Broadband Millimeter Wave Finline Antenna Simulation and Performance

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ABSTRACT

Analysis on fin line antenna with broadband and tolerable VSWR characteristic was done. Emphasis were placed in the formulation of the taper equations for the transmission fin line and radiation section and verification of good matching at the waveguide to air interface.

1. INTRODUCTION

Vivaldi tapered slot antenna (Fin Line antenna) [1,3,5] 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.

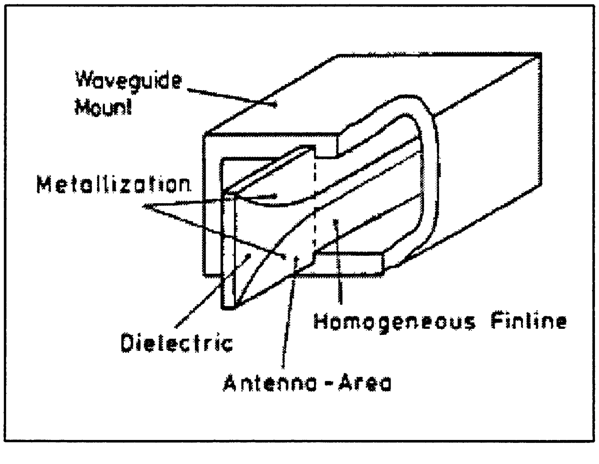

Figure 1: Fin line antenna

Such antennas are inexpensive to fabricate and could be useful as low cost and integrated antenna receiver/transmitter units. . They can be produced using photolithographic techniques, reducing the additional costs for a multiple-beam system.

An illustration of a Fin Line antenna [1] fed from fin line in WR28 waveguide is illustrated in figure 1.

2. DESIGN

The design of the antenna consists of two parts: the radiation taper contour (slotted line) and the fin line taper contour, which acts as a feeding to the antenna. There are a few notable points.

1. The characteristic impedance (Zo) of the fin line for the feeding is calculated using method proposed by P.Pramanick and P.Bhartia [7].

2. The frequency-dependent expression for the characteristic impedance Zo of the unilateral fin line is derived by fitting a curve to the accurate spectral domain [7,9] as shown in figure 2 is given by:

Equation 1

$$Zo = \frac{240\,\pi^2\,[\,p\ \ln \mathrm{cosec}(\pi w/2b) + q]\,(b/a)}{0.385[\ln \mathrm{osec}(\pi w/2b) + 1.762]^2(\lambda o/\lambda g)}$$

where, $w//b >= 0.3$

$p = 0.17\,(b/\lambda o) + 0.0098$

$q = 0.138\,(b/\lambda o) + 0.873$

where, $w/b > 0.3$

$p = -0.763(b/\lambda o) + 0.58(b/\lambda o) + 0.0775\,[\ln (a/d)]2 - 0.668[\ln(a/d)] + 1.262$

$q = 0.372\,(b/\lambda o) + 0.914$

where
a= Length of the waveguide cavity
= 7.112mm
b= Height of waveguide cavity
= 3.556mm
w= Slot width of unilateral fin line
= 0.2mm

It is reported that the above equation is accurate within ± 2% for d/a <=1/20, and within ± 3% for d/a > 1/20 and over the range of frequency 0.25<= b/ λo <=0.6.

3. Recognizing that fin lines are essentially ridged waveguide with a dielectric backing, the following approximate formula by Meier [9] for the guide wavelength λg of the fin line is used:

Equation 2

$$\lambda_g = \lambda_o / [\, K_e - (\lambda_o/\lambda_{cr})^2 \,]^{0.5}$$

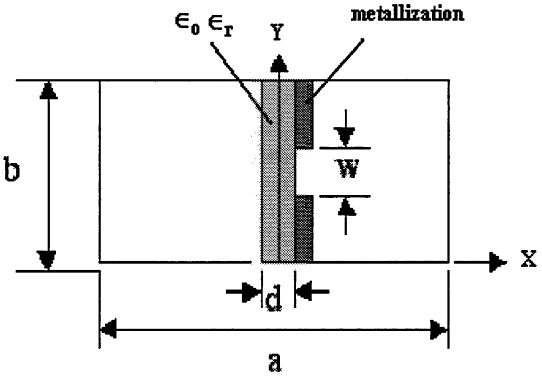

Figure 2: Cross-sectional View of Unilateral Fin line

4. Using equation 1 and 2, a polynomial equation that describes the relationship of the characteristic impedance (Zo) and the slot width (w) of the fin line at 32 GHz can be found by using Matlab ployfit function.

Equation 1

$$Zo = 0.78\,w^4 - 7\,.27w^3 - 3.49w^2 + 1.69.18w + 131.81$$

5. An exponential taper impedance function [12] is chosen for the design of the fin line matching transition. The length L_b is set to be 2λo at the lowest reflection coefficient.

Equation 2

$$Z(z_2) = Z_2 \exp [\, z_2 / L_b \ln (Z_1/Z_2) \,]$$

where Z_1 = impedance at z_2 = 0.1 mm.
Z_2 = impedance at z_2 =1.778 mm.

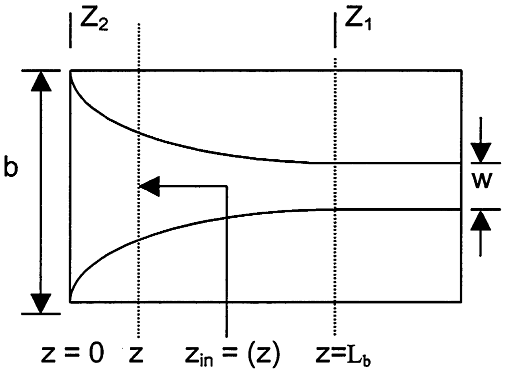

Figure 3: Fin Line Taper (transmission)

6. A fin line taper equation for the feeding at the operating frequency 32GHz is obtained by substituting equation 1 into 2.

