Design and implementation of circularly polarized microstrip patch antenna to construction array For Spin–Stabilized Satellites with octagonal shape

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Keywords: microstrip patch antenna, antenna array, satellite cylindrical structure of octagonal shape, omnidirectional radiation pattern, circular polarization, 90 °-Hybrid feed.

Abstract

In the present work, design of circularly polarized microstrip patch antenna is presented in S-band of centre frequency 2.29 GHz. This microstrip patch antenna is considered to be the basic element of an array consisting of eight microstrip patches distributed and mounted on eight surfaces of cylindrical structure of octagonal shape. The field of radiation pattern of the antenna array is calculated for E and H-planes and it seems to be an omnidirectional pattern. A 90°-hybrid feed for each element is designed to excite the antenna with circular polarization within suitable matching for patch antenna and the hybrid.

الخلاصة

يتنــاول البحــث تصــميم وبنــاء هــوائي شــريطي ذو قطعــة واحــدة يبــث موجتــه فــي حزمــة – S ترددهــا المركــزي 2.29 GHz وباســتقطاب دائــري. تــم اعتبــار هــذه القطعـــة الشـــريطية مـــع وحـــدة تغـــذيتها كعنصـــر أساســـي للهـــوائي المتسلســـل المتضـمن توزيـع ثمـان قطـع شـريطية علـى ثمانيـة اوجـه مـن نمـوذج لهيكـل قمـر صـــناعي ذو شـــكل مـــثمن، حيـــث تـــم حســـاب المخطـــط الإشـــعاعي للهـــوائي المتسلســل للمســتويين الاساســيين (E,H) وابــدى خــواص كليــة الاتجــاه. تــم تصـميم وحـدة هجينــة لكـل قطعـة شـريطية لهـا مـدخل واحـد ومخـرجين لإشــارتين متســاويتين بالمقــدار ومختلفتــين بــالطور (90 درجــة فــرق احــداهما عــن الأخــرى)، هــذان المخرجــان يغــذيان القطعــة الشــريطية المربعــة مــن حافتيهــا المتعامــدتين لتوليـد موجـة ذات اسـتقطاب دائـري آخـذين بنظـر الاعتبـار الموائمـة المناسـبة بـين ممانعتي القطعة الشريطية والوحدة الهجينة.

1- Introduction:

The microstrip antennas are finding to increase popularity due to their advantages of low profile, small size, lightweight, low cost, mechanical rigidness with good conformity to the supporting structure and ease of fabrication therefore the microstrip antennas are widely used as an efficient radiator in both mobile and aerospace communication systems [1,2,3]. Since they are manufactured by the photolithographic process developed for printed circuits, they can be mass - produced to be combined in antenna arrays and could thus provide inexpensive antenna for direct reception of microwave signals from satellites, for television and mobile communication services. The omnidirectional pattern can be obtained by arranging a number of microstrip patches that are conformable to a surface of cylindrical body such as a spinning satellite .The aim of the present work is to design a circularly polarized microstrip patch which is a basic element of array arranged on eight surfaces of a cylindrical body of octagonal shape.

2- Antenna Array Design:

The designed antenna array is consist of eight microstrip patches distributed and fixed on eight surfaces of the cylindrical structure of octagonal shape as shown in Fig. (1) The cylindrical body of octagonal shape has a diameter of 110 cm and height of 85 cm. The microstrip patches of the antenna array are fed by signals of same amplitude and phase trough a combinations of power dividers. The resonant length of microstrrip patch “a” can be determined by:

$$a = 0.49\ \lambda d \text{ --------------(1)}$$

Where λd is the wavelength in a dielectric substrate

The width of the microstrip patch is assumed to be “b” and will be equal to the resonant length to excite the circular polarization.

3 - Antenna Feeding Unit:

3.1 Input impedance of the patch element:

The square microstrip path of (a= b= 37mm) is printed on duriod 3003 Rogers substrate of dimensions 8.8cm × 16cm (the available area on the surface of the cylindrical body of octagonal shape) and of dielectric constant $\epsilon_r = 3.2$. Using the microwave office software the above microstrip patch element is been analysed for the available ground plane of 8.8cm × 44cm. The input impedance of two ports are shown in Fig. (2). The first port is at the patch edge, which is parallel to the largest length of the ground plane while the second port is at the other patch edge. The impedances at frequency 2.29 GHz are 333 and 313 Ω for the first and second patch ports respectively. The difference in the impedances is due to the different limited dimensions of the ground plane. Practically the input impedance of the two patch ports has been measured as 325 Ω for the first port and 310 Ω for the second.

