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Rectangular Patches Array Utilized Coaxial Edge Feeding and 90^0 Phase Shifter for Achieving CP Property

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Abstract This manuscript presents various technical issues concerning the development of rectangular patches array antennas deployed in a-3D weather radar system. It was initially designed to operate at 9.35 GHz. The fabricated 20-elements patch array was remodeled and further investigated to fully characterize its fundamental electrical properties. To guarantee more accurate and valid numerical modeling two rectangular patches arrays, i.e. two and twenty elements arrays, were built and computed. The recorded results of two kinds of array antennas have been verified and confirmed very close agreement in terms of 3D and 2D-beampatterns, S_{11}, axial ratio (*AR*) and gain properties.

Key words 3D-weather radar, rectangular patch, feeding technique, and passive phase shifter

1. Introduction

The popularity and broad applications of microstrip antenna incorporated in most of the modern wireless communication peripherals has been inherently triggered by the potential advantages of its structure. Microstrip antenna is recognized to be the easiest, simplest, and lowest cost antenna in terms of the design construction, mass production, installation and maintenance [1-3]. Through the precise designing and manufacturing, it can be created as a very powerful antenna to mitigate any disturbing phenomena encountered along free space channel on the particular wireless communication network. However, to maintain the quality of the signal reception (or transmission), the antenna with the CP property is essentially required in any kinds of high altitude communication platforms such as weather radar application, GPS-SAR, and satellite communications [2, 4-5]. The issue on the antenna construction for radar applications is quite critical and required very strict technical specifications. This is also required for the antenna system in the specific applications to monitor and to estimate various weather conditions [6]. One of the most important part of weather radar system lied on its sensors array which, in practice, is obviously a microstrip antenna structure.

A 3D-weather radar system has been investigated and developed at Josaphat Microwave Remote Sensing Laboratory (MRSL), Chiba University under cooperation with Weathernews Inc., Japan. The research project covers a number of main parts including hardware and software developments such as antenna construction and testing, RF-signal processing unit development, and electronic circuit design and fabrication. The current model of 3D-weather radar 1.8 k Watts has been designed to operate at the resonant frequency 9.398 GHz suitable for ship navigational and early warning systems. The physical size of both transceiver and radar display units is relatively small of 0.4572 meter and 0.1778 meter, respectively. It is high performance radar configuration and low power consumption. The radar system has been particularly constructed to perform the high quality of sunlight viewability, repeatable of programmable navigation data, variable antenna speed and multibands RF transceiver part.

The antenna system deployed for a 3D-weather radar application was initially coming-up with the twenty elements array of small rectangular patch antenna manufactured by an industry partner. The main objectives of the study reported in this manuscript are solely intended to report the examination of particular antenna design through the numerical computation using finite element HFSS algorithm and to collect some technical specifications for the advanced development of various robust patch antenna array structure applicable for the 3D-weather radar sensor. To fully characterize and understand the fundamental practical operation of the antenna prototype several examination attempts are required. Whole investigation results released in this paper was part of several prestigious research projects which are proactively developed and implemented in Josaphat MRSL, Chiba University such as GPS-SAR, radar system, and mini satellite communication.

2. Patch Antenna Prototype: *Basic Structure*

Fundamentally, the prototype of rectangular patch structure built to configure the array form, i.e. two and twenty elements patches respectively, is illustrated in Fig.1. This is a quite popular structure to form a small rectangular patch antenna. It consists of the top radiating perfect electric conducting (PEC) material (width = 15 mm and length = 9.5 mm, respectively); the dielectric substrate; and the ground plane structure. Both the dielectric and grounding materials have the same dimension of 25 mm x 21.5 mm. These numbers represent their width and length, respectively. As shown in Fig.1, it is clearly drawn that the top radiating patch structure was subtracted in two sides around the centre feeding part using other three little rectangular patches. Two little rectangular patches has the same area size, i.e. $SxH2$ mm^2, where S=0.75 mm and $H2$=2 mm. Another patch area equals to $SxH1$ mm^2, where S=0.75 mm and $H1$=6.5 mm. The whole radiating patch antenna is connected to RF-feeding port via a short transmission line. The transmission line has the dimension of L=*2mm* width and ($H2$+6 mm) length.

