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Experimental Investigations on Square Patch Stacked Antenna Array with 90° Hybrid Feed

V.Saidulu

Department of Electronics & Communication EngineeringMahatma Gandhi Institute of Technology Gandipet, Hyderabad,saiduluvadtya@gmail.com

Abstract: *The present paper deals with the design and development of 90° hybrid feed square patch stacked antenna. The design of square patch and 90⁰ hybrid feed has been carried out at the frequency of 3.0 GHz on epoxy glass substrate; the radiation pattern of the square patch has been experimentally investigated. The effect of stacked patches placed above the square patch has been studied experimentally for different cases like 1, 2, 3 and 4 stacked patches placed one above the driven square patch. From the experimental result it has been found that performance of the case of 1 + 2 (one driven element and two parasitic element) is optimum with bandwidth of 16 % and VSWR 1.42 the performance degrades the no of practical elements is increased that is for case 1 + 3 and 1 + 4 etc., The performance of 1 + 2 case of also found to be superior to the performance 1+ 0 and 1+1 cases experimentally investigated, also been carried out for cross Polarization and co – polarization.*

Keywords - *Input impedance, cross-polar, co-polar, Gain, Bandwidth, resonat frequency etc.*

I. INTRODUCTION

Microstrip antenna is a radiating patch and consisting of one side of dielectric substrate and ground plane in other side. Patch antennas can categorize in various types such as rectangular, circular, square and triangular shape etc. Rectangular and circular shapes of patch antennas are more popular because of essay fabrication [1-12]. The present paper deals with the design and development of 90° hybrid feed square patch stacked antenna. The design of square patch and 90^0 hybrid feed has been carried out at the frequency of 3.0 GHz on epoxy glass substrate; the radiation pattern of the square patch has been experimentally studied**.** The effect of stacked patches placed the above the square patch has been studied experimentally for different cases.

II. ANALYSIS

Square microstrip patch antenna is analyzed using cavity model of analysis. The region between the microstrip and the ground plane can thus be treated as a cavity having a magnetic wall along the edge and the electric walls above the microstrip and below the ground plane. The fields inside the cavity can be expressed in terms of discrete modes individually satisfying the boundary conditions [13-18]. The boundary conditions are:

$$\overline{E}m = \psi m \overline{Z}; \quad \overline{H}m = (1/j\omega\mu)\,\overline{Z} \times \nabla t\psi m;$$
$$\nabla^2 t + K^2 m)\psi m = 0; \qquad (1)$$

$d\Psi m/dn=0$; on the magnetic wall

The electric field for (1,0) and (0,1) modes are given by

$$E_x \alpha \frac{\cos(PX^1/a)}{K-K_{10}} \qquad (2)$$

Where $$E_y \alpha \frac{\cos(PY^1/b)}{K-K_{01}}$$

$$K_{01} = (\pi/b); \quad k_{10} = (\pi/a) \qquad (3)$$

$$\frac{E_y}{E_x} = \frac{\cos(PY^1/b)(K-K_{10})}{\cos(PX^1/a)(K-K_{01})} \qquad (4)$$

If a = b, and K_{01}=K_{10}. is not satisfied. This means that perfect square patch cannot generate, CP is fed at a single point.

Therefore, Let O < c= a-b<< a (or b)

Thus $k \cong k_{01} \cong k_{10}$ (5)

The effective wave number, „k" is defined as

$$K = K_0 \sqrt{\epsilon(1-j\delta_{eft})} \quad (6)$$

However, for an ideal cavity

$$\delta_{eft} = 1/Q \quad (7)$$

$$K = K_0 \sqrt{\epsilon_r}[1-j/zQ] = K^1\text{-}K^{11}$$

$$\text{i.e., } K^1 = K_0 \sqrt{\epsilon_r},\ K^{11} = (K_0\sqrt{\epsilon_r})/2Q,\ K^1/K^{11} = -2Q \quad (8)$$