3.2 90° – Hybrid Feed

First, it is required to transfer the impedance of the two ports from 325 Ω and 310 Ω to 50 Ω by using a quarter-wave transformer. The line impedances are determined, 129 Ω of width 0.45 mm and 125 Ω of width 0.55 mm for the first and second ports respectively. The designed hybrid has two inputs (with one terminated by 50 Ω) and two outputs of 90 degrees out of phase. The coupling from the input to the output is calculated and plotted in Fig. (3).
The maximum and minimum coupling were -2.97 dB and -3.65 dB respectively for the whole bandwidth. The isolation between the two inputs of the hybrids is calculated as shown in Fig. (4) while the phase of the outputs related to the input is shown in Fig. (5). The previous results are obtained using the Genesys software. The printed prototype consisting of hybrid and microstrip patch element is photographed in Fig (6).
The return loss and SWR of the input hybrid practically measured by network analyzer (hp 8510) were 1.13 and -24.2 dB respectively at frequency 2.29GHz as demonstrated in Figs. (7) and (8) respectively.

4- Radiation Pattern:

The radiation pattern of antenna array can be determined by using the calculations of the field depending on the field radiation pattern of the basic element (microstrip patch) of the array. The far field radiation pattern of a rectangular microstrip patch operating in the fundamental mode TM01 is of broadside type in both E and H planes. The pattern of a patch over a large ground plane may be calculated by modeling the patch radiator as two parallel uniform magnetic line sources of length “a”, separated by a distance “b” [4]. The effect of the ground plane and substrate is handled by imaging the slot at an electric distant Kt, where “K” is the wave number in a dielectric of thickness “t”.

The electric field of single microstrip patch is Formulated by [5] :

$$\mathrm{E}(\theta,\Phi) = \mathrm{E}_\theta(\theta,\Phi) + E\phi(\theta,\Phi) \text{..........}(2)$$

When:

$$E_\theta(\theta,\phi) = \theta^0 R \frac{\sin\Psi_a}{\Psi_a} \cos\Psi_b \cos(Kt\cos\theta)\sin\theta \text{.......}(3)$$

$$E\phi(\theta,\phi) = \phi^0 R \frac{\sin\Psi_a}{\Psi_a} \cos\Psi_b \cos(Kt\cos\theta)\cos\theta\cos\phi \text{.....}(4)$$

$$\Psi_a = k_0 \frac{a}{2}\sin\theta\cos\Phi \, and \, \Psi_b = k_0 \frac{b}{2}\sin\theta\sin\phi \text{..............}(5)$$

$$\text{With} : R = j\frac{aE_z}{\pi tr}\exp(-jk_0 r) \text{..............}(6)$$

The image factor cos (Kt cos θ) is obtained by assuming that the path radiating slot is embedded in half – space of dielectric substrate. The microstrip patch of a = b = 3.7 cm is printed on a substrate have ϵ_r =3.2 and thickness of 1.52 mm. The radiation patterns of principle (E- plane and H- plane) are obtained in Fig. (9)

Far-field pattern of the array for H-plane can be calculated by summation of each field element fixed at reference point of observation taking into consideration the phase difference due to the path difference between the elements, The summation of elements can be calculated by [6]:

$$E_r^2 = E_1^2 + E_2^2 + 2E_1E_2 \cos \Psi .... (7)$$

Where:
Er = resultant field
E1,2 = field element no 1,2
Ψ = is the phase difference between element (1) and (2)

Three cases for calculating the H-plane pattern of the designed array are considered with its element demonstrated in Fig. (10) when the satellite rotates around the spin-axis as follows:

(a) The observation line is passing through the center of the microstrip patch and vertical to the plane containing the patch element (Ø = 0).
(b) The observation line is centered between the two adjacent patches (Ø = 22.50).
(c) The observation line is between “a” and “b” above (Ø = 11.250).

Based on the H-plane pattern of microstrip patch element, the normalized electric field of each element with the angle of inclination from the observation line are listed in Table (1) for the mentioned three cases above. The field radiation pattern is plotted in Fig.(11). The E-plane radiation patter of the array remains constant as the E-plane radiation pattern of the element.

5- Conclusions:

Design of circularly polarized microstrip patch antenna has been introduced in S - band with center frequency 2.29 GHz. The dimensions of this patch has been determined as 37mm x 37mm which has been printed on a dielectric material of Єr =3.2 and thickness of 1.5mm.
Eight microstrip patches have been distributed on the surfaces of a cylindrical structure of octagonal shape. The beamwidth of the array has been calculated and found as 126 and 360 in E-and H plane with a ripple of 5dB in the H –plane. For the designed array , a 90° – hybrid feed has been designed and implemented for each patch element to obtain the circular polarization. It has been found that the measured SWR was 1.13 and the return loss was - 24.2 dB at the input of the hybrid feed.