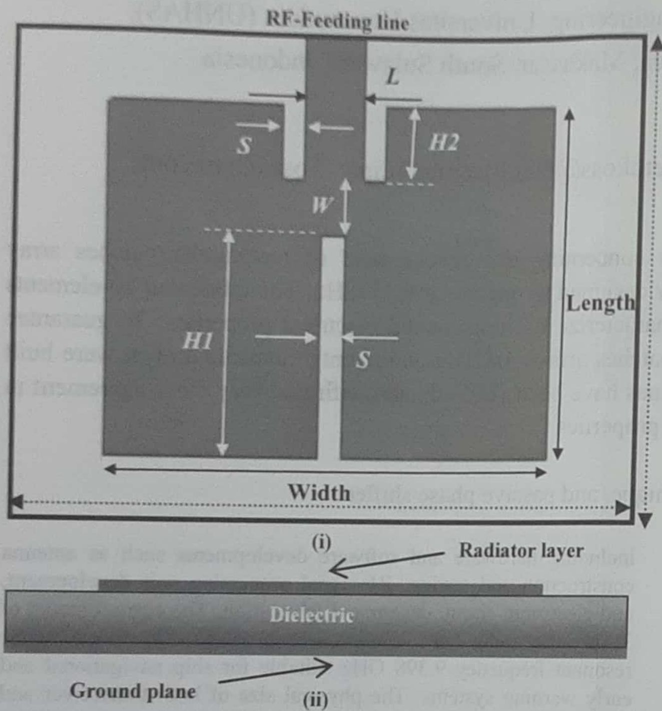

Fig.1 A single rectangular patch antenna: (i) Top view,(ii) Side view

The RF-energy fed through the transmission line is split-up into two equal amount of microwave energy at both right and left sides of rectangular radiators via the branching patch unit of W width. The total RF emission illuminated onto free space is the accumulation of both rectangular radiators and several amounts spread-up from the transmission line part.

3. Numerical Computation of Array Structures

The previous fabricated antenna prototype has currently been reviewed and remodeled to obtain the more powerful prototype with circular polarization property. The numerical computation processes were carried-out and have successfully regenerated two 3-D antenna types which consisted of two patch elements array and the twenty elements array. These two arrays are depicted in Figs.2 (i) and (ii), respectively. Both arrays were built from the single rectangular patch structure (see Fig.1). The detailed construction and the physical dimensions described in Figs.2 (i) and (ii) to compute are representing the exact measured size of the printed circuit layout of the manufactured twenty elements array antenna. Several modifications such as slight alteration of track patch size in the passive phase delay unit due to the technical modeling difficulties and the measurement accuracy on a number of parts of rectangular patch structures and the supporting printed patch transmission line unit.

In practice, the study which focusing on a rectangular patches array design was divided into two parts. ***First step***, two elements of patches array were constructed in which one of the two elements connected to the 90^0 passive phase delay unit (see Fig.2). Constructing two patches structures in such manner that they are capable to illuminate two orthogonal linear RF energy components with a ninety degrees out of phase is a well known method to generate the array antenna performing circular polarization (CP) behavior [1, 4-5]. ***Second step***, a ten elements array located on the left side and another ten elements array is positioned on the opposite way and connected to a phase shifter circuit 90^0.

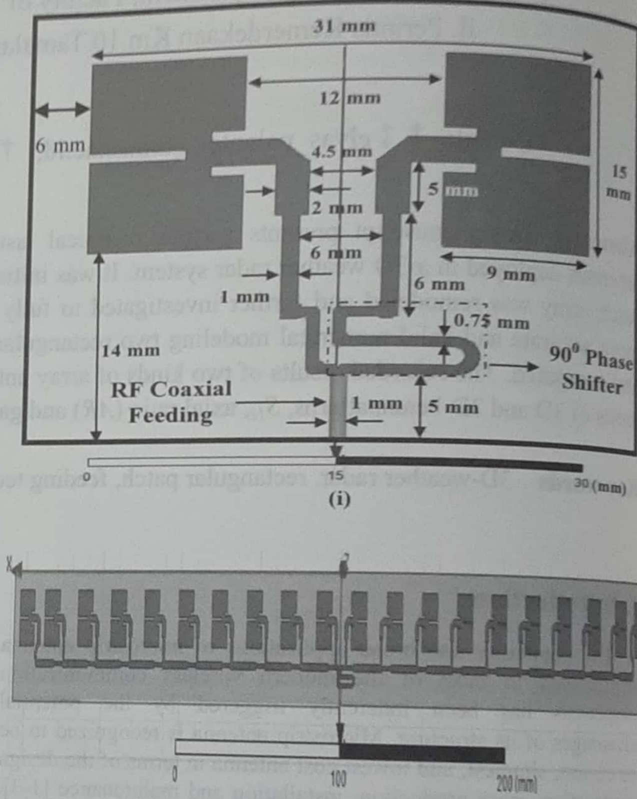

Fig.2. Rectangular patch array antenna: (i) 2 elements, (ii) 20 elements

The main purpose of the insertion of phase shifter is merely for achieving CP property of whole twenty elements array. The exact physical parameters that are clearly assigned to each part of two elements array, as described in Fig.2 (i), were also applied for the twenty elements patch array (see Fig.2 (ii)). It should be noted that the size of both dielectric substrate and ground plane components are 415 mm (length) and 35 mm (width), respectively. All in all, the whole rectangular patch array construction is of very small size, compact, easy to construct and very low cost for mass production, installation, and maintenance. It fits and suitable to be incorporated into the current MR1715 3D-weather radar prototype utilized and under developed at Josaphat MRSL and Weathernews Inc., Chiba, Japan.

