B-6

MICROWAVE BROADBAND PHASED ARRAY ELEMENT: DESIGN AND PERFORMANCE. (MICROSTRIP HORN OPENED BY CONDUCTING FLAPS).

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ABSTRACT
In this paper the design and performance of a broadband phased array element with adecuate angular coverage is presented. It was also desirable that this element were easily adaptable to microstrip technology as an alternative to notch or Vivaldi antennas. Radiation field calculation, design parameters study, design process as well as pattern and reflection coefficient measures of a prototipe are included.

INTRODUCTION

For selecting phased array elements both physical and technological approaches should be followed. While the former are refered to the radiation pattern, matching and frecuency band, the latter refers to easy implementation and array integration. An interesting alternative to horn radiators, as the ridged horn, for broadband phased arrays are the slot antennas, such Vivaldi aerial, that have the advantages of lightweight and easy construction of the planar technology. In this paper the performance and design of an antenna that intends to synthesize the advantages of both the horn and the planar slot antennas is presented. It is easily adaptable to microstrip tecnology because it consists on a microstrip line oppened by conducting flaps and, since the feeder line is the microstrip, it is expected to have less feed problems that the Vivaldi wich needs a microstrip to slot transition. The present antenna can also be considered as an element for a dual polarization array alternating vertical polariced slot subarrays with the here presented horizontally polariced elements. (1)
In figure 1 the geometry of the antenna is presented.
Since the antenna is considered as an aperture radiator the design is planned like a matching from the 50 Ohm microstrip line to the apperture as it is done in some broadband antenna designs (2).
The matching is done first widening the strip forming a microstrip horn and then opening the ground plane and the upper metallization forming a flaps structure so that the problem is reduced to the design of two non uniform transmission line

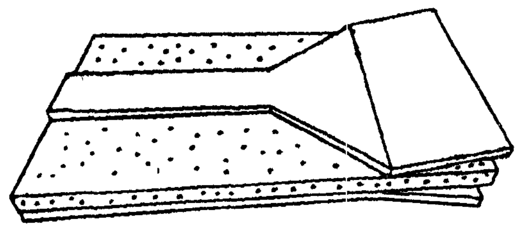

Figure 1: Microstrip horn opened by conducting Flaps.

adaptors. The first is a non uniform width microstrip line while the second one is an adaptor from total to partially filled parallel plate. In this way a continuous structure is obtained.

APPERTURE DESIGN RADIACTION PATTERN

As the antenna studied is considered a phased array element, radiation pattern must fit the scanning requeriments on azimut plane as well as permit of the subarrays integration in elevation with certain up the horizon coverage. Those performances should keep in the operating frecuency band,
In order to choose appropiate aperture dimensions the radiated fields should be computed. The assumption that the terminal plane region is the dominant radiation apperture was done in order to avoid the mathematical difficulties over the choice of the appropiate current form on the structure. It was also assumed that the field distribution on the apperture were the same dimensions partially filled waveguide one. The flaps region field is assumed to be excited for the field distribution of a cuasi TEM mode at the end of the microstrip horn without variation on the field with the y coordinate.
So the field distribution in the flaps region is

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in air

$Hy = A\cosh((G/2)-|x|)\alpha)\exp(-jk_z z)$

$Ex = A\, k_z/w\,\varepsilon_o \cosh((G/2-|x|)\alpha)\exp(-jk_z z)$

$Ez = -A\alpha\sigma/w\varepsilon_o Sh((G/2-|x|)\alpha)\exp(-jk_z z)$

$Ey=0 \qquad Hx=0 \qquad Hz=0$

in dielectric

$Hy = B\cos(\beta x)\exp(-jk_z z)$

$Ex = -Bk_z/w\varepsilon \sin(\beta x)\exp(-jk_z z)$

$Ez = -Bk_z/w\varepsilon\cos(\beta x)\exp(-jk_z z)$

$Ey=0 \qquad Hx=0 \qquad Hz=0$

from continuity

$A\cosh((G/2-g/2))\alpha) = B\cos(\beta g/2)$

$$\beta tg(\beta g/2) = \alpha e_r tgh((G/2-g/2)\alpha) \qquad [1]$$

from dispersion relation

$$k_z^2 = \varepsilon_r k_o^2 - \beta^2 = k_o^2 + \alpha^2 \qquad \lambda z = \lambda_o / 1 + (\alpha\lambda_o/2x)^2 \qquad [2]$$

from [1] and [2] wavelenght can be obtained and mode impedances will be:

$$Za = Z_o \frac{\lambda_o}{\lambda_z} \qquad Zd = Z_o \frac{\lambda_o}{\lambda_z \varepsilon_r}$$