6- References:

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Ø = 0	Element No.	1	2	3	4	5	6	7	8
	Field amplitude	1	0.64	0.64	0	0	0	0	0
	θ	0	+ 45	- 45	+ 90	- 90	-	-	-
Ø = 11.25^0									
	Element No.	1	2	3	4	6	6	7	8
	Field amplitude	0.95	0.5	0.9	0	0.18	0	0	0
	θ amplitude	+11.25	56.25	- 33.75	-	- 78.75	-	-	-
Ø = 22 .5^0									
	Element No.	1	2	3	4	5	6	7	8
	Field	0.9	0.335	0.9	0	0.335	0	0	0
	θ	+ 22.5	67.5	- 22.5	-	- 67.5	-	-	-

Ɵ = angle of element inclination from the observation line

Ø = angle of satellite rotation from the observation line.

Table 1 : Field distribution of the antenna array

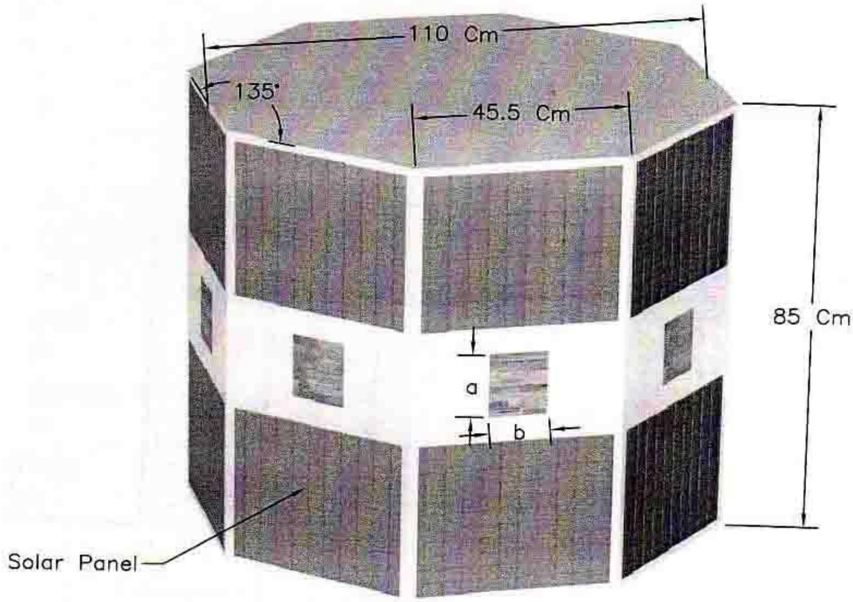


Fig (1): Locations of Microstrip patch antenna elements on the satellite structure.