Let $P = K' - K_{10}$

The triangle K K' K_{10} and K_{10} k' K are similar, so that

$$P + Q = K_{01} - K_{10} = K^1/2Q\ (A + 1/A) \quad (9)$$

$$P = \frac{|K^{11}|}{A},\ Q = K_{10}K^1 \quad (10)$$

Therefore, $p = |K''|[A + 1/A]$

$$\text{Also } K^1 = K_{10}+K^1 / 2QA \quad (11)$$

From equation (9) and (10)

$$A^2 - \frac{2QC}{b}A + (1+C/b) = 0 \quad (12)$$

In general, two possible solutions exist for A, which gives rise to two possible feed loci

When A = 1 in equation (13)

Or $1 - 2QC/b + (1 + C/b) = 0$

But $C = a - b$

So $a/b = (2Q+1) / (2Q-1)$ (13)

Equation (12) given the feed loci:

A is the solution of (12) i.e.,

$$A_{1,2} = (QC/b) \pm \sqrt{(QC/b)^2 - (1+c/b)^2} \quad (14)$$

For a nearly square patch c<<b

$$A_{1,2} = (-[1+c/b])^{1/2}$$

$$A_1, A_2 = (1+c/b) \equiv 1 \quad (15)$$

III. RADIATION FIELD

For a rectangular patch antenna, the equivalent magnetic source distribution around patch boundary for mnth mode resonance is given by

$$K_m = I_y \cos(n\pi / b),\ X = 0$$

π α ϕ w ωθ

$$K_m = I_x \cos (m\pi x / a),\ y = 0 \qquad (16)$$

$$K_m = I_y (-1)^m \cos (n\ \alpha\ y / b),\ x = a$$

$$K_m = -I_x (-1)^n \cos (m\ \pi\ x / a),\ y = b$$

for above given source distribution mnth mode, the electric field is given by following equations:

$$E = -j\ K\ (I_\theta f\phi - I\phi\ f_\theta\ ) \qquad (17)$$

Where, $f_\theta = \cos(\theta)\ [\cos\phi - g_1(\theta,\phi) + \sin\theta - g_2(\theta,\phi)]$

$$f\phi = -[\sin(\phi) g_1(\theta,\phi) - \cos(\phi) - g_2(\theta,\phi)]$$

The E- plane and H-plane patterns for (0,1) mode is linearly – polarized.

IV. DESIGN OF 90^0 HYBRID

90^0 hybrid can be designed so that its output impedance matches with the load at its output port. All the section of these hybrid are λ/4 long, λ being the center frequency in the dielectric.

λ0 = wavelength in the free space.

Referring to Fig (1), when power is fed at port(1), it gets divided equally between ports (2) and (3) no power is coupled to port (4)

Therefore,

- - - - - - - - - -,

$$S_{11} = S_{14} = 0 \qquad (18)$$

Let $K = [S_{13}]^2 / (12)^2$, power splitting ration

Then $\overline{Z}\ d = 1/\ yd \qquad (19)$

$\overline{Y}_a = [(K+1)/K]^{1/2} \qquad (20)$

$\overline{Y}_b = 1/\sqrt{K} \qquad (21)$

$\overline{Y}_c = \overline{Y}_d / \sqrt{K} \qquad (22)$

K = 1 and making $Z_d = Z_0 = 50\Omega$

$Z_a = 50/\sqrt{2} = 35 - 35\Omega$

$Z_b = Z_c = Z_d = Z_0 = 50\Omega$

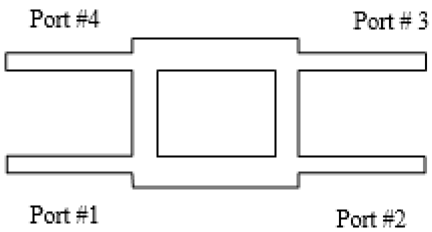

Fig.1 90° Hybrid

For epoxy glass substrate:

Dielectric constant ($\in_r$) = 4.5

Height of the substrate (h) = 0.16cm

Thickness of the strip (t) = 0.001cm

Operating frequency (f) = 3.0 GHz

Free space velocity (C) = $3x10^{10}$ cm/sec.

