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Analytical Analysis of 8 element ring width rectangular Microstrip patch antenna array

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Abstract**:** *Microstrip patch antennas are extensively used in applications where there is a constraint in size like cell phones and satellites. In this paper, design of 8 element ring width rectangular microstrip patch antenna array at 5.2GHz (C-band) using HFSS is proposed. This array design is precisely useful for the communication coverage of the tight spotted areas with beam width ranging* 10^0 *to* 15^0*. The feeding technique used in this proposed design is edge feed. Parametric analysis of ring width rectangular microstrip patch antenna array is performed for varying ring width values. Introduction of the slot leads to design of ring width rectangular microstrip patch antenna array. The operating frequency lowers due to this slot. The curves of antenna parameters with respect to ring widths and the polynomial expressions that best fits the graph are obtained using MATLAB by performing analytical analysis. The obtained best-fit expressions in MATLAB can be used to predict the antenna parameters due to the slot without using any simulation software.*

Keywords: *High Frequency Structure Simulator (HFSS), Microstrip patch antenna, ring width, edge feed.*

I. Introduction

To design light weight, compact, low cost antennas for wireless communication systems, many research efforts are done. The most common type of antenna used in present communication systems is micro strip patch antenna which is narrow band and wide beam antenna. Any continuous radiator shapes are possible for microstrip antennas but most widely used are square, rectangular, circular and elliptical. Better bandwidth and low robust structure is provided by the patch antennas. It is inexpensive to manufacture and design microstrip antennas, because of simple physical geometry [1-4]. Maximum directivity of 6-9 dB is provided by a single patch antenna. An important role is taken up by microstrip antennas in today's wireless communication. Low cost, lightweight, easy integration and fabrication and operable over wide range of frequencies of micro strip antennas has made it to be widely used since last decade.

Though microstrip patch antenna is used in many applications but it is not suitable for applications where high gain and high directivity are required and this problem is solved by microstrip patch antenna arrays. Narrow beam width is obtained using arrays and this helps in improving the target resolution and EMI problems are reduced with low side lobes around the main beam[11].Thus, applications like radars and reflectors on satellite where high gain is required use these microstrip patch antenna arrays. Microstrip patch antenna array of 8 elements is designed, necessary parameters calculation along with the results are presented.

The analytical approach is used to relate antenna parameters and ring width of the patch antenna due to introduction of the rectangular slot. The analysis of the changes occurring in the parameters due to introduction of the slot is time consuming using simulation software's, so this analytical approach is proposed.

II. Designing Of Single Element Microstrip Patch Antenna

The width and length of patch antenna are calculated for operating frequency of $f_r = 5.2\text{GHz}$ and for substrate with a dielectric constant of $\varepsilon_r = 4.4$ and height of $h = 1.6$ mm.
The width of the patch is:

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} = 17.56 \text{ mm} \quad \dots (1)$$

The effective dielectric constant is:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-1/2} = 3.87496 \text{ mm} \quad \dots (2)$$

Patch length is:

$$L = \frac{\lambda_0}{2\sqrt{\varepsilon_{reff}}} - \left(0.824h\frac{(\varepsilon_{reff} + 0.300)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.800\right)}\right) = 13.2 \text{ mm} \quad \ldots (3)$$

Microstrip feed line is designed for the characteristic impedance of $Z_0 = 50\Omega$, and the design equations[1] are as follows:

$$W_f = \left(\frac{8e^A}{e^{2A} - 2}\right)h\,, \qquad \frac{W_f}{h} \leq 2$$

$$\ldots (4)$$

$$= \frac{2h}{\pi}\left[(B-1) - ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left\{ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right\}\right], \qquad \frac{W_f}{h} \geq 2$$

Where,

$$A = \frac{Z_0}{60}\left\{\frac{\varepsilon_r + 1}{2}\right\}^{1/2} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left\{0.23 + \frac{0.11}{\varepsilon_r}\right\} \text{and } B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}}$$

$$L_f = \frac{\lambda_0}{4\sqrt{\frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1 + 12\frac{h}{W_f}\right)^{-1/2}}} \quad \ldots (5)$$

On substituting the required values, the dimensions of the microstrip feedline are obtained as,
$L_f = 7.9035$ mm and $W_f = 3.059$ mm.
Quarter wave transformer is used to match source impedance to load impedance and its design equations are,

$$Z_t = \sqrt{Z_0 Z_{in}}$$

Where, Z_{in} is the input edge impedance of the patch,
Substitute the value of Z_t instead of Z_0in equation (4), to design the quarter wave transformer.
The dimensions of the quarter wave transformer are obtained as $L_t = 8.3124\ mm$ and $W_t = 0.5345\ mm$.

