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Design and Simulation of Microstrip patch array antenna for C Band Application at IMT (4400-4900 MHz) advanced spectrum with Series feed and parallel feed

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Abstract - Micro strip patch array antenna has proved importance of itself in wireless application fields. In current worldwide society, communication systems are rapidly switching from wired to wireless networks. Wireless technology provides less expansive equipments and a flexible way for communication systems. Patch array antenna provides various important applications, such as satellite communication, Radar systems, Global positioning system, WIMAX (worldwide interoperability for microwave access), RFID (Radio frequency identification) and wireless telecommunication systems. In this article 2x1 and 4x1 patch array antenna with series feed and parallel feed arrangement has been designed and simulated on HFSS (High frequency structure simulator) simulation tool. Proposed patch array antenna with parallel feed arrangement, uses 50 ohm and 100ohm line with suitable width and length for feeding of the patch elements. In the series fed patch array, straight feeding micro strip line and rectangular patch (as radiating element) element are connected directly at corners without power dividers and impedance transformers. Series feeding arrangement avoids feeding line loss in comparison to parallel feeding arrangement. Here proposed patch array antenna at 4.55 GHz resonance frequency, provides it's suitability in C Band applications (4-8 GHz) like satellite communication and long distance radio telecommunications. IMT (International mobile telecommunication) [4400-4900 MHz] Band supports cooperative communication in 3GPP LTE advanced standard. Antenna parameters like return loss, Bandwidth and Gain, obtained after simulation has been discussed and compared for all simulated (parallel fed and series fed) patch array.

Index Terms - Micro strip patch antenna, Patch array antenna, Micro strip line inset feed, Series feed, parallel feed, Return loss and Bandwidth.

1. Introduction

Wireless technology provides less expansive equipments and flexible way for communication purpose. Antenna has its own importance in communication systems; it provides radiation of electromagnetic energy uniformly in all directions. Antenna is a transducer, which converts one form of energy in to another. Here it is designed to transmit or receive electromagnetic waves from one source to destination. Micro strip antennas have several advantages over other conventional microwave antennas and therefore widely used in many practical applications.

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Modern communication system requires low profile, light weight, high gain and simple structure antennas to assure mobility and high efficiency characteristics. Key features of microstrip antenna satisfy such characteristics. Limitations of micro strip antennas are narrow frequency band and disability to operate at high power levels of waveguide, coaxial line or even strip line. Therefore, the challenge in micro strip antenna design is to increase bandwidth and gain [1]. Microstrip antennas are currently one of fastest growing segments in wireless application fields. Microstrip antenna technology began its rapid development in late 1970's. Microstrip antennas are used in wide range of applications, some of which are: GPS patch antennas, WLAN/MIMO 3G communication systems and range radar sensors. Size of microstrip patch antenna depends on frequency band of operation, for example: a low frequency band antenna can have a height of several meters, while another operating in a much higher frequency band can have a several centimeters of length only (i.e. A cell phone antenna).

Figure-1 shows a rectangular microstrip patch antenna, it consists of four major parts: conductive patch, ground plane, substrate and feeding line. Conductive patch and ground plane are usually made from same material (such as copper of high conductivity). Material of the substrate and its thickness are also important, type of the substrate has its significant role in determination of antenna dimensions. Substrate of high permittivity results in larger dimension of patch antenna. Here in this article FR-4 is selected for Substrate, it has relative permittivity equals to 4.4. Substrate is above the ground and conductive patch is on top of the substrate (as shown in figure-1). Excitation of patch is accomplished via feed line. When the patch is excited by feed, bottom of the patch at a certain point in time will have positive charge distribution and ground plane will have negative charge distribution.

Attractive forces between these two charges will hold most of them on bottom surface of the patch and top surface of ground. On the patch surface repulsive charges within the same polarity, tend to push some of charges towards edge. These charges create fringing effects and cause radiation.