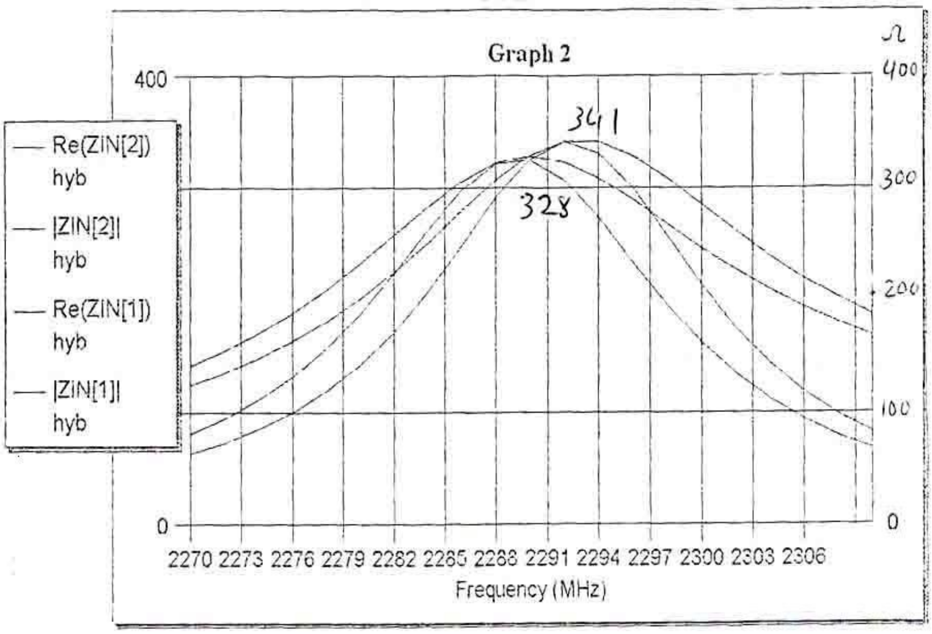
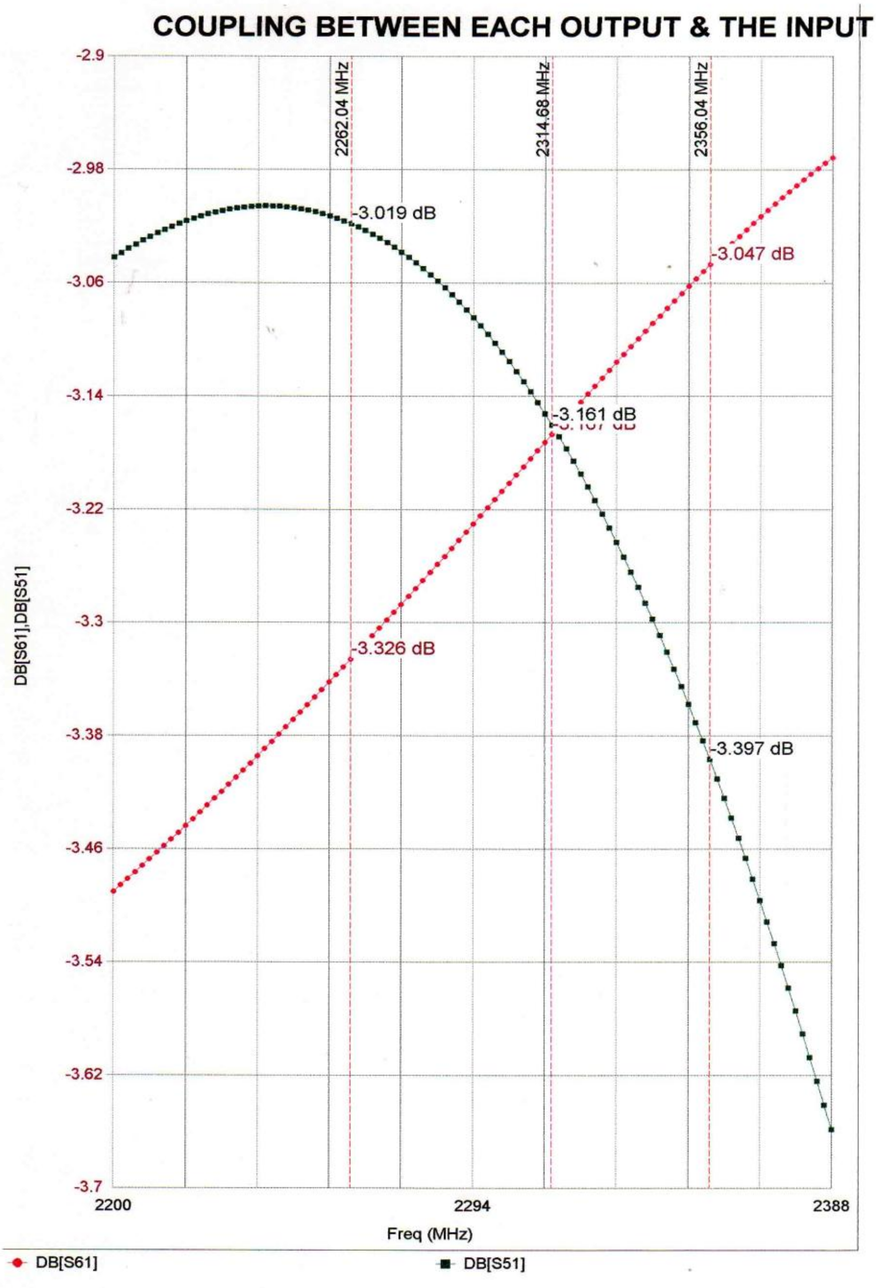