The obtained theoretical values are to be optimized using HFSS to obtain the required results. Thus, the optimized values are used to design single element microstrip patch antenna and then extended to 8 element patch antenna array.

III. Simulation Of 8elements Patch Antenna Array Without Slot

HFSS stands for High Frequency Structures Simulator. It is antenna design based software. Using the dimensions of patch, matching transformer and feed line, the model of the 8 element microstrip patch antenna is drawn, validated and optimized in HFSS.

3D model and results of 8 element microstrip patch antenna array without introduction of the slot [5] is as shown in Fig.1and its results are as shown in the Fig.2 to Fig.5.

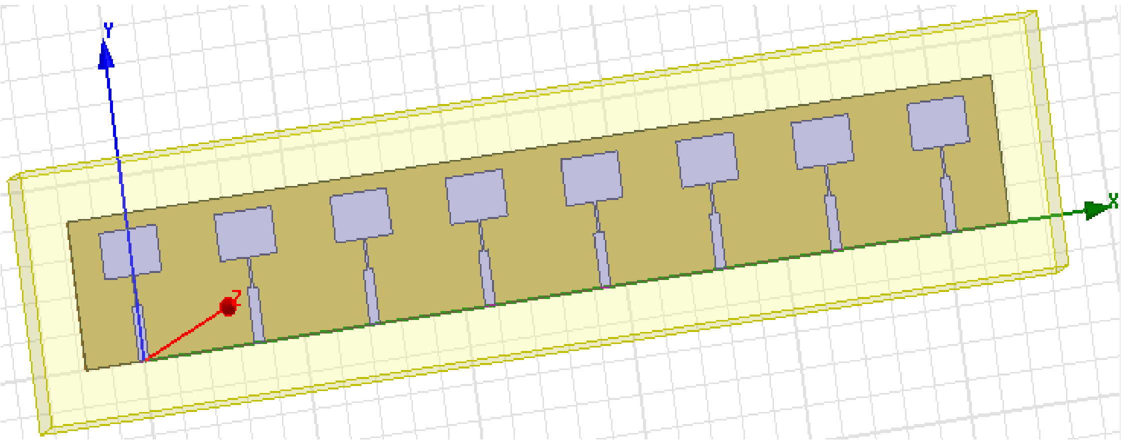

Fig.1: 3D model of 8 element microstrip patch antenna array without slot.