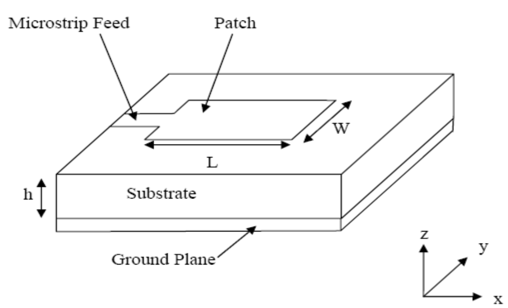

Fig. 1 Rectangular patch with feed line

As shown in Fig.1 radiating patch is on top of the dielectric substrate, this may be of any shape but generally rectangular and circular geometry is preferred. For radiating patch and ground plane, generally we select copper material for simulation. Selection of material for Dielectric substrate depends on its relative permittivity (it is taken greater than or equal to 2.2 and less than or equal to 12). FR-4, R-Alumina, silicon, Teflon, RogersRTduroid5880 and modified epoxy, these are several materials for dielectric substrate. Dielectric constants in lower end of range can give us better efficiency and large bandwidth but at expanse of large element size. In some applications we need small size antenna, substrate with high dielectric constant is a better choice for this case. High dielectric constants have greater losses so they are less efficient and have relatively small bandwidth [2].

Some disadvantages of single micro strip patch element antenna (such as narrow bandwidth, low gain and lower efficiency) can be overcome by formation of patch array configuration. Different array configurations of micro strip antenna can give high gain, wide bandwidth and improved efficiency. Distribution of voltages among elements of an array depends on feeding network. Proper impedance matching throughout the corporate and series feed network provides high efficiency micro strip antenna [3-5].

2. Feed arrangements

Feeding of micro strip array antenna is by series-feed network (figure 2) or corporate feed network (figure 3):

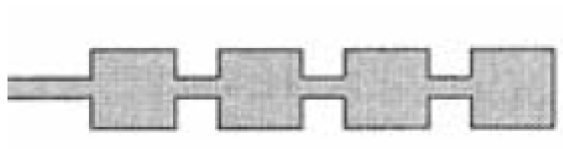

Fig. 2 Series feed arrangement

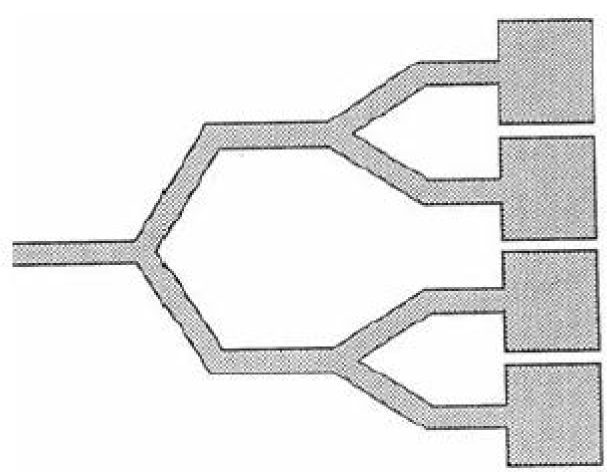

Fig.3 Parallel feed arrangement

Microstrip antennas are used in arrays as well as single elements [4, 5, and 6]. By using array in communication systems we enhance the performance of the antenna like increasing gain, directivity scanning the beam of an antenna system, and other functions which are difficult to do with the single element.

If we reduce the width of the patch, the radiation conductance is insufficient to match the input. We can use the microstrip patch as a transmission line and connect a line opposite the feed to lead to other patches. If we space the patches by half wavelengths, the impedances of the patches will add in phase at the input, because it rotates once around the Smith chart in lambda/2. The Characteristic impedance of the connecting lines has no effect at center frequency. The junction of transmission- line feeder and the patch introduces extra phase shift [2]. The difference in phase between two adjacent elements in series-fed array as given in [33] as,

$$\phi = 2\pi f l / v = 2\pi l / \lambda \quad \text{.... (1)}$$

Where, f = frequency of the electromagnetic signal, l = length of line connecting adjacent elements, v = velocity of propagation, and λ = signal wavelength. The main limitation in series-fed arrays is the large variation of the impedance and beam-pointing direction over a band of frequencies.