If impedance in the flaps region is studied as a function of G/g it can be seen that increasing G/g (distance between metallic plates, dielectric thickness ratio) the mode impedance approaches to free space impedance (figure 2).
A cuadratic phase term is introduced in the assumed apperture fields in order to account for phase variations along the apperture because of the cilindrical nature of waves when the guide is open. The assumed field on the apperture is

$$E = Eg\, e^{-\frac{1}{2}\frac{\beta_F x^2}{R_F}} \quad e^{-iBm\frac{1}{-}\frac{y^2}{Rm}}$$

where Eg is the field distribution in a same dimensions guide, B_F and B_m mean values of the phase constant along the Flaps and microstrip respectively, and Rf, Rm the distance from the phase origin plane. From this field distribution, radiation fields are computer as their spatial Fourier transform (3).

ADAPTORS DESIGN.MATCHING
As we said both the microstrip and the flaps region are designed like nonuniform line adaptors.
If a non-uniform line of 1 lenght for matching two uniform transmission lines is considered and assuming a purely imaginary propagation factor $\Gamma = j\beta$ the reflection

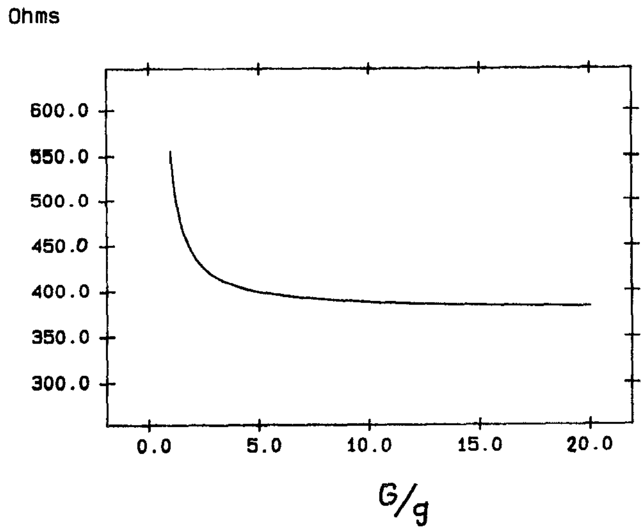


Figure 2: Mode impedance in flaps region as a function of G/g.

coefficient of the line can be obtained and is given by:

$$r\, e^{j\beta l} = \int_{-1/2}^{1/2} \frac{d\ln Z_o}{dz}\, e^{j\beta z}\, dz$$

Both the total lenght and the impedance taper will determine the r value in the bandwidth.
Several impedance tapers may be selected and the total adaptor lenght will determine, with the terminal impedances, the maximun reflection coefficient in the operating frecuency band. In (4) some of these impedance tapers are presented comparing their performances.
In the present work Chebyshev taper was selected owing its optimun characteristics of broadband and minimun lenght for a given reflection coefficient. For this particular case impedance taper is given by:

$$\ln Z(x) = 1/2\ln(Z_1 Z_2) + r_o A^2 \phi(x,A)$$

beeing Z1 and Z2 the extreme impedances.
The A parameter is related to the reflection coefficient

$$r\, e^{j\beta l} = r_o \frac{\cos(\beta l)^2 - A^2)^{1/2}}{Ch\, A}$$

and if $A = \beta l$ at the lower frecuency of the band the maximun reflection coefficient in the operating frecuency band will be

$$r_m = \frac{r_o}{ChA}$$

where r_o is the reflection coefficient without adaptor and Bl the adaptors total l. ϕ is given by

$$\phi(x,A) = -\phi(-x,A) = \int \frac{I_1(A\ 1-z^2)}{A\ 1-z^2}$$

where ϕ can be computed as

$$\phi(x,A) = \sum_k a_k b_k$$

and

$$a_o=1 \qquad a_k = \frac{A^2}{(4k(k+1))} a_{k-1}$$

$$b_o=x/2 \qquad b_k = \frac{x/2(1-x^2)^{k+2k}}{2k+1} b_{k-1}$$

When the phase variation along the structure is not significative it can be considered constant and the total electrical lenght computed as

$$l = \frac{A}{\beta}$$

A study of the phase constant in both of the structures was done in order to analize the validity of considering it constant it along the maching network.
For the microstrip