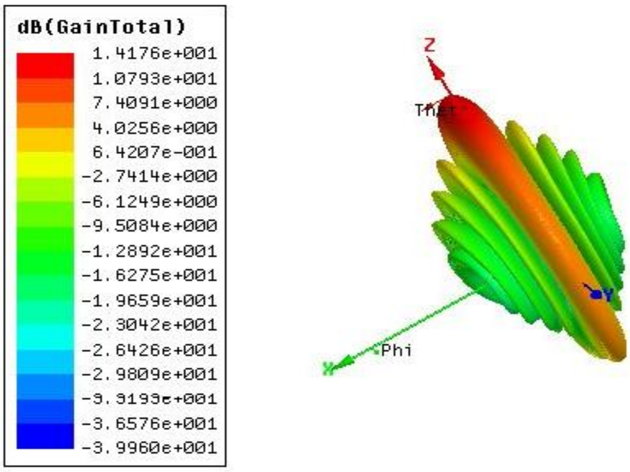

Fig.2: Gain of 8 element Microstrip patch antenna array without slot

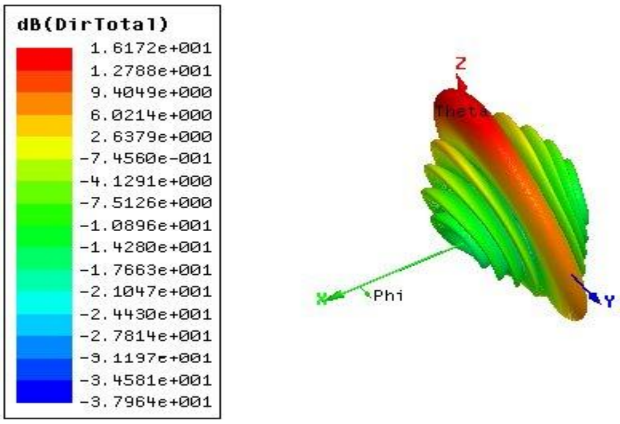

Fig.3: Directivity of 8 element Microstrip patch antenna array without slot

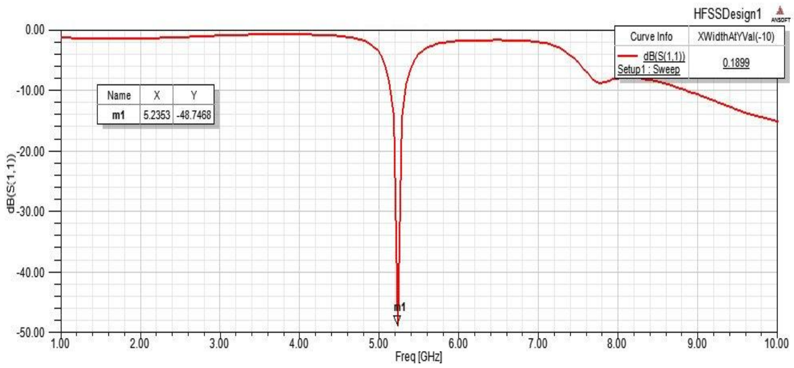

Fig.4: Return loss plot of 8 element Microstrip patch antenna array without slot

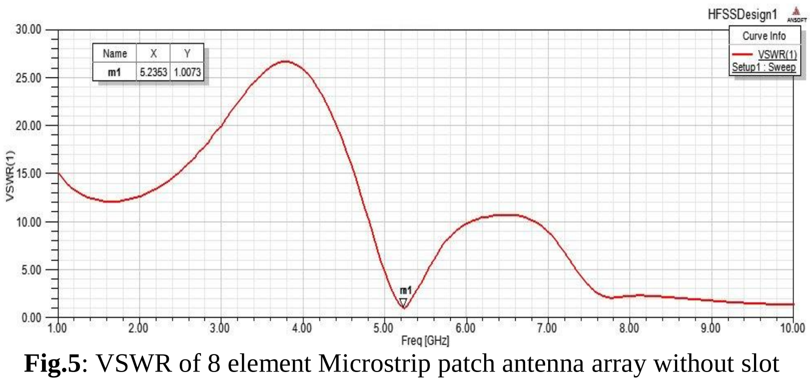

Fig.5: VSWR of 8 element Microstrip patch antenna array without slot

IV. Simulation of 8 Element Ring width Rectangular Microstrip Patch Antenna

The ringwidth rectangular patch antenna array is obtained by introducing a rectangular slot on the radiating patch[6]. The maximum dimension of the slot considered is W=16.56mm, L=11.56mm and the minimum dimension of the slot considered is W=5.56mm, L=0.56mm. By varying the dimensions of the rectangular slot, the patch antenna array with ringwidth variations from 0.5mm to 6mm is obtained, where 0.5mm ring width is obtained for maximum dimension and 6mm is obtained for minimum dimension of the rectangular slot. With the introduction of the rectangular slot, the operating frequency lowers because wavelength increases[7].

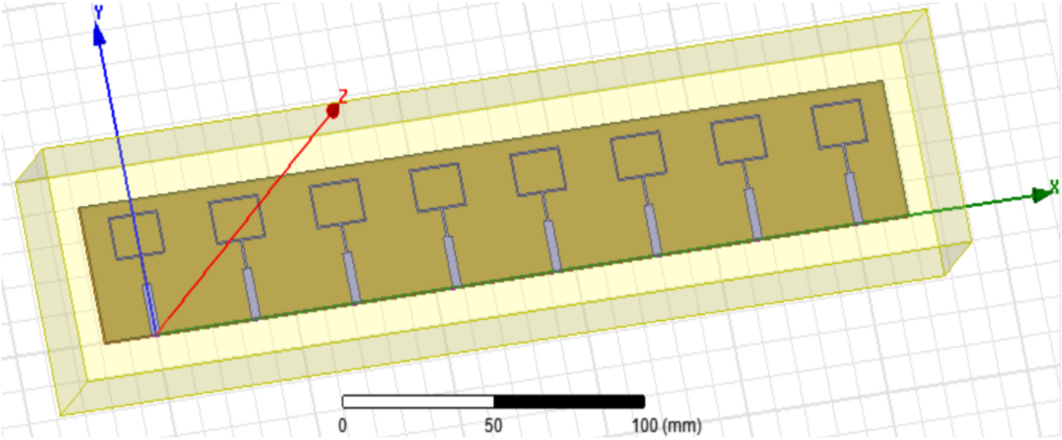

Fig.6: 3D model of 8 element 0.5mm ringwidth rectangular microstrip patch antenna array