The corporate-feed network is used to provide power splits of 2n (i.e., n = 2; 4; 8; 16; 32, etc.). This is accomplished by using either tapered lines or using quarter wavelength impedance transformers. Corporate-fed arrays are general and versatile. With this method the designer has more control of the feed of each element (amplitude and phase) and it is ideal for scanning phased arrays, multi beam arrays, or shaped-beam arrays [4]. The radiated field formula that is given in Equation of E (above in series feed), is same for this array and array factor as given in equation-

$$FA = \sin^2\left(N\pi (d_x/\lambda)\sin\theta\right) / N^2 \sin^2\left(\pi (d_x/\lambda)\sin\theta\right) \quad \text{.... (2)}$$

Combining the element radiation pattern and array factor we get the normalized power radiation pattern.

3. Design Equations

Microstrip patch array antennas are designed to outperform the single patch in terms of return loss, bandwidth and gain. The patch elements in array configuration can be fed by series feed (single line) or parallel feed (multiple lines) arrangement [4]. Designing of patch array antenna is initiated by determining the dimension of patch, substrate and feeding line.

Width of the patch is given by:

$$W = \frac{1}{2 f_r \sqrt{\mu_0 \varepsilon_0}} \sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{c}{2 f_r} \sqrt{\frac{2}{\varepsilon_r + 1}} \quad \text{......... (3)}$$

Length of the patch:

$$L = \frac{1}{2 f_r \sqrt{\varepsilon_r} \sqrt{\mu_0 \varepsilon_0}} - 2\Delta L \quad \text{.. (4)}$$

Length extension:

$$\Delta L = h(0.412) \frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \quad \text{.. (5)}$$

Effective dielectric constant:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \quad \text{.. (6)}$$

Inset length of the patch for inserting microstrip feed line:

$$y_o = 10^{-4}\left\{ \begin{array}{l} 0.001699\varepsilon_r^7 + 0.13761\varepsilon_r^6 - 6.1783\varepsilon_r^5 + 93.187\varepsilon_r^4 - 682.69\varepsilon_r^3 + \\ 2561.9\varepsilon_r^2 - 4043\varepsilon_r + 6697 \end{array} \right\} \frac{L}{2}$$

$$(2 \le \varepsilon_r \le 10) \quad \text{... (7)}$$

Width of the feed line:

$$Z_o = \frac{120\pi}{\sqrt{\varepsilon reff}\left(1.393+\frac{W}{h}+\frac{2}{3}\ln\left(\frac{W}{h}+1.444\right)\right)} \quad .. (8)$$

Length of the feed line:

$$R_{in(x=0)} = \frac{Z_o}{Z_T} = cos^2\left(\frac{\pi}{L}x_o\right) \quad .. (9)$$

Here, transmission line model is used for calculation of all dimensions of the patch. Above equations (3-9) depicts all dimensions required for designing of patch. Width (w) of the patch is determined by equation 3, actual length of the patch and effective dielectric constant is obtained by equations 4, 5 & 6. Inset length of the patch for inserting micro strip feed line, is obtained with help of equation 7 [7]. This equation gives length inside patch, where exact 50 ohm impedance is achieved with suitable microstrip feed line. Width and length of feed line is obtained with equation 8 & 9.

4. Microstrip patch arrays with parallel and series feed arrangement:

Here, 2x1 and 4x1 patch arrays are drawn and simulated on HFSS with parallel feed and series feed arrangement. Further comparison has been done on these drawn and simulated array results. Mainly return loss and Bandwidth obtained with these arrays are discussed and compared to each other.

4.1 Designing of 2x1 patch array with parallel feed network:

Here, 2x1 patch array has been designed with parallel feed arrangement and inset fed patches. Proposed patch array antenna operates in IMT advanced spectrum (4400-4900 MHz) for C Band applications. Patch width = 30.50 mm and length = 26.50 mm, substrate is FR-4 (dielectric constant = 4.4) and its height equals to 1.6 mm. inset length for patch = 7.8262 mm, width of 100 ohm line = 1.4079 mm and its length is lambda/4, width of 50 ohm line = 4.8262 mm and its length is lambda/4. These width and length are optimized up to some extent, where we can obtain proposed results.