$$\beta = \frac{2\pi}{\lambda_o} \sqrt{\varepsilon_{ef}}$$

While for the partially filled waveguide

$$\beta = \frac{2\pi}{\lambda_o} \sqrt{1+(\alpha\lambda_o/2\pi)^2}$$

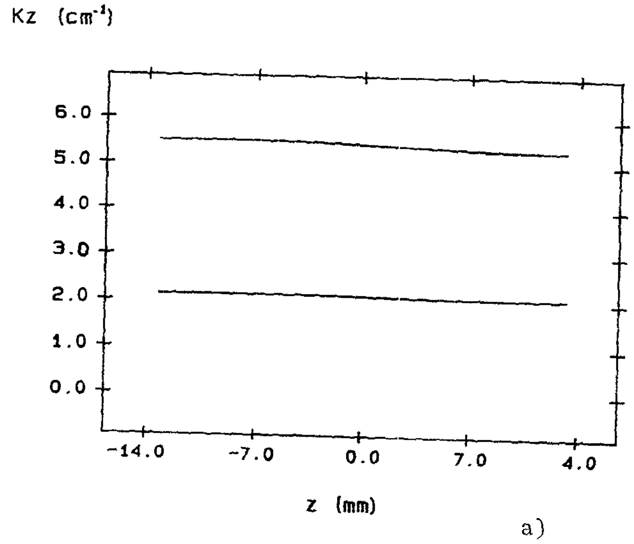
In figures 3 and 4 the phase constant variation along the Chevyshev adaptor for microstrip and flaps respectively are presented. It can be seen that this variation is more significative in the flaps region that in the microstrip so what was done is to divide the total electrical lenght into sections and for each section impedance was calculated, and then the dimensions that realize that impedance. Having the dimensions the guide wavelenght at each of these points was calculated and the average between two succesive steps used to calculate tha physical separation for equal electrical lenghts (5).

DESIGN SEQUENCE

The design sequence proposed is:
- Substrate choice (matherial and thickness) with adecuate 50 Ohms strip width for lowering transition to coax and leakage losses.
- Aperture dimension choice (H,h,L) in order to fit coverage requeriments.
- Microstrip horn, from 50 OHm strip width to H plane apperture lenght, design.
- Flaps region, from microstrip horn mouth to apperture design.

RESULTS

A prototipe of this element in 31 mil inch Cuclad (ER=2.17) substrate was designed and constructed and both the E and H radiation patterns and the reflection coefficients were measured. The prototipe shows good scanning characteristics as well as appropiate coverture in elevation.



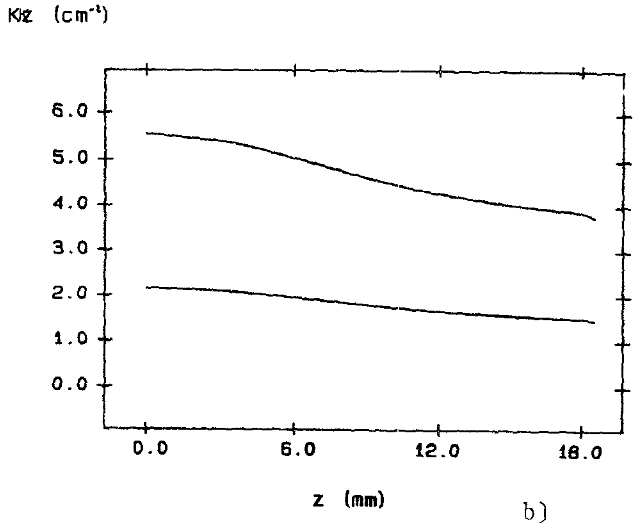


Figure 3: Phase constant variation along the adaptors, a) Microstrip, b) Partially filled waveguide.

In figure 6 the reflection coefficient is presented as a function of frecuency. Matching improvement efforts are beeing making at the present including the measure of some other designed prototipes with a microstrip horn prolongation that would permit, to distinguinsh the reflection effects in microstrip horn from the flaps region by mean of a network analyzer time window. Other substrate thickness are also beeing considered for flaps matching improvement.