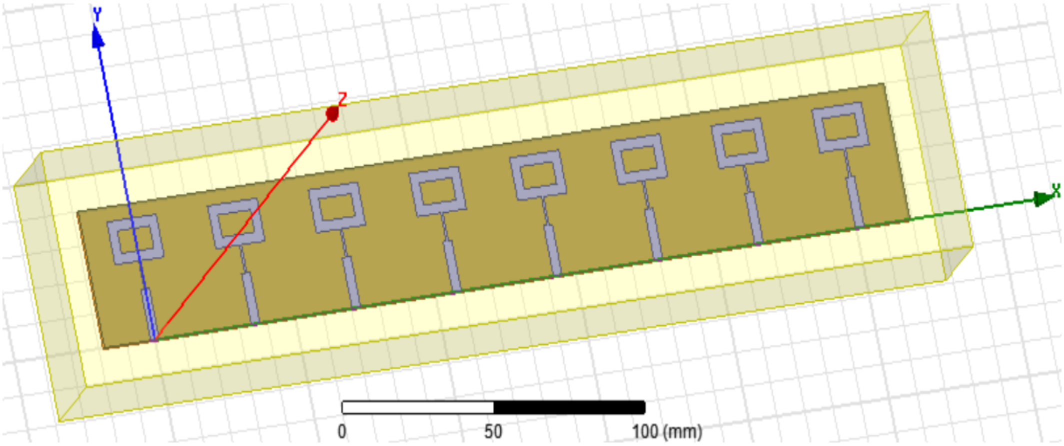

Fig.7: 3D model of 8 element 2.5mm ringwidth rectangular microstrip patch antenna array

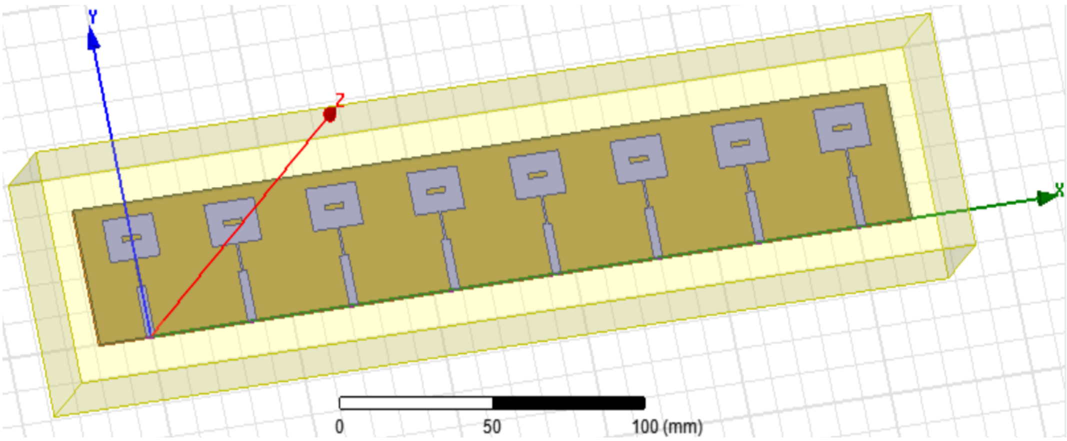

Fig.8: 3D model of 8 element 5.5mm ringwidth rectangular microstrip patch antenna array

Parametric analysis is performed for ringwidth variations of 0.5mm to 6mm return loss and VSWR are plotted as shown in Fig.9 and Fig.10. It is observed that the operating frequency of 5.2GHz is shifted towards the left hand side with variations of the operating frequency ranging from 3.435GHz to 5.0824GHz. Return loss is decreasing with the increase in ring width. Return loss of -2.7621 dB,-18.0179 dB is obtained for the ring widths of 0.5mm and 6mm respectively [8-9]. VSWR satisfies its ideal value condition for the ring width variations of 4mm to 6mm. Maximum beam width of 10.279 is obtained at ringwidth of 4mm.