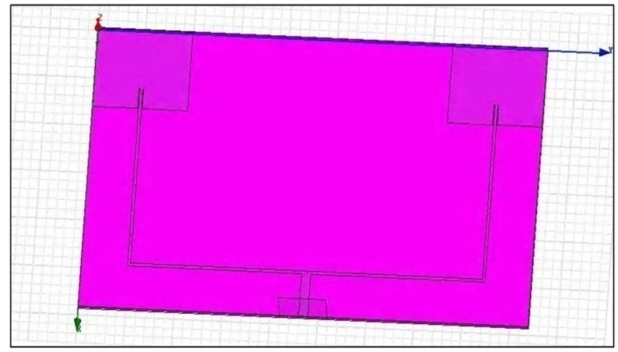

Fig. 4 drawn 2x1 patch array with parallel feed on HFSS

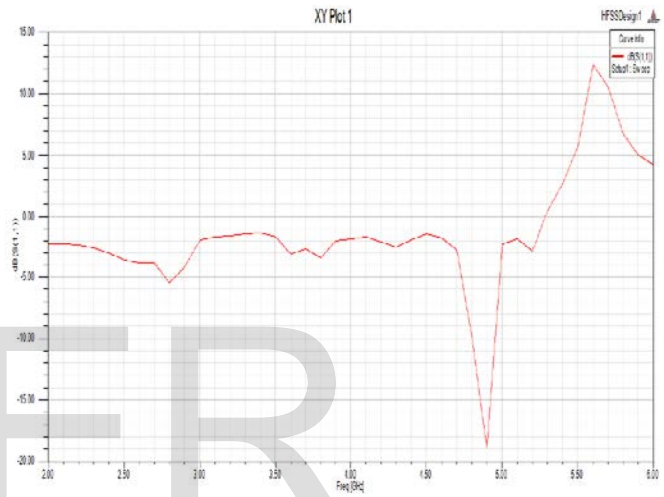

Fig. 5 Return loss at 4.9 GHz is -19 dB with 2x1 array parallel fed

We obtain return loss up to -19 dB at 4.9 GHz with 150 MHz at 10 dB pass band.

4.2 Designing of 4x1 array with parallel feed network:

Here in this section 4x1 patch array has been designed with parallel feed arrangement. Proposed patch array operates in C-Band application at resonant frequency of 4.9 GHz, with FR-4 (Relative permittivity = 4.4) as the substrate and its height equals to 1.6 mm. dimension of rectangular patch is same as in series feed array i.e. width = 30.50 mm and length = 26.50 mm.

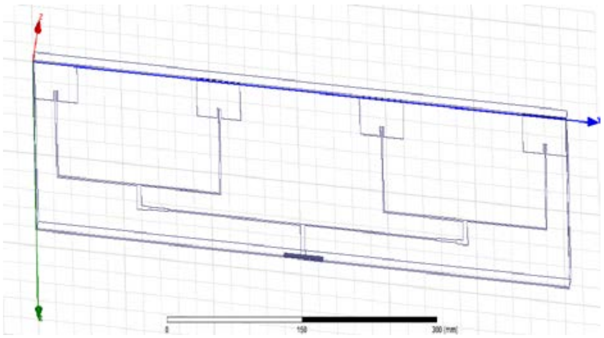

Fig. 6 4x1 patch array with parallel feed arrangement (Inset fed patch)

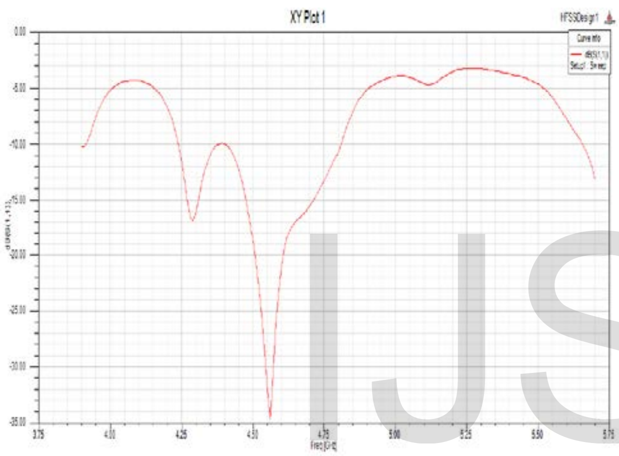

Fig. 7 Return loss graph of 4x1 patch array (with parallel feed arrangement)

Above fig. 7 shows, 4x1 patch array (inset fed patch and parallel feed arrangement) gives return loss up to -35 db and Bandwidth 600 MHz (at 10 dB pass band).