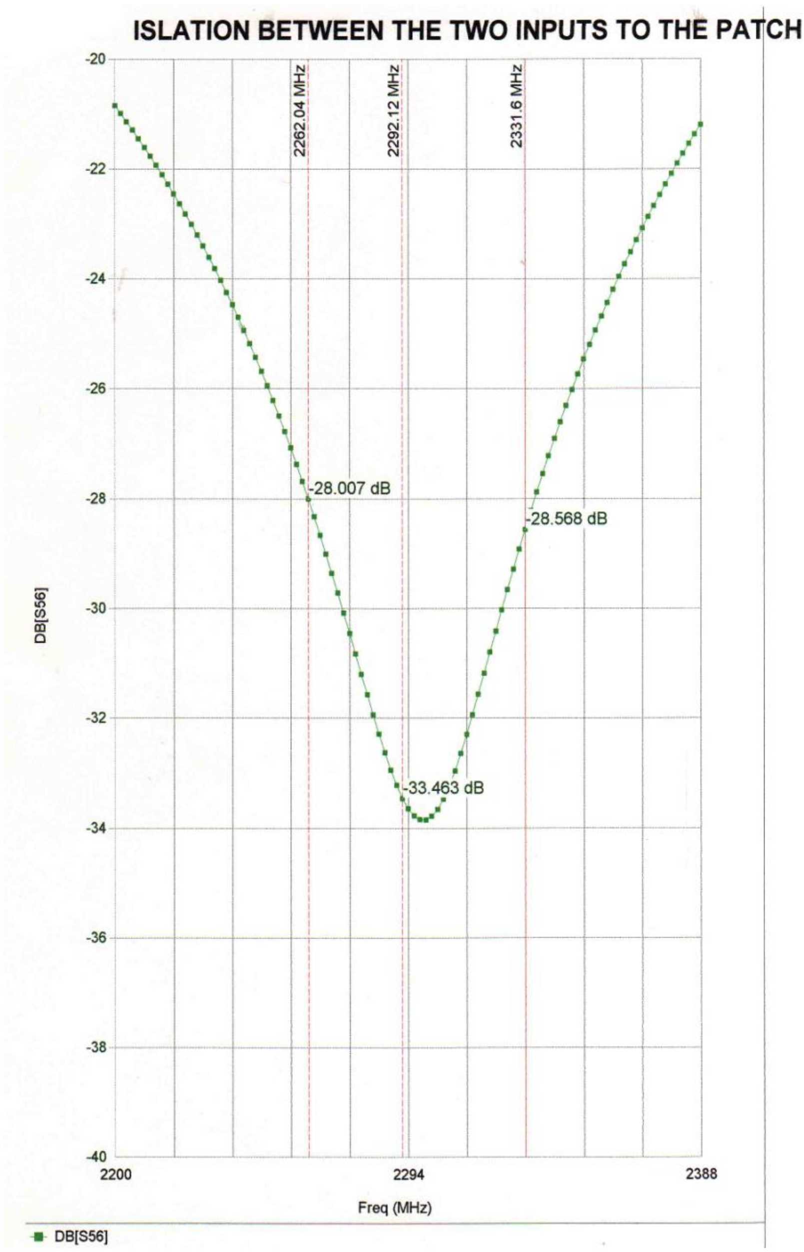