V. DESIGN OF STRIP WIDTH

The strip widths have been calculated by using iterative method. The following formulas

$$Z = \frac{\eta_0}{2\pi\sqrt{\in_e}} \ln[8h/w^1 + 0.25\, w^1/h];\ w^1/h \leq 1$$

$$= \frac{\eta_0}{\sqrt{\in_e}} [w^1/h + 1.393 + 0.667 \ln (w^1/h + 1.444)]^{-1} \frac{w}{h} \geq 1$$

Where $\eta_0 = 120\pi\Omega$.

$$W^1/h = w/h + 1.25t/\pi h\,(1 + \ln 2h/t),\ w/h \geq 1/2\pi \quad (23)$$

$$\in_e = \frac{\in_r+1}{2} + \frac{\in_r-1}{2} + F\,(W/h)\text{-}C \quad (24)$$

Where $F\,(W/h) = (1+12h/w)^{-1/2},\ W/h \geq 1$

$$C = \frac{\in_r-1}{4.6} \quad \frac{t/h}{\sqrt{w/h}}$$

The width of the patch is shown in Table1.

TABLE 1: WIDTH OF THE PATCH ANTENNA

Strip impedance (Ω)	Effective dielectric constant ($\in_r$)	Widths (cm)
50	3.425	0.216
35.35	3.460	0.386

VI. DESIGN OF THE PATCH

The patch size has been calculated by using iteration method. The approximate patch dimension is determined as

$a^1 = C/2f_0 \sqrt{\in_e} = 2.486$

To account for the fringing field, the change effective dimension is given be 2Δ, where

a^1= 0.00346

Thus $a = a^1 - 2\Delta = 2.5cm$

Hence the patch size is $a \times a = 2.5 \times 2.5cm^2$

VII. INPUT IMPEDANCE

The input impedance at any arbitrary point, which is at a distance „Z" from the corner, is given by

$$Y\ in\ (z) = 2G\ [\cos^2(\beta z) + \frac{G^2 + B^2}{Y_o^2} \sin^2\beta Z - \beta/y_0 \sin(2\beta Z)]^{-1} \quad (25)$$

At Z = 1.12 cm

Y in(1.12) = 0.0130

Z in(1.12) = 70.183Ω

However, as the patch is fed at two points, the effective impedance seen as the feed points is parallel combination of two impedance of 70.183Ω. Hence the input impedance of the patch as seen at ports 1 or 4 is 35.598 Ω each.

VIII. FEED POINT

The feed point is determined by the geometry if the hybrid and the patch. The patch is square and the two feed points are λ/4 away on adjacent sides of the square and equal distance from the corner of the square. Thus one can get

$$Z = \sqrt{2} \times 0.6719 \quad (26)$$

$$= 1.12cm$$

IX. QUARTER WAVE TRANSFORMER

The mismatch between the 50 Ω, stub and 35.598 Ω, patch is minimized by using a quarter wave transformer of impedance.

$$Z = \sqrt{35.598 \times 50} = 42.981$$

The width for this is found to be

$$W(42.98) = 0.4026 \text{ cm}$$

X. LENGTHS OF λ/4 SECTIONS

As the width are different for different impedance arms, so are their dielectric constants, hence the respective wavelengths are also different is shown in Table 2. The final results

Table 2: Impedance Of The Section And Quarter Wavelengths

Impedance of the section (Ω)	**Quarter wavelengths (cms)**
50	1.3508
35.35	1.3438

The completes the design of the microstrip patch antenna with a branch line 90^0 hybrid as shown in Fig2.