AKNOWLEDGES

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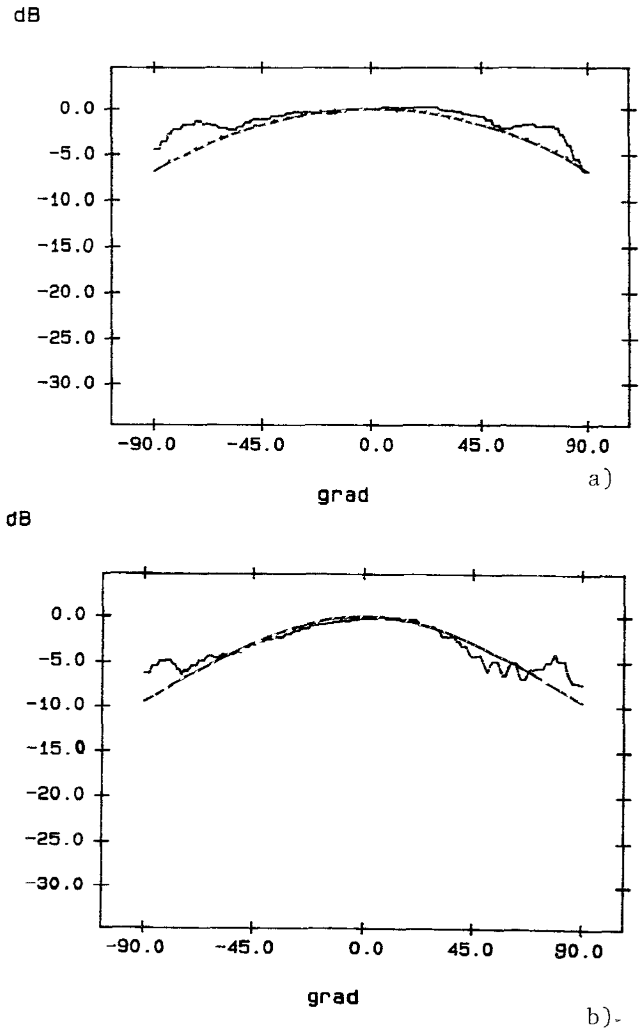

Figure 4: E plane radiation pattersns at 8 a) and 17 b) Ghz. (Solid lines experimental, dotted lanes computed).

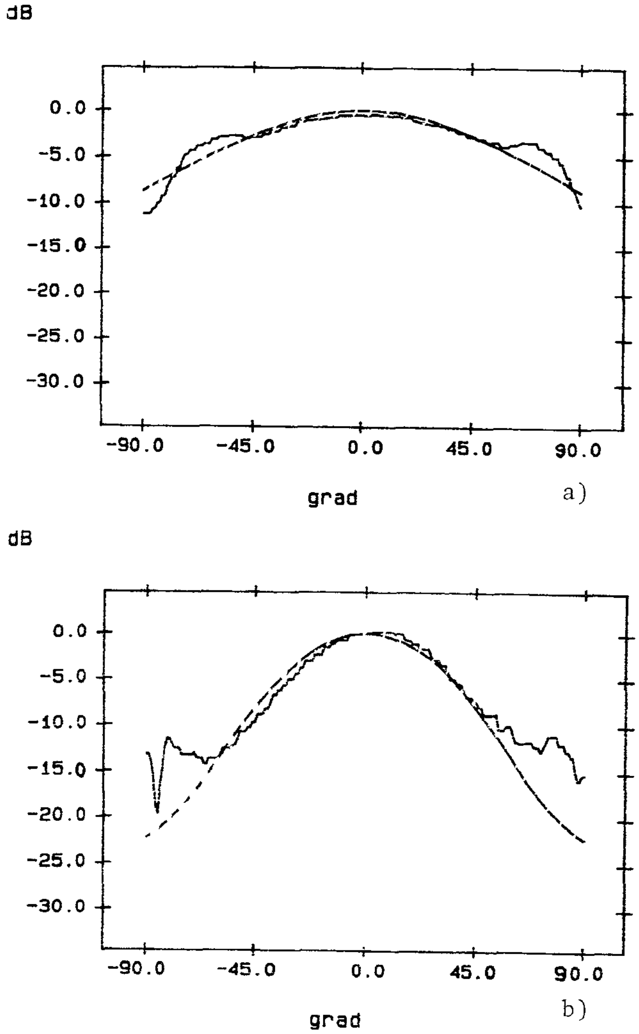

Figure 5: H plane radiation patterns. Ibid.

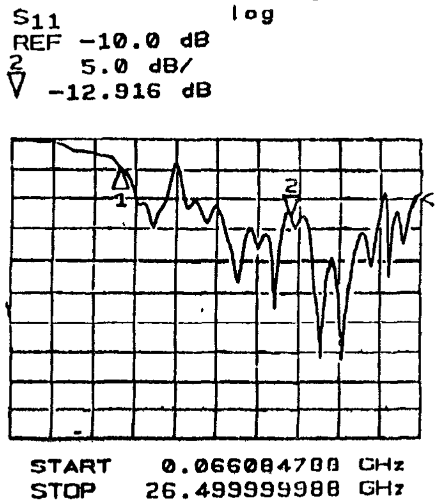

Figure 6: Measured reflection coefficient as a function of frecuency.