4.3 Designing of 2x1 patch array with series feed network:

Here, 2x1 patch array with series feed arrangement has been designed. Patch width and length are same as in previous arrays. For feeding of these patches microstrip line is used, with suitable width and length. Length of this line is selected lambda/2, due to this impedance of the patch will add in phase at the input, because it rotates once around in smith chart by lambda/2. Width of this line is selected 1.231 mm and width of quarter wave transformer (used at edge of substrate, where wave port is formed) is = 3.21 mm and its length is lambda/4.

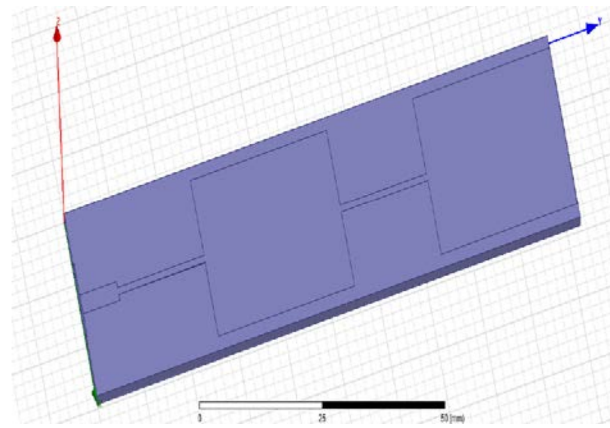

Fig. 8 2x1 patch array with series feed network

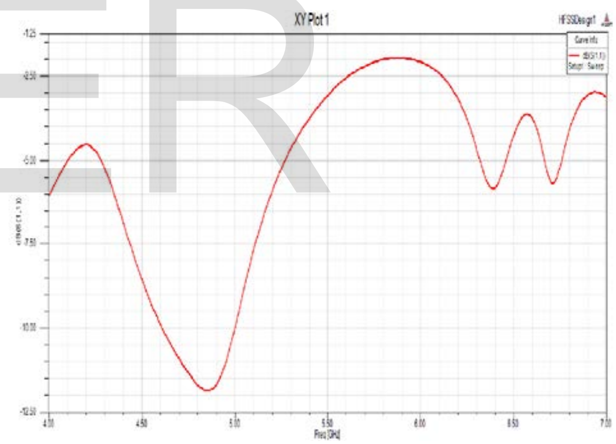

Fig.9 Return loss at 4.8 GHz is -12 dB with 400 MHz bandwidth (at 10 dB pass band)

Return loss obtained in fig.9 with 2x1 array (series feed) is, -12 dB with 400 MHz bandwidth (at 10 dB pass band).

4.4 Designing of 4x1 array with Series Feed network:

Here in this section 4x1 patch array antenna has been designed with series feed arrangement. This patch array outperforms the single patch in terms of return loss, bandwidth and gain. Proposed patch array operates in C-Band applications at center frequency of 4.9 GHz, with FR-4 (relative permittivity =4.4) as the substrate and its height equals to 1.6 mm. dimension of the rectangular patch is, width (W) = 30.50 mm and Length (L) = 26.50 mm.

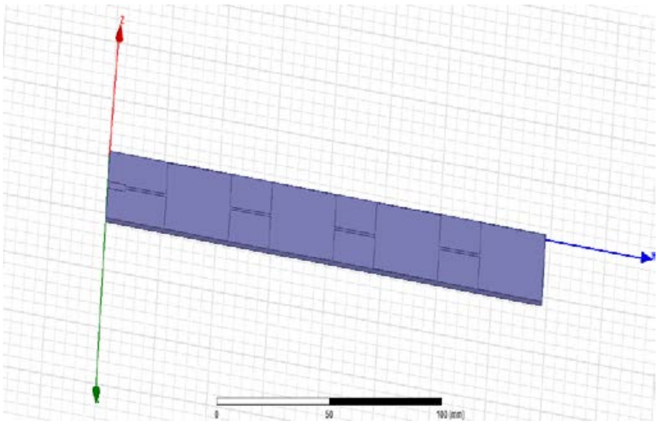

Fig.10 4x1 array with series feed arrangement

Width and length of the patch are optimized up to some extent. This optimized width and length helps to give return loss at desired center frequency. Width and length of transmission line connecting patches are 1.3 mm, 26.381 mm. dimension of the wave port is obtained from emtalk.com, by having input as relative permittivity, substrate height and width of transmission line.

