Simulation and Optimum Design of Finline/Slotted Line Millimeter Wave Antenna

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ABSTRACT

Simulations are carried out using XFDTD software to determine the set of input values for several parameters of the fin line antenna, to give an optimized radiation performance in the principal planes. A further modification is proposed and implemented in the optimized design by extending the waveguide in a horn antenna fashion to create a larger aperture. The modified design is aimed to improve the overall reflection coefficient of the antenna.

1. INTRODUCTION

Horn antennas require a long length to exhibit high gains. These flaws can be improved by developing an array of Vivaldi tapered slot (fin line)antennas [1, 5, 8] fed from fin lines in waveguides.

The open structure of the planar antennas does not allow main beam efficiencies as high as those of horn antennas, But this advantage is outweighed by producing closely packed arrays of planar antennas and using them as multiple beam systems. Each Vivaldi tapered slot antenna can produce a wideband and end-fired radiation. Arrays of such antennas provide lightweight alternatives for focal-plane applications in satellite communication antennas involving beam shaping and beam switching. This design enables the user to integrate the feeds with mixer or amplifier devices on the same substrate that carries the antenna structure.

2. SIMULATION

A Vivaldi tapered slot antenna based on the initial design 1 on Millimeter wave antenna in fin line technique proposed by Beyer [1, 5, 8] were being analyzed. Further simulations using XFDTD software were carried out by varying several parameters involved. The optimization is targeted towards improving the maximum gain and lowering the side lobes as shown in figure 1.

These parameters include the length [4], height [5], and thickness of substrate [2,3,5], dielectric relative permittivity, minimum slot width [1,4], maximum slot width [3,6,10], and slope of the taper for the radiating section [3,4].

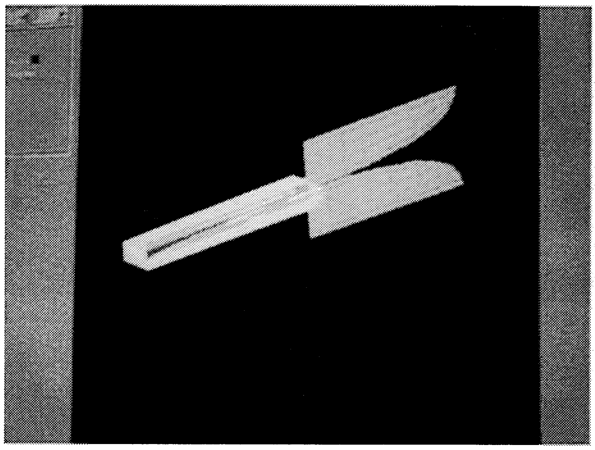

Figure 1: Optimized Design 2

The antenna design 2 has the following changes with respect to the initial design 1.

a) Extended length of 29.748mm
b) Maximum substrate height of 17.42mm
c) Air dielectric for the antenna section
d) Taper of slope in antenna section does not follow the exponential equation [5] closely. The modified slope is very gentle for the first portion, and steeper towards the end .

The far field simulation results of Design 1 and 2 are tabulated in table 1.

From table 1, it is shown that the maximum gain of the optimized design has improved and side lobe levels have reduced. But further work should be done to improve the matching at the waveguide to air interface and lower the optimum S_{11}.

The feeding used in the XFDTD simulation was through a perfectly conducting probe connected to the coaxial cable. The probe is inserted at the center of the broad side of a WR28 rectangular waveguide in order to excite a TE_{10} mode. It is inserted into the waveguide at a distance of a quarter of the guided wavelength ($\lambda_g/4$) from one end, and oriented in the direction of the electric field. A RF short is created at this end of the waveguide by sealing up the aperture with perfectly conducting material. Signals emitted from the feed source with see a region of high impedance at this end of waveguide, and will propagate in the other direction towards the antenna section.

The feeding used in the XFDTD simulation is illustrated in figure 2.

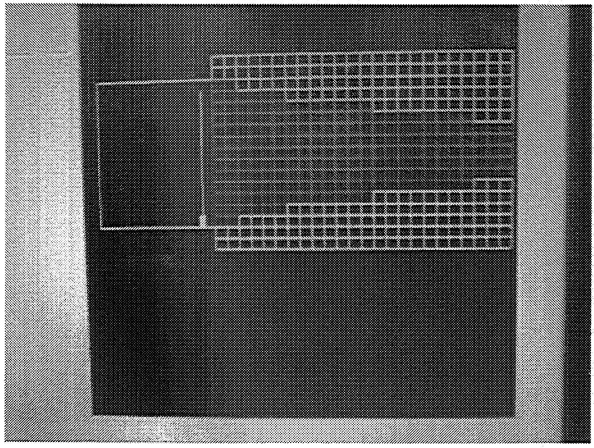

Figure 2: XFDTD Feeding source

3. DESIGN

The existing WR28 waveguide is extended outwards in a diverging fashion, resembling a E-plane horn antenna or H-plane horn antenna.

