Therefore, it will couple if it is *not* centered on that virtual wall. Figure 3 shows a plate that was slotted to use series coupling. The long dimension of these series slot must remain on the center line between the virtual walls of the other mode in order to confine the coupling to the desired mode. Figure 3 shows the alternating offsets in the direction of the lengths of slots. Again, coupling is to the mode traveling perpendicular to the length of the slot.

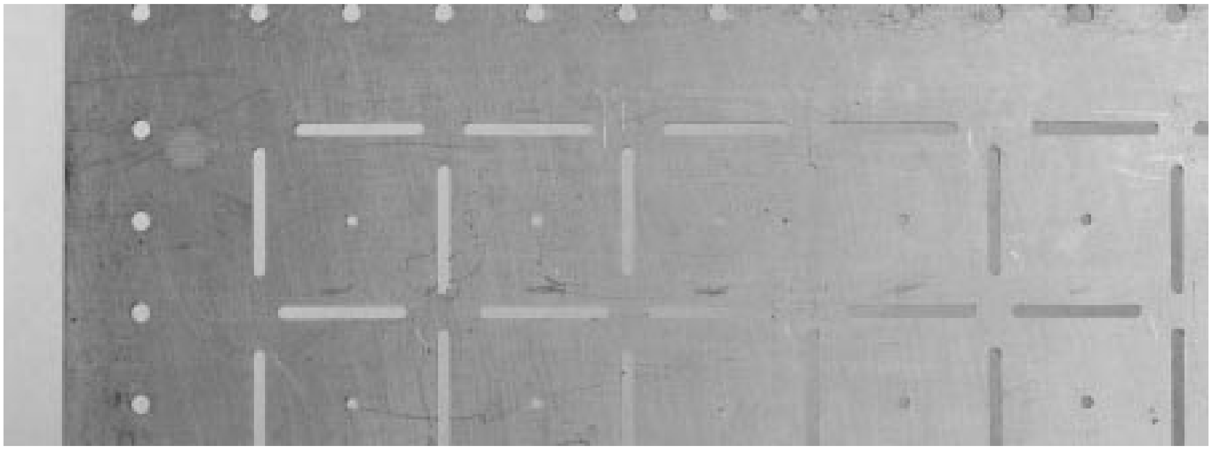

Figure 3. Offsetings to achieve series coupling slots.

The Grating Lobe Problem

Throughout this development program the antenna patterns in the principal planes have been ideal uniform illumination patterns with the nominal -13 dB sidelobes. These square antennas should have -26 dB sidelobes in the diagonal planes. Instead, -12 dB was obtained in the original tests. It is easier to discuss this grating problem by looking at Figure 2 since the second set of slots were not yet cut in that picture.

Examination of Figure 2 shows that the slot stagger pattern repeats in a group of slots in a 2 x 2 pattern. These groups of four slots have their centroids $1.4\lambda_0$ apart. In taking principal plane cuts, i. e. pattern cuts in the xz or yx plane, the slots collapse to a pattern of slots $0.7\lambda_0$ apart. In the diagonal plane, however, the centers of the collapsed groups of four slots are $1\lambda_0$ apart. Thus the -12 dB diagonal plane grating lobe peaks.

Grating Lobe Solutions

One of the objectives of this work has been to achieve overall aperture efficiencies of >90%. That objective is aided by the fact that with $TE_{m,0}$ modes the I^2R losses in the metal are only 66% of the losses in the m $TE_{\mathbf{1,0}}$ waveguides that would be used to cover the same aperture area. That is because the virtual walls are lossless in $TE_{m,0}$ waveguides.

To completely eliminate the diagonal plane grating lobes (also called "2nd order beams in some writings) all slots have to be on an unperturbed square matrix. In this work, that has been accomplished in three different ways. Satisfactory solutions were found in**:**

1. Irises placed inside the $TE_{m,0}$ waveguides excited longitudinal shunt slots even though the slots were not offset. To avoid affecting the other mode, these irises are in the plane of the virtual walls of the orthogonal mode. Irises, and zero offset slots are seen in Fig. 4. These irises were designed make no contact with the slotted plate.