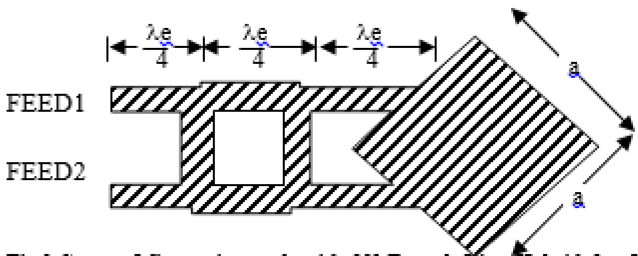

Fig.2 Square Microstrip patch with 90° Branch Line Hybrid for CP Operation

XI. DEVELOPMENT OF ANTENNA

Fig. 3 Microstrip Antenna Fabrication Process

Fig. 3 Microstrip Antenna Fabrication Process

XII. EXPERIMENTAL INVESTIGATIONS

Experimental setup for radiation pattern :

The set for experimental measurements of radiation pattern is shown in Fig 4.

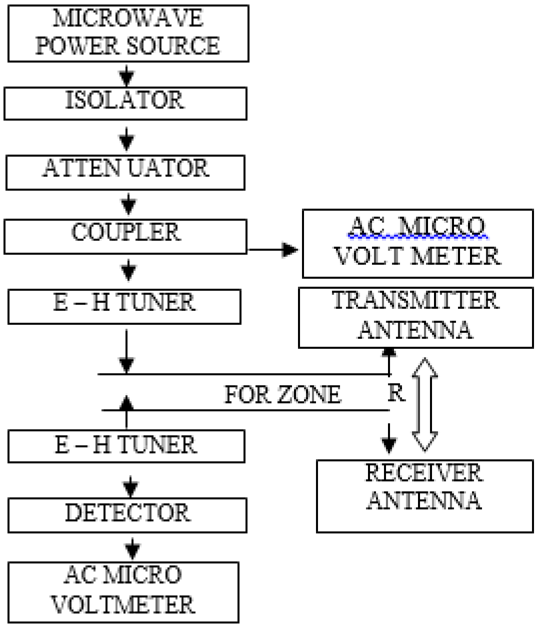

Fig.4 Expermental setup for radiation pattern and VSWR measurement

Experimental set – up for VSWR

The set – up for VSWR is shown in Fig 4. This set – up had same component as that in radiation pattern measurement. The set – up except slotted line which was connected to the locate and quantity the minima point the antenna with load.

Specification of components

I. Stable RF source in S – Band
II. Co –axial – Isolator >> 30dB
III. Output Power : upto 10 mW
IV. Receiving antenna
V. Antenna : Pyramidal Horn
VI. Aperture size: 23 x 29 cm
VII. Gain : 20dB

Experimental Measurements

The set – up was used for measuring the co-polar and cross-polar pattern of the antenna is shown in Fig.4. During the experiment, the output of the source was fairly constant. The source of the microwave power was quite stable and the frequency variations were negligible small. Isolator was used to avoid the reflection from the antenna. The receiver system was kept in the far zone ($2d^2 / \lambda$). Using the set up the radiation patterns of the antenna was measured. The data of measured radiation pattern using different number of parasitic elements are shown in Tables 3 to 5, which are also shown plotted in Figures 5 to 7. Using the Figures 5 to 7 calculated maximum radiated power in (dB), Beam-width (degree) actual ration and gain was shown in Tables 8 to 14. Using the set-up in Fig.4 measuring the VSWR. The data VSWR was shown in Table 13. Using the VSWR data, return-loss were we calculated. The data of return loss was shown in Table 12 and also shown the plot in Fig.8. Calculated the bandwidth from the plot of VSWR, The data of band width was shown in table 14.