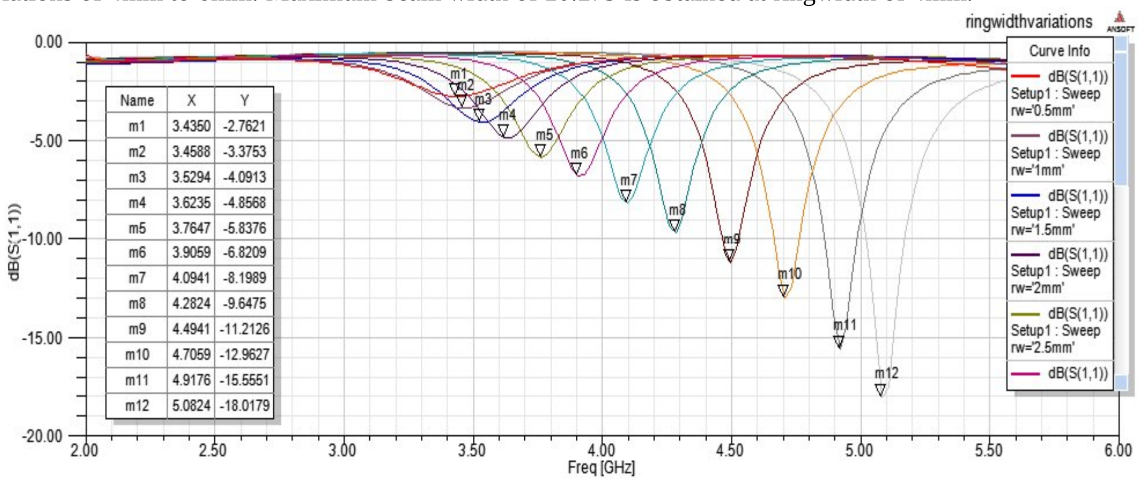

Fig.9: Return loss plot obtained with ring width variations from 0.5mm to 6mm

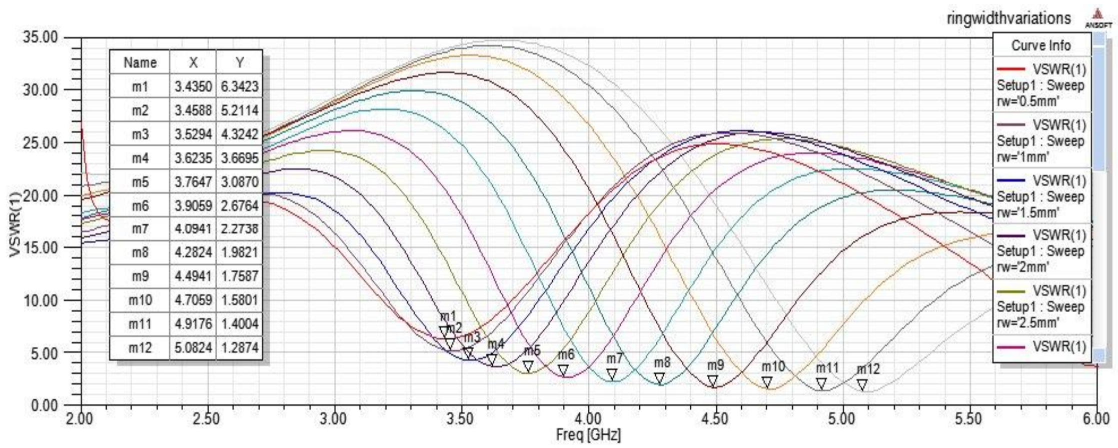

Fig.10: VSWR obtained with ringwidth variations from 0.5mm to 6mm

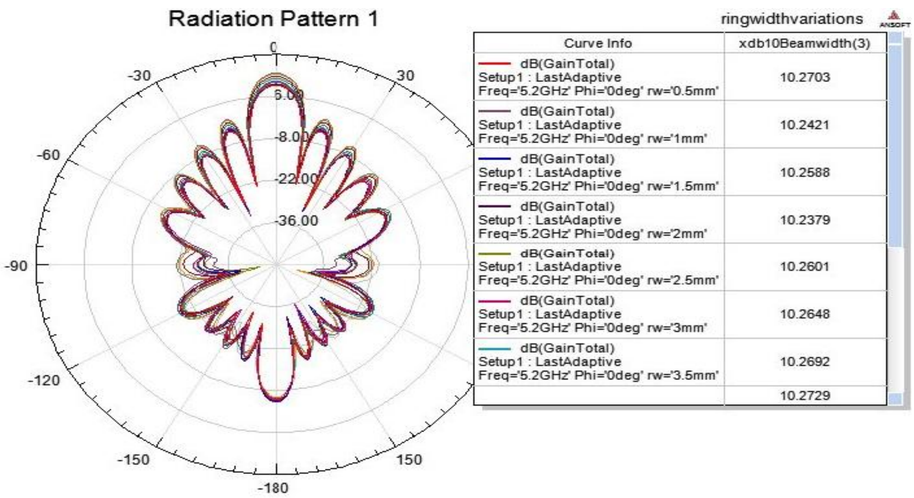

Fig.11: Radiation pattern obtained with ring width variations from 0.5mm to 6mm

The antenna parameters of 8 element rectangular microstrip patch antenna array with ring width variations[10] from 0.5mm to 6mm are as shown in Table 1.