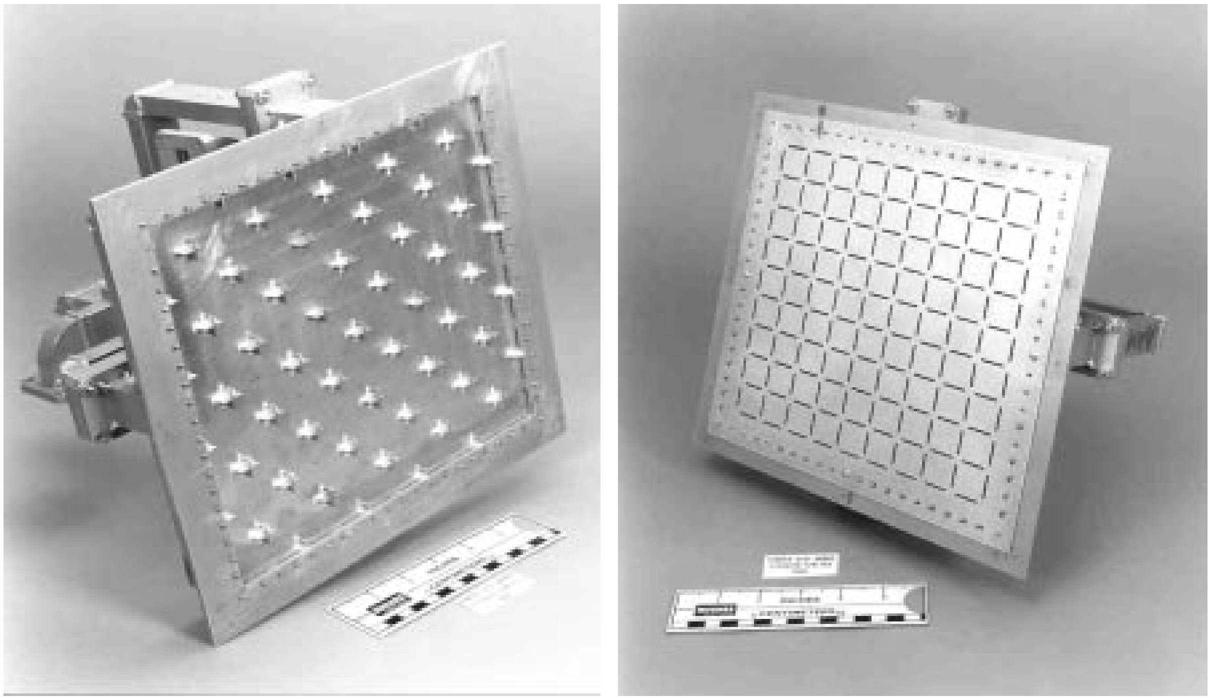

Figure 4. Irises, for producing coupling to zero-offset slots.

2. Probe excitation of centered longitudinal slots has long been used.[2] Again, the probes for exciting one set of slots are positioned at the virtual walls of the other mode.
3. Cutting longitudinal shunt slots at an angle through a $0.125\lambda_0$ thick plate so that slots are offset on the side of the plate inside the waveguide, but in line on the radiating face. After validating all concepts with an $m = 10$ unit, a complete unit was designed, constructed, and tested for pattern shape and overall efficiency.

Performance Test

This work culminated in the performance test of the $TE_{28,0}$ mode unit. The patterns were in excellent agreement with the ideal theoretical. In the diagonal plane the grating lobes were totally eliminated by the technique stated in Item 3 of the section just above.

Conclusions

This work has met the objective of producing an antenna design that is dual polarization, easily manufactured, and achieves very high antenna aperture efficiency. The multiplicity of waveguide channels, used in so many slotted waveguide array antennas, has been replaced by a single very wide waveguide. Also, the multiciplicity of radiating slots are all in one thin metal plate that can be handled by high speed fabrication processes.

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