TABLE - 3 DATA OF CO-POLAR RADIATION PATTERN FOR 90 HYBRID FEED SQUARE PATCH STACKED ANTENNA

Angle	Relative Power (dB)				
	Driven elemen	**Driven element**	**Driven element**	**Driven element**	**driven element**
-90	-14.49	-12.78	-12.78	-13.7	-15.02
-80	-14.4	-10.36	-9.77	-11.28	-13.7
-70	-13.31	-10.56	-7.14	-12	-13.84
-60	-12	-8	-5.6	-9.38	-13.2
-50	-10.95	-6.1	-3.8	-8.33	-12.13
-40	-10.3	-4.92	-2.75	-6.95	-11.67
-30	-8.98	-3.93	-1.7	-6.03	-10.75
-20	-7.34	-3.28	-1.25	-5.25	-9.2
-10	-6.3	-2.49	-0.48	-4.46	-8.01
0	-5.6	-2	0	-4.07	-6.56
10	-6.49	-2.95	-0.483	-4.52	-7.15
20	-7.48	-3.75	-1.02	-5.64	-8.46
30	-931	-4.66	-1.9	-7.28	-10.23
40	-10.8	-6.03	-2.89	-8.4	-11.64
50	-12	-7.34	-4.46	-10.3	-12.66
60	-13.51	-9.25	-5.77	-11.2	-13.7
70	-14.03	-11.87	-8.98	-13.05	-13.7
80	-14.69	-11.93	-10.95	-12.46	-13.75
90	-14.62	-12.78	-12.13	-14.75	14.33

TABLE - 4 DATA FOR CROSS - POLAR RADIATION PATTERN 90° HYBRID FEED SQUARE PATCH STACKED ANTENNA

Angle (Degree)	**Relative Power (dB)**				
	Driven element	**Driven element +1**	**Driven element +2**	**Driven element +3**	**Driven element +4**
-90	-17.4	-16.53	-16.45	-15.73	-17.69
-80	-16.36	-12.17	-11.26	-15.03	-17.76
-70	-16.71	-11.62	-11.05	-12.8	-16.15
-60	-14.06	-9.37	-7.69	-11.47	-15.1
-50	-12.37	-7.21	-5.45	-10.56	13 85
-40	-11.06	-6.05	-4.06	-8.88	-12.59
-30	-10.07	-5.2	-2.66	-8.04	-11.33
-20	-9.3	-4	-1.89	-6.85	-10.14
-10	-8.11	-3.13	-0.98	-5.52	-9.52

TABLE 5: DATA OF RELATIVE POWER VS ANGLE IN DEGREE FOR DIFFERENT PATCHES

Angle (Degree)	Relative Power (dB)				
	Driven element	Driven element +1	Driven element +2	Driven element +3	Driven element +4
0	-7.06	-2.62	-0.45	-4.69	-7.9
10	-8.32	-3.36	-1.1	-5.73	-9.43
20	-9.86	-4.6	-2.13	-7.51	-10.84
30	-10.8	-6.36	-3.36	-9.23	-12.1
40	-13.08	-8.18	-4.8	-10.9	-14.2
50	-14.64	-11.38	-6.71	-13.32	-15.15
60	-15.58	-12.87	-10.4	-14.71	-16.02
70	-16.85	-11.96	-9.93	-15.38	-16.76
80	-16.64	-13.94	-12.87	-16.63	-17.48
90	-18.57	-16.38	-16.7	-17.22	-17.55