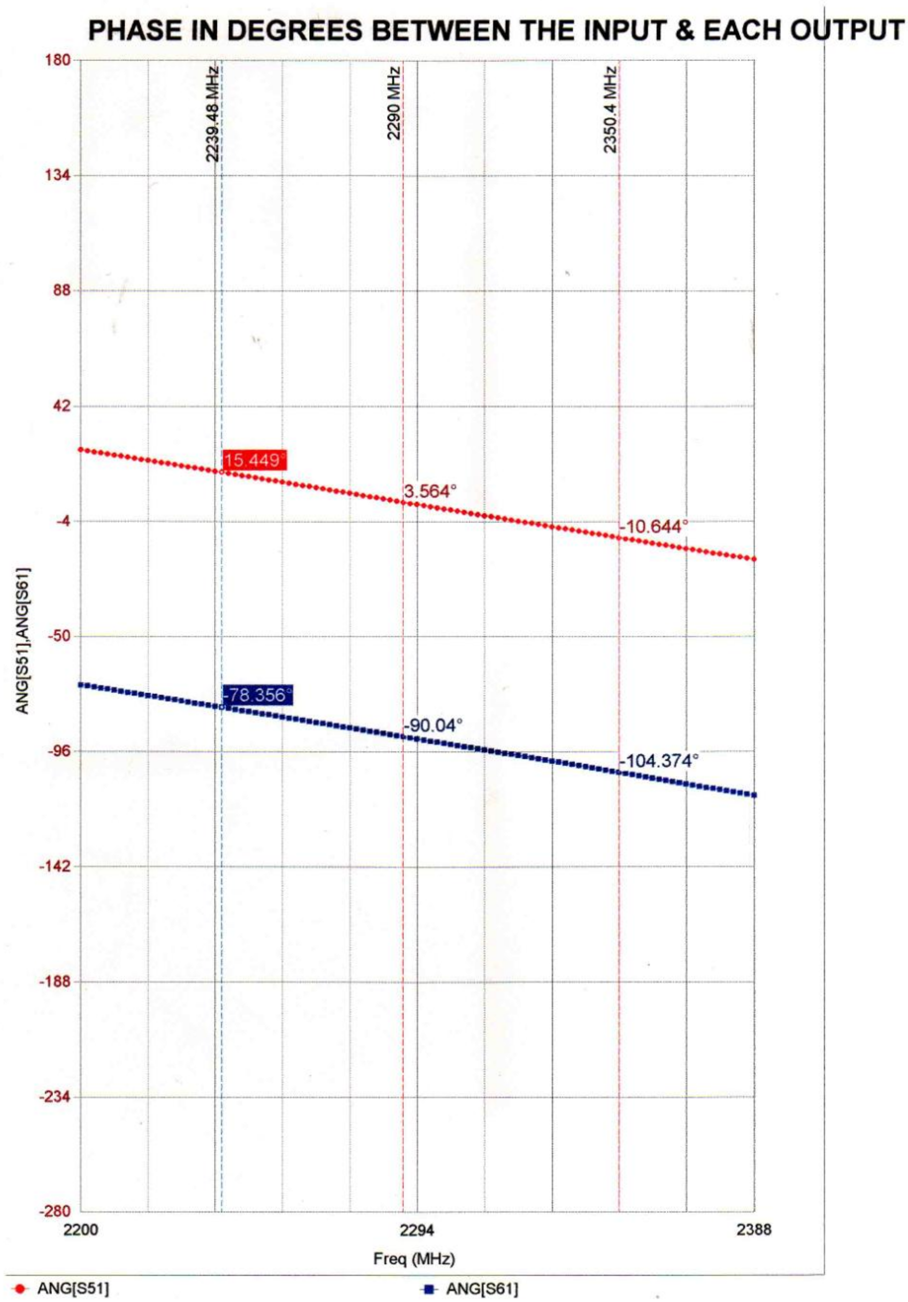
Fig (2): Input impedances of two ports



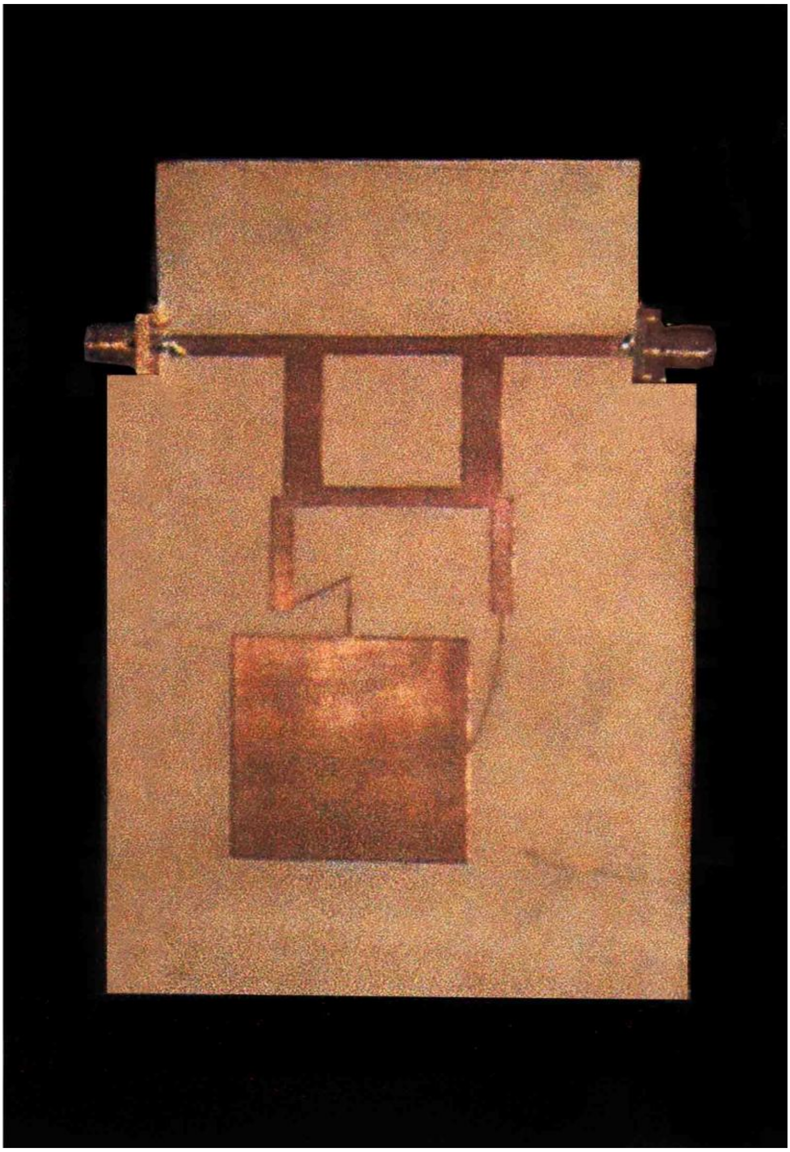
Fig(3): coupling between each output and input