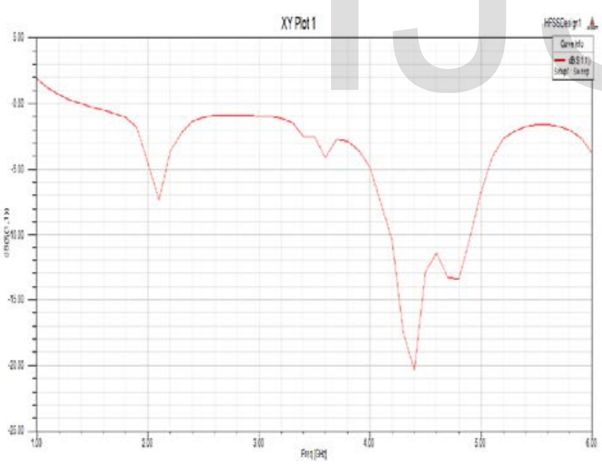

Fig.11 Return loss obtained with 4x1 array (series feed arrangement)

From the above return loss curve (Fig.11), return loss obtained is -20 dB at 4.9 GHz and Bandwidth at -10 dB pass band is 550 MHz.

5. Results and Discussion:

Results obtained on Simulation of Patch and its Array on HFSS software:

S. N.	Patch and its array configuration	Return loss obtained at Resonant frequency	Bandwidth achieved at 10 dB Pass Band
1.	2x1 array with parallel feed	-19 dB at 4.9 GHz [figure 5]	300 MHz (4.7 to 5.0 GHz)
2.	4x1 array with parallel feed	-35 dB at 4.55 GHz [figure 7]	600 MHz (4.25 to 4.85 GHz)
3.	2x1 array with series feed	-12 dB at 4.8 GHz [figure 9]	400 MHz (4.6 to 5.0 GHz)
4.	4x1 array with series feed	-20 dB at 4.4 GHz [figure 11]	550 MHz (4.4 to 4.95 GHz)

As shown in above table, return loss up to -35 dB [figure 7] and bandwidth up to 600 MHz is achieved with 4x1 array (Inset fed patch and parallel feed arrangement). As we increase number of patch elements to form an array better return loss and bandwidth is obtained. Here all 2x1 and 4x1 arrays are designed at 4.6 GHz frequency range (center frequency). This frequency range is suitable for C Band applications. With 2x1 patch array (inset fed patch and parallel feed arrangement), return loss obtained is -19 dB, 300 MHz (4.7 to 5.0 GHz) Bandwidth [figure 5] and 4x1 patch array (inset fed patch and parallel feed arrangement) gives return loss up to -35 db and Bandwidth is 600 MHz (4.25 to 4.85 GHz).

2x1 patch array with series feed arrangement gives return loss -12 dB and 400 MHz bandwidth [figure 9] at resonant frequency 4.8 GHz. 4x1 patch array with series feed arrangement gives return loss -20 dB and 550 MHz Bandwidth (4.4 to 4.95 GHz) [figure 11].

6. Conclusion:

Microstrip patch array antenna with inset fed patch and parallel feed arrangement, gives better results as compared to other drawn series fed 2x1 and 4x1 array patches. In this Article, 2x1 and 4x1 patch array [with inset fed patch and parallel feed arrangement], 2x1 array and 4x1 patch array [with series feed arrangement] has been designed. 4x1 patch array gives better result as compare to other drawn patches. With 4x1 patch array [inset fed patch and parallel feed arrangement], -35 dB return loss and 600 MHz bandwidth (at 10 dB pass band) is achieved at 4.55 GHz. This frequency range is suitable for C Band applications.

We can see from above table much improved result is achieved with 4x1 array (with inset fed patch and parallel feed arrangement) formats, as compared to series fed 4x1 array patch and 2x1 array formats. Further if we increase number of patch elements to form an array, such as 16 elements or 32 elements, much improved result could be obtained.

7. Reference:

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