Table 1: Antenna parameters obtained in HFSS for ring width variations, 0.5 mm to 6 mm

Ring width	Shifted operating frequency (fr)	S_{11}(in dB)	VSWR	Directivity (in dB)	Gain (in dB)	Beamwidth at $\varphi=0^0$.
0.5 mm	3.435 GHz	-2.7621	6.3423	16.16	9.7839	10.2703^0
1 mm	3.4588 GHz	-3.3753	5.2114	16.075	9.864	10.2421^0
1.5 mm	3.5294 GHz	-4.0913	4.3242	16.038	9.9998	10.2588^0
2 mm	3.6235 GHz	-4.8568	3.6695	16.081	10.196	10.2379^0
2.5 mm	3.7647 GHz	-5.8376	3.087	16.175	10.349	10.2601^0
3 mm	3.9059 GHz	-6.8209	2.6764	16.375	10.732	10.2648^0
3.5 mm	4.0941 GHz	-8.1989	2.2738	16.608	11.174	10.2692^0
4 mm	4.2824 GHz	-9.6475	1.9821	16.922	11.893	10.2729^0
4.5 mm	4.4941 GHz	-11.2126	1.7587	17.155	12.754	10.2397^0
5 mm	4.7059 GHz	-12.9627	1.5801	17.171	13.656	10.2633^0
5.5 mm	4.9176 GHz	-15.5551	1.4004	16.903	14.295	10.2551^0
6 mm	5.0824 GHz	-18.0179	1.2874	16.517	14.423	10.214^0

V. Model Generation Using Mat lab

In MATLAB, "Curve fitting tool" is used for the analytical analysis of the parameters like shift in operating frequency, return loss, gain, directivity and VSWR with the ring width variations from 0.5 mm to 6mm. Using this "cftool", curve that fits the data in Table 1 is generated and thus polynomial expression is obtained which inturn can be used to obtain the antenna parameter values at any value of ring width without using any simulation software.

The best fit equation obtained for the shifted operating frequency with respect to ring width variations is$-0.001059x^4 + 0.005854x^3 + 0.05266x^2 - 0.02161x + 3.429$.

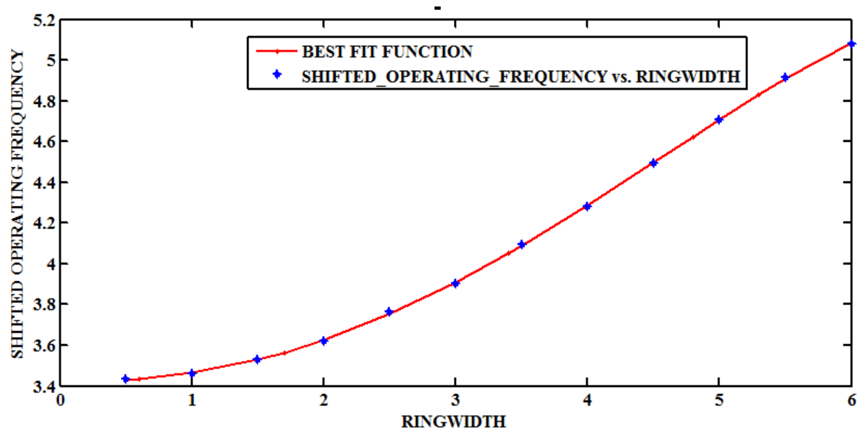

Fig.12: Best fit curve for shifted operating frequency with respect to ring width variations.

The best fit equation obtained for the return losswith respect to ring width variations is $-0.005426x^4 + 0.02943x^3 - 0.2874x^2 - 0.7873x - 2.311$.

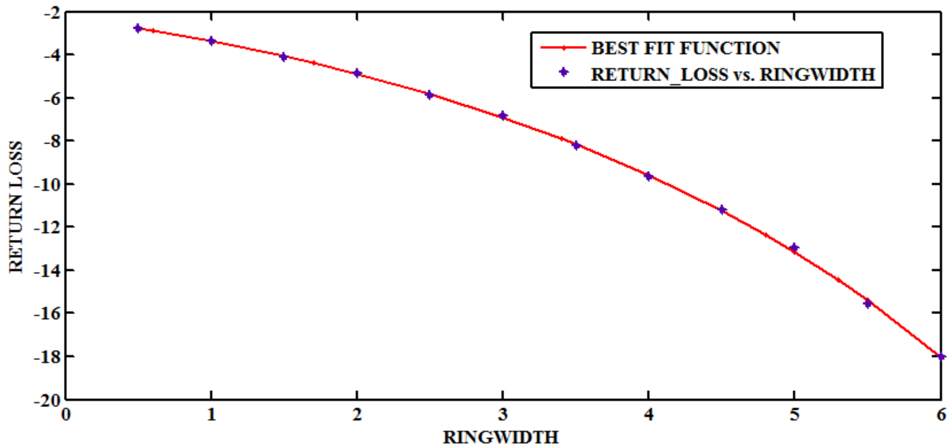

Fig.13: Best fit curve for return loss with respect to ring width variations.