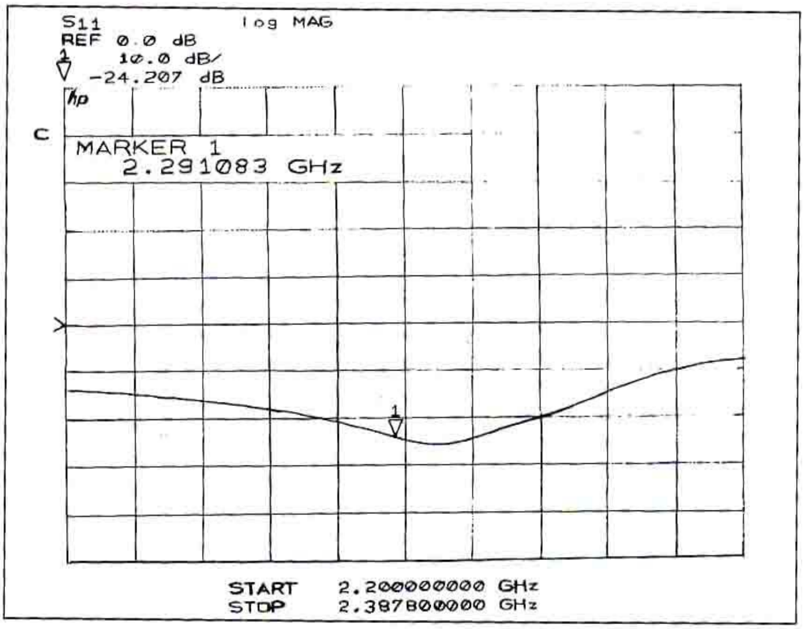
Fig(4): Isolation between two inputs to the patch.



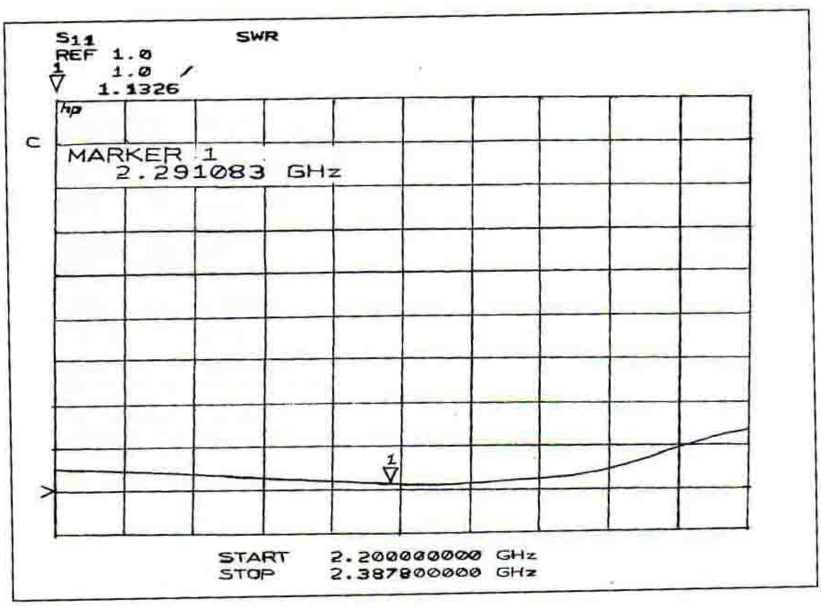
Fig(5): Phase in Degrees between the inputs and each output.



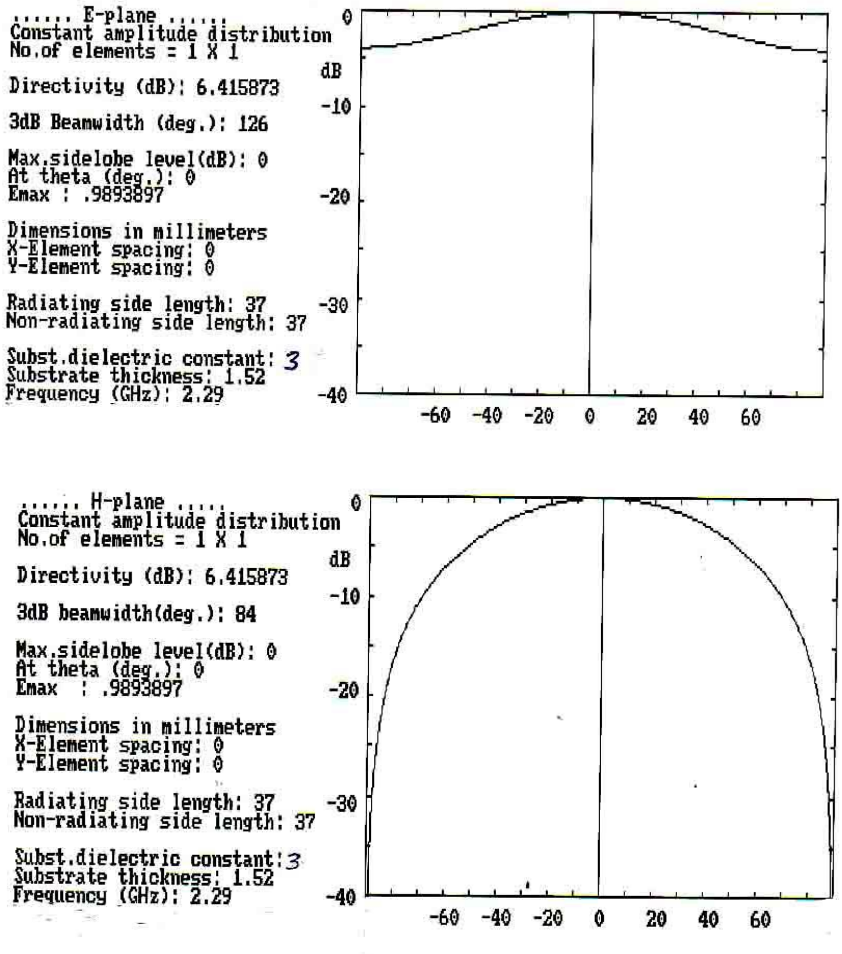
Fig(6): Photograph of the prototype of microstrip antenna (basic element) with 90°- hybrid feed.