TABLE – 6 DATA OF RETURN – LOSS FOR 90 ^{0} HYBRID- FEED SQUARE PATCH STACKED ANTENNA

Frequency (GHz)	Driven element	Driven element +1	Driven element +2	Driven element +3 parasitic	Driven element +4 parasitic
2	-1.434	-1.51	-1.52	-1.38	-1.28
2.1	-1.7	-1.76	-1.86	-1.62	-1.55
2.2	-1.99	-2.12	-2.29	-1.85	-1.79
2.3	-2.49	-2.65	-2.87	-2.21	-2.12
2.4	-3.18	-3.49	-3.74	-2.92	-2.65
2.5	-3.76	-4.12	-4.37	-3.78	-3.38
2.6	-4.37	-5	-5.07	-4.59	-4.18
2.7	-5.33	-6.46	-7.35	-5.61	-5.04
2.8	-6.72	-8.84	-10.35	-7.85	-6.36
2.9	-8.8	-11.28	-12.73	-10.16	-7.7
3	-11.5	-13.84	-15.2	-12.62	-10.58
3.1	-8.8	-10.88	-12.51	-9.84	-7.63
3.2	-6.15	-8	-9.31	-7	-5.26
3.3	-4.87	-5.95	-6.81	-5.43	-4.21
3.4	-3.67	-4.43	-5	-4.1	-3.25
3.5	-2.92	-3.39	-3.67	-3.13	-2.68
3.6	-2.49	-2.78	-2.92	-2.65	-2.29
3.7	-2.11	-2.43	-2.53	-2.27	-1.93
3.8	-1.82	-1.99	-2.12	-1.89	-1.72
3.9	-1.66	-1.76	-1.82	-1.7	-1.62

4.0	-1.41	-1.53	-1.59	-1.5	-1.34

TABLE 7: DATA OF VSWR FOR 90° HYBRID FEED SQUARE PATCH STACKED ANTENNA

Frequency (GHz)	Driven element	Driven element +1 parasiti	Driven element +2 parasiti	Driven element +3 parasitic	Driven element +4 parasitic
2	12.14	11.48	11.4	12.6	13.5
2.1	10.2	9.88	9.35	10.7	11.2
2.2	8.76	8.2	7.6	9.4	9.69
2.3	7	6.6	6.1	7.9	8.2
2.4	5.51	5.04	4.71	6	6.6
2.5	4.69	4.29	4.05	4.66	5.2
2.6	4.05	3.52	3.23	3.87	4.23
2.7	3.36	2.81	2.5	3.2	3.54
2.8	2.71	2.13	1.91	2.36	2.85
2.9	2.12	1.75	1.6	1.9	2.4
3	1.72	1.51	1.42	1.61	1.84
3.1	2.12	1.8	1.62	1.95	2.42
3.2	2.94	2.3	2.04	2.6	3.4
3.3	3.66	3.03	2.68	3.3	4.2
3.4	4.8	4	3.54	4.3	5.4
3.5	6	5.18	4.8	5.6	6.53
3.6	7	6.3	6	6.6	7.6
3.7	8.25	7.17	6.9	7.68	9
3.8	9.55	8.76	8.2	9.2	10.12
3.9	10.48	9.88	9.55	10.2	10.7
4.0	12.28	11.34	10.94	11.6	12.92

TABLE - 5 DATA OF AXIAL RATIO FOR 90 ^{0} HYBRID FEED SQUARE PATCH STACKED ANTENNA

Angle (Degree)	Driven element	Driven element +1 parasiti	Driven element +2 parasiti	Driven element +3 parasitic	Driven element +4 parasitic
-90	-2.91	-3.75	-3.67	-2.03	-2.67
-80	-1.96	-1.81	-1.49	-3.75	-4.06
-70	-3.4	-1.06	-3.9	-0.8	-2.31
-60	-2.06	-1.37	-2.09	-2.09	-1.9
-50	-1.42	-1.11	-1.65	-2.23	-1.72
-40	-0.76	-1.13	-1.31	-1.93	-0.92

-60	-1.09	-1.27	-0.96	-2.01	-0.58
-20	-1.96	-0.72	-0.64	-1.6	-0.94
-10	-1.81	-0.64	-0.5	-1.06	-1.51
0	-1.46	-0.62	-0.45	-0.62	-1.34
10	-1.83	-0.41	-0.617	-1.21	-2.28
20	-2.38	-0.85	-1.11	-1.87	-2.38
30	-1.49	-1.7	-1.46	-1.95	-1.87
40	-2.28	-2.15	-1.91	-2.5	-2.56
50	-2.64	-4.06	-2.25	-3.02	-2.49
60	-2.07	-3.62	-4.63	-3.51	-2.32
70	-2.82	-0.09	-0.95	-2.33	-3.06
80	-1.95	-2.01	-1.92	-4.17	-3.73
90	-3.95	-3.6	-3.93	-2.47	-3.22