Using the closed-form expression [11], the characteristic impedance of an elemental fin line segment just inside the interface is found to be approximately 162Ω. The radiating section is approximated as a slotline, and the characteristic impedance of an elemental slotline segment just outside the interface is found using equation (2) below [13]. This equation is only valid for slotlines satisfying the following constraints:

1. $2.22 \leq \varepsilon_r \leq 3.8$
2. $0.0015 \leq w/\lambda_o \leq 0.075$

Equation 1

$$\begin{aligned} Z_o = {} & 60 + 3.69\sin[(\varepsilon_r - 2.22)\pi / 2.36] \\ & + 133.5\ln(10\varepsilon_r)\sqrt{(w/\lambda_o)}+ \\ & 2.81[1-0.011\varepsilon_r(4.48+\ln\varepsilon_r)](w/d)\ln(100d/\lambda_o)+ \\ & 131.1(1.028 - \ln\varepsilon_r)\sqrt{d/\lambda_o} + \\ & 12.48(1+0.18\ln\varepsilon_r)(w/d)/\{\sqrt{[\varepsilon_r-2.06+0.85(w/d)^2]}\} \end{aligned}$$

Substituting the following values of:

1. Substrate dielectric constant $\varepsilon_r = 2.22$
2. Slot width $w = 0.2$mm
3. Substrate thickness $d = 0.254$mm
4. Wavelength at frequency = 32GHz, $\lambda_o = 9.375$mm

into equation 2, we obtain a characteristic impedance of 140.8Ω.

When we expand the opening aperture of the waveguide, whilst maintaining the same slotwidth at the interface, the characteristic impedance of the fin line section just inside the waveguide decreases. Calculations are done for each of the extension techniques to design a final aperture whereby the characteristic impedance is reduced to 140.8Ω, thus matching to the characteristic impedance of slotline just outside the interface.

Upon getting the dimensions of the new enlarged aperture, the waveguide is extended in the ±z direction in an exponential nature [5] similar to the contour of the taper in the radiating section. This is to ensure a gradual smooth transition of the electric field from waveguide into the free-space.

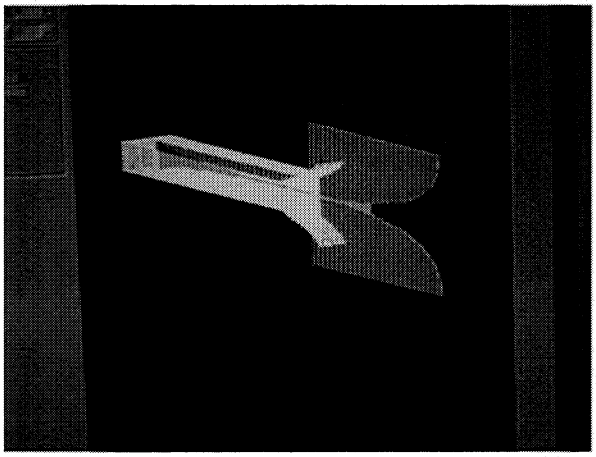

Figure 3: E-plane Horn

Similar design process is carried out for this modified design. But the extension of the waveguide in this design is in the ±y direction. The extension also follows an exponential nature [5] similar to the contour of the taper in the radiating section.

The modified waveguide designs are applied on the optimum design 2 of the substrate. The geometry of the modified antenna with the extension of the waveguide in a E-plane horn and H-plane horn fashion are shown in figures 3 and 4 respectively.

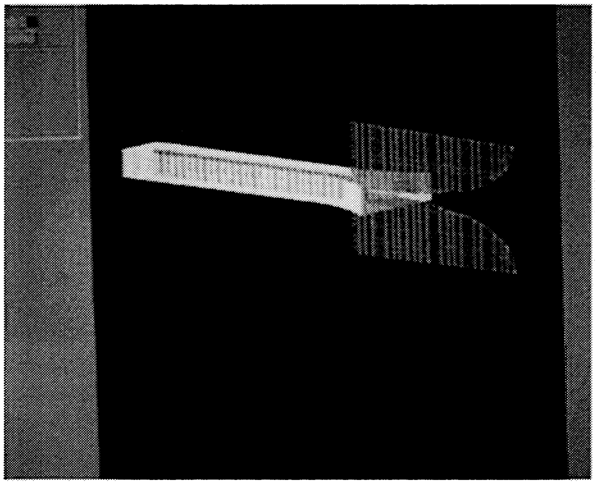

Figure 4: H-plane Horn

The results are the 4 designs are tabulated in table 1 and table 2.

		Max Gain (dBi)	3dB Beam width	Sidelobe Level (dBi)
Initial Design	E-plane	**6.00**	**66.00**	**-2.30**
	H-plane	6.00	46.00	-7.40
Optimized Design	E-plane	**8.85**	**40.00**	**-5.80**
	H-plane	8.90	41.00	-5.90
Modified Design (E-plane Horn Extension)	E-plane	**8.33**	**32.35**	**-1.78**
	H-plane	7.86	64.60	-5.00
Modified Design (H-plane Horn Extension)	E-plane	**8.50**	**30.20**	**0.00**
	H-plane	5.57	36.92	-5.71

Table 1. Simulated results

Type of Design	Lowest S_{11} value at approximately 30GHz(dB)
Optimized Design	-7.71
Modified Design (E-plane Horn Extension)	-10.90
Modified Design (H-plane Horn Extension)	-11.06

Table 2. Lowest Value of S11 for Different Designs

4. CONCLUSIONS

XFDTD simulations can also be carried out to determine the set of input values for several parameters of the antenna, to give the desired radiation performance in the principal planes. A modification in the form of extending the waveguide in a horn antenna fashion has been proven to improve the overall reflection coefficient of the antenna. But it must be noted that the fabrication process for the waveguide housing will be much more complex and hence will incur more costs, as more stringent dimensions are needed.

The simulation results can give a reasonable good estimation of the actual maximum gain. But the simulated reflection coefficient S_{11} is purely adequate for comparing the matching efficiencies of different antenna designs.

5. RECOMMENDATIONS

A suitable absorbing material can be placed at the waveguide-to-air interface to absorb any stray radiation emitted from the two gaps formed by the substrate and the open end of the waveguide. The absorption of the stray radiation can provide us with a better radiation pattern characterized by higher maximum gain, improved directivity and lower sidelobe levels.

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