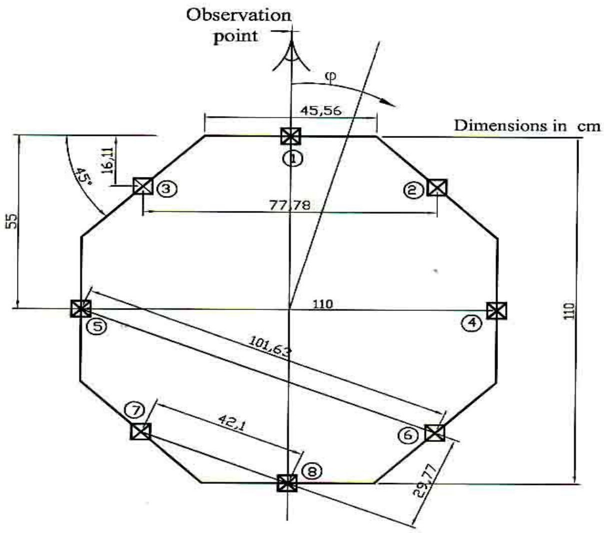
Fig(7): Measurement of Return loss by network analyzer (hp 8510).



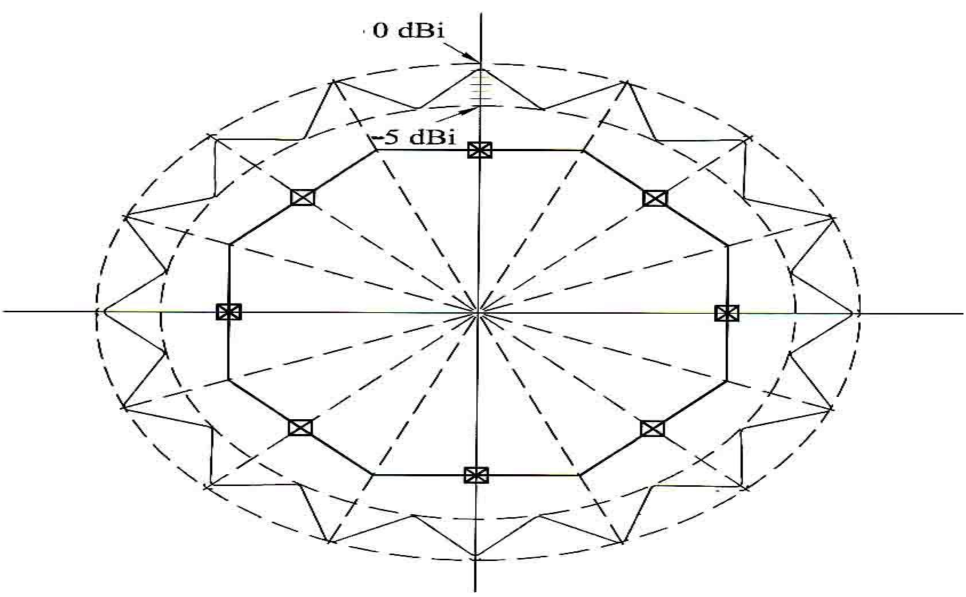
Fig(8): Measurement of Standing wave ratio (SWR) by network analyzer (hp 8510).



Fig(9): Radiation pattern in E and H-planes of the basic element of microstrip patch antenna.



Fig(10): Distribution of the patch elements on the surface of the satellite structure



(Top view)

Fig(11): Radiation pattern of the antenna array for H-plane.