TABLE 8: DATA FOR BEAM-WIDTH (DEGREE)

No. of Elements in 90^0 Hybrid - feed square patch stacked antenna	Beam-width (Degree)	
	Co-Polar	Cross-Polar
1+0	59	56
1+1	79	64
1+2	98	65
1+3	69	60
1+4	50	53

TABLE 9: DATA FOR MAX. RADIATED POWER(dB)

No. of Elements in 90° Hybrid - feed square	Maximum radiated power(dB)	
	Co-Polar	Cross-Polar
1+0	-5.6	-7.06
1+1	-2	-2.62
1+2	0	-0.45
1+3	-4.07	-4.69
1+4	-6.56	-7.9

TABLE 10: DATA FOR AXIAL RATIO(dB)

No. of Elements in 90 Hybrid - feed	Axial ratio (dB)
1+0	-1.46
1 + 1	-0.62
1+2	-0.45
1+3	-0.62
1+4	-1.34

TABLE 11: DATA FOR GAIN (dB)

No. of Elements in 90 Hybrid - feed	Gain (dB)
1+0	8.95
1 + 1	7.11
1+2	6.10
1+3	7.97
1+4	9.91

TABLE 12: DATA FOR RETURN – LOSS (dB)

No. of Elements in 90 Hybrid - feed	Return-loss (dB)
1+0	-11.5
1 + 1	-13.84
1+2	-15.2
1+3	-12.62
1+4	-10.58

TABLE 13: DATA FOR VSWR

No. of Elements in 90 Hybrid - feed square patch stacked antenna	VSWR
1+0	1.72
1 + 1	1.51
1+2	1.42
1+3	1.61
1+4	1.84

TABLE 14: DATA FOR BAND – WIDTH

No. of Elements in 90 Hybrid - feed square patch stacked antenna	Band – Width (%)

1+0	5.33
1 + 1	10.66
1+2	16
1+3	8
1+4	2.66

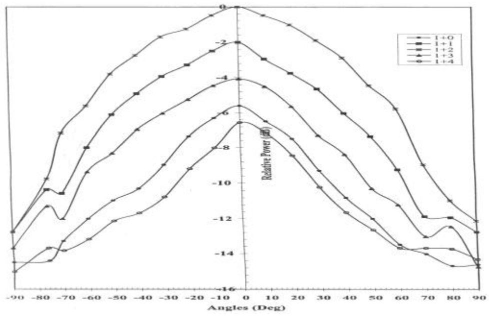

Fig. 5 Co-polar radiation pattern of 90o hybrid-feed square patch stacked antenna

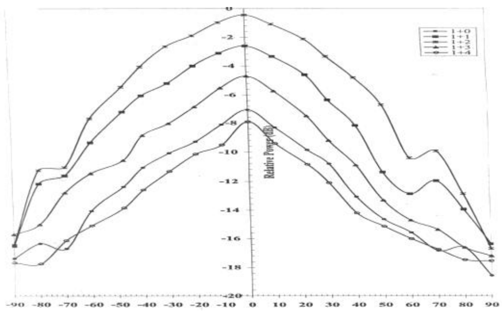

Fig.6 Cross-polar radiation pattern of 90^o hybrid-feed square patch stacked antenna