Equation 3

$$z_2 = [1 / -0.05838\ ]\ln [\,(0.78\,w^4 - 7.27w^3 - 3.49w^2 + 169.18w + 131.81)/ 486.70)]$$

7. Usage of exponential equation

$$Y_1 = 0.1 {*} e^{(0.152 {*} Z_1)} \qquad [1]$$

for the radiating section giving a new maximum slot width [3].

8. Maximum substrate height (h) obtained by adding one guide wavelength to maximum slot width [5] as shown figure below.

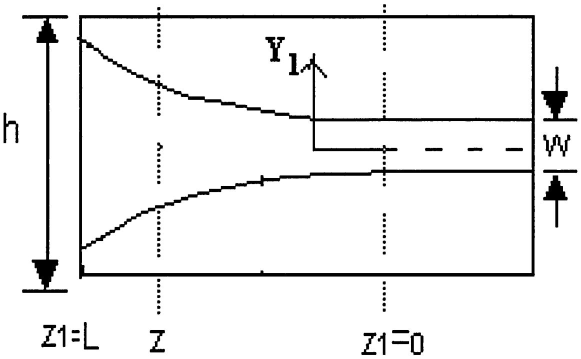

Figure 4: Fin Line Taper (radiating)

9. Using slotline as an approximation for the slotted line, the value of the characteristic impedance Zo of ten points along the slotted line from a minimum slotwidth of 0.2 mm to 8.94mm are calculated using the characteristic impedance equations 4 and 5 of the slotline [4,8].

Equation 4

Constraints

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

$$Z_o = 60 + 3.69 \sin[(\varepsilon_r - 2.22)\pi / 2.36] + 133.5\ln(10\varepsilon_r)\sqrt{(w/\lambda_o)} + 2.81[1 - .011\varepsilon_r(4.48 + \ln\varepsilon_r)]\,(w/d)\ln(100d/\lambda_o) + 131.1(1.028 - \ln\varepsilon_r)\sqrt{d/\lambda_o} + 12.48\,(1 + 0.18\ln\varepsilon_r)(w/d)/\{\sqrt{[\varepsilon_r - 2.06 + 0.85(w/d)^2]}\}$$

Equation 5

Constraints

1. $2.22 \leq \varepsilon_r \leq 3.8$
2. $0.075 \leq w/\lambda_o \leq 1.0$

$$Z_o = 133 + 10.34(\varepsilon_r - 1.8)^2 + 2.87[2.96 + (\varepsilon_r - 1.582)^2] * [\{w/d + 2.32\varepsilon_r - 0.56\} * \{(32.5 - 6.67\varepsilon_r) * (100d/\lambda_o)^2 - 1\}]^{0.5} - (684.45d/\lambda_o) * (\varepsilon_r + 1.35)^2 + 13.23[(\varepsilon_r - 1.722)w/\lambda_o]^2$$

The following values of the four constants below are substituted into the two equations 4 and 5.

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

10. At the waveguide-air interface, the values of the characteristic impedance for the elemental fin line and elemental slotline at slot width w=0.2mm using equation 1 and 5 are found to be 162.873Ω and 140.8Ω respectively.

11. Constant slot width is maintained at this interface to allow smoother transition from the fin line transmission segment to the radiating segment.

12. The fin line inserted into in the E-plane of a rectangular waveguide [9] is a wideband transmission line operating in the millimeter wave region. For the slotted line, radiation starts when the slot width is approximately equal to half the free space wavelength. This implies that different segments of the slotted line with different slot width start radiating at different frequency [2]. It also suggests that the slotted line can operate at a range of frequency, thus exhibiting broadband characteristics.

13. As the characteristic impedance on both sides of the waveguide-air interface is approximately the same, thus connecting the fin line and slotline at the interface would guarantee good matching.

3. EXPERIMENTAL RESULTS

From the experimental S_{11} plot in figure 3, the measured S_{11} value has a maximum value of -12dB at 27.5 GHz and a minimum value of -42dB at 36.75 GHz.

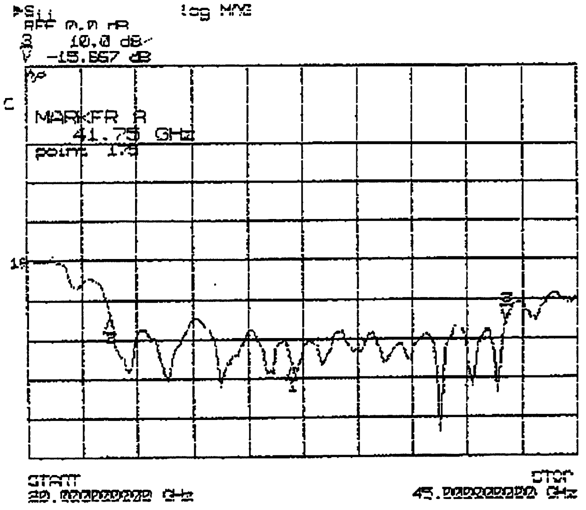

Figure 5: S_{11} plot of the antenna

4. CONCLUSIONS

In the frequency range from 23 GHz to 41 GHz, the calculated VSWR ranges from 1.02 to 1.67. Hence, the tolerable VSWR for this frequency range is approximately 1.67.

The results show that this Vivaldi antenna design is a broadband design with an acceptable VSWR for a wide range of frequencies.

Broadband operation at a tolerable VSWR is achieved by employment of a good matching design at the waveguide to air interface and applying optimum taper interface equations for the fin line antenna. High gain narrow band can be achieved by further improving the matching at the waveguide to air interface.

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