The best fit equation obtained for the VSWR with respect to ring width variations is $-0.004247x^4 - 0.08232x^3 + 0.6798x^2 - 3.105x + 7.726$.

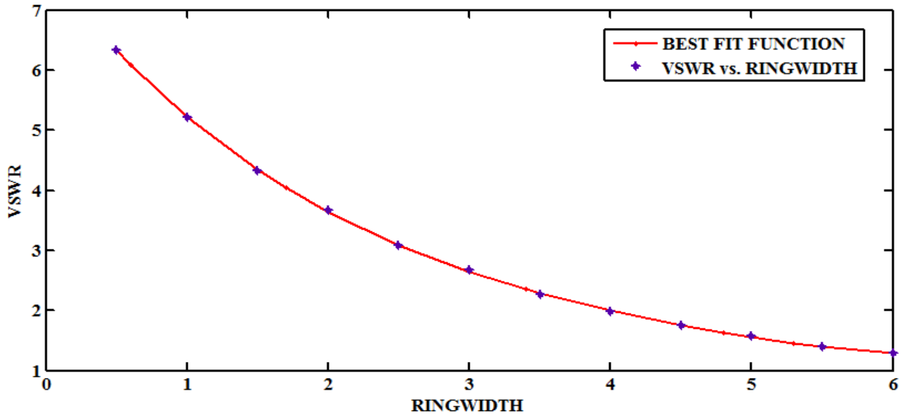

Fig.14: Best fit curve for VSWR with respect to ring width variations.

The best fit equation obtained for the Gain with respect to ring width variations is $-0.007632x^5 + 0.0936x^4 - 0.3727x^3 + 0.7061x^2 - 0.3837x + 9.836$.

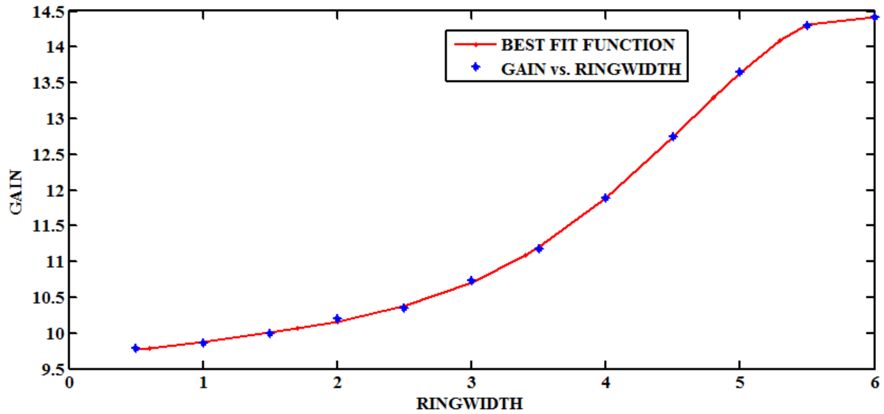

Fig.15: Best fit curve for gain with respect to ring width variations.

The best fit equation obtained for the Directivity with respect to ring width variations is $0.002639x^6 - 0.0486x^5 + 0.3303x^4 - 1.059x^3 + 1.801x^2 - 1.583x + 16.62$.

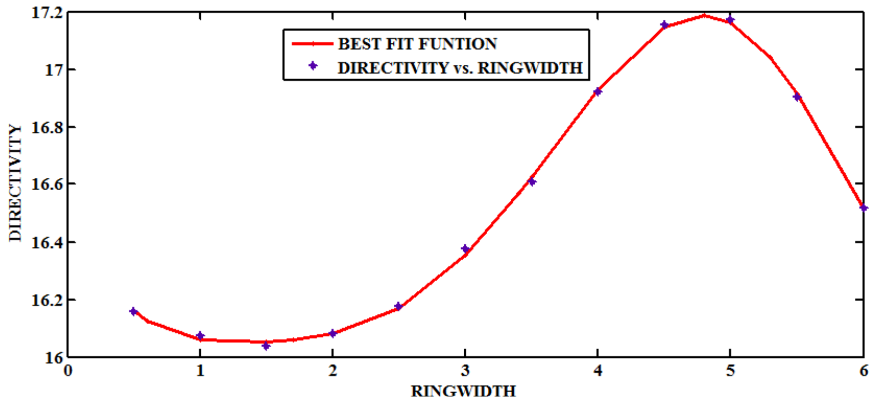

Fig.16: Best fit curve for Directivity with respect to ring width variations.