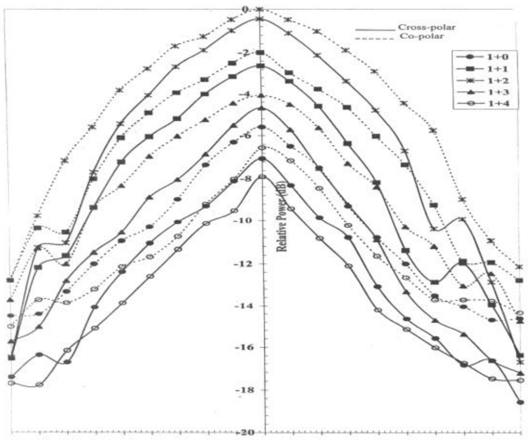

Fig.7.Radiation pattern of 90^o hybrid-feed square patch stacked antenna for co-polar and cross-polar plan

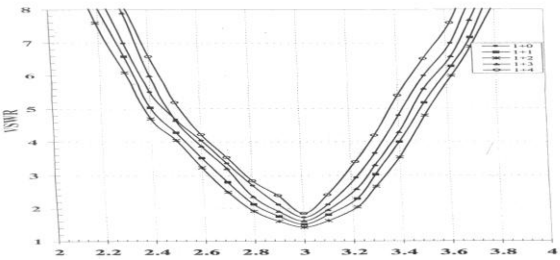

Fig.8 Variation of return-loss with Frequency for 90^o hybrid-feed square patch stacked antenna

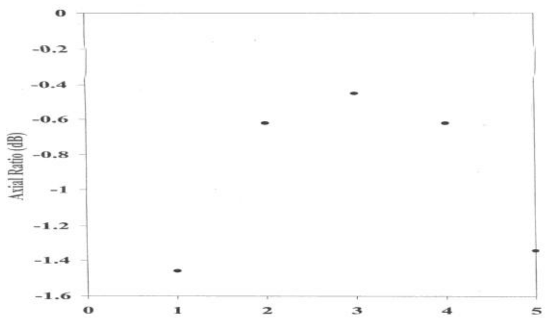

Fig.9. Variation of axial ratio with number of elements.

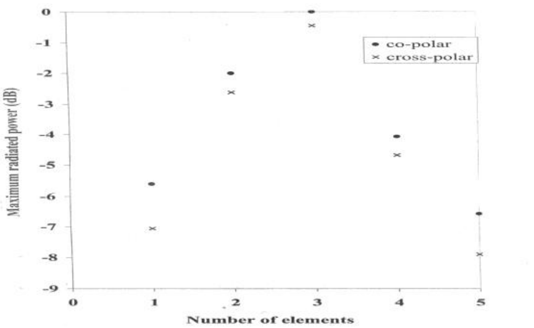

Fig.10. Variation of maximum radiated power with number of elements

XIII. RESULTS AND DISCUSSION

Measurements were made for various parameters such as co – polar and cross –polar radiation pattern, VSWR, return – loss and max. radiated power and axial ratio which are shown in Fig. 5 to 10. The observation of Fig.5 and 6 indicates that radiated power is maximum for the antenna with 2 parasitic elements. Initially the radiated power increase with parasitic elements and becomes maximum for 2 parasitic elements and decreases if number of parasitic element is increased. This is also observed from the VSWR data and return loss Fig. 8. VSWR is obtained at 3 GHz for the cases of optimum 2 parasitic element and return loss of found to be less than -15 dB. The variation of the radiated power shown in Fig.10 for co–polar and cross – polar cases. It is observed that radiation increases with parasitic element and becomes maximum for 2 parasitic elements loaded patch. The radiated power decreases with increasing value of parasitic elements. The Axial ratio is found to be maximum. for 3 parasitic elements antenna and value falls with increasing and decreasing no. of parasitic elements. However the axial ratio with the limits and radiation remains in circular – polarization.

CONCLUSION

A 90 ^{0} hybrid – feed square patch stacked antenna has been designed on epoxy glass substrate. The patches are square patch, for feeding, a suitable point on patch is marked where input impedance is 50Ω. The antenna is developed by using phtolithographic process. From the experimental results it has been found that the performance of the square patch stacked with 2 parasitic elements is found to be optimum.

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