The best fit equation obtained for the Beam width at 0^0 with respect to ring width variations is $0.01\{1000.26+1.295\cos(1.956x)+0.9428\sin(1.956x)+1.094\cos(3.912x)+1.254\sin(3.912x)+0.3614\cos(5.868x)+0.2076\sin(5.868x)+2.086\cos(7.824x)-0.1792\sin(7.824x)+0.7187\cos(9.78x)-0.4765\sin(9.78x)\}$

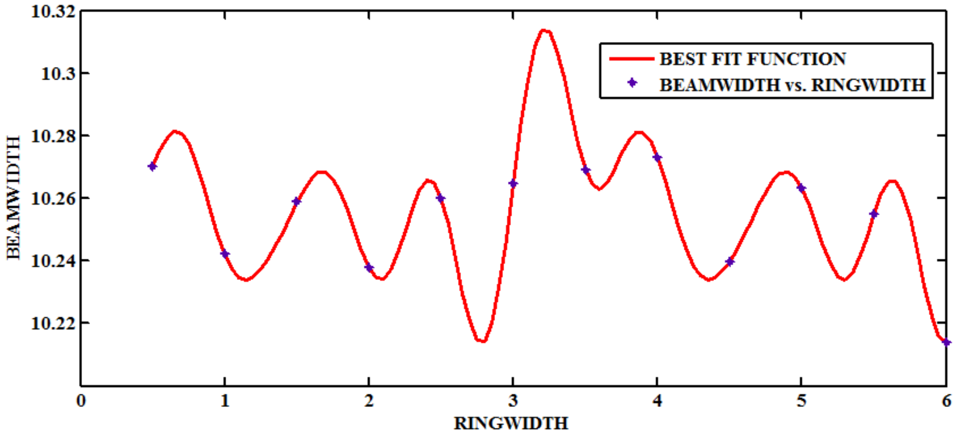

Fig.17: Best fit curve for Beam width with respect to ring width variations.

VI. Validation Of The Results

The obtained best fit equations are validated at ring width variations of 0.6mm, 1.7mm, 3.4mm, 4.8mm, and 5.3mm as shown in Table 2.1 and Table 2.2.

It is observed that the simulated results and the values obtained in MATLAB are almost equal. Thus, the obtained best fit equations can be used to design an 8 element ring width microstrip patch antenna at the required parameter values.

TABLE 2.1: Validation of Simulated results in HFSS with MATLAB results

Ring width	Shifted operating frequency (fr) in HFSS	Shifted operating frequency (fr) in MATLAB	Directivity in HFSS	Directivity in MATLAB	Beam width at $\varphi = 0^0$ in HFSS	Beam width at $\varphi = 0^0$ in MATLAB
0.6 mm	3.435GHz	3.435GHz	16.129dB	16.12 dB	10.279^0	10.279^0
1.7 mm	3.552 GHz	3.564 GHz	16.052dB	16.06 dB	10.272^0	10.268^0
3.4 mm	4.07 GHz	4.052 GHz	16.555 dB	16.56 dB	10.249^0	10.28^0
4.8 mm	4.635 GHz	4.623 GHz	17.201 dB	17.18 dB	10.262^0	10.265^0
5.3 mm	4.823 GHz	4.829 GHz	17.033 dB	17.04 dB	10.269^0	10.239^0

TABLE 2.2: Validation of Simulated results in HFSS with MATLAB results

Ring width	Returnloss in HFSS	Returnloss in MATLAB	VSWR in HFSS	VSWR in MATLAB	Gain in HFSS	Gain in MATLAB
0.6 mm	-2.87 dB	-2.88 dB	6.09	6.09	9.74 dB	9.79 dB
1.7 mm	-4.39 dB	-4.38 dB	4.03	4.04	10.09 dB	10.06 dB
3.4 mm	-7.78 dB	-7.8 dB	2.37	2.36	11.06 dB	11.08 dB
4.8 mm	-12.28 dB	-12.33 dB	1.64	1.63	13.3 dB	13.28 dB
5.3 mm	-14.27 dB	-14.4 dB	1.47	1.46	14.11 dB	14.09 dB

VII. Conclusion

Thus, analytical design is done for 8 element ring width microstrip patch antenna array. Operating wavelength increases with the increase in the size of the slot, so the operating frequency decreases, resulting in the shift of operating frequency towards left. It is observed that the beamwidth obtained is in the range 10^0 to 15^0, so this design can be implemented in tight spotted area for the communication purpose. Maximum bandwidth of 189.9MHz can be achieved using this design. Instead of performing simulations in HFSS software, which is time consuming, the obtained best fit equations in MATLAB can be used as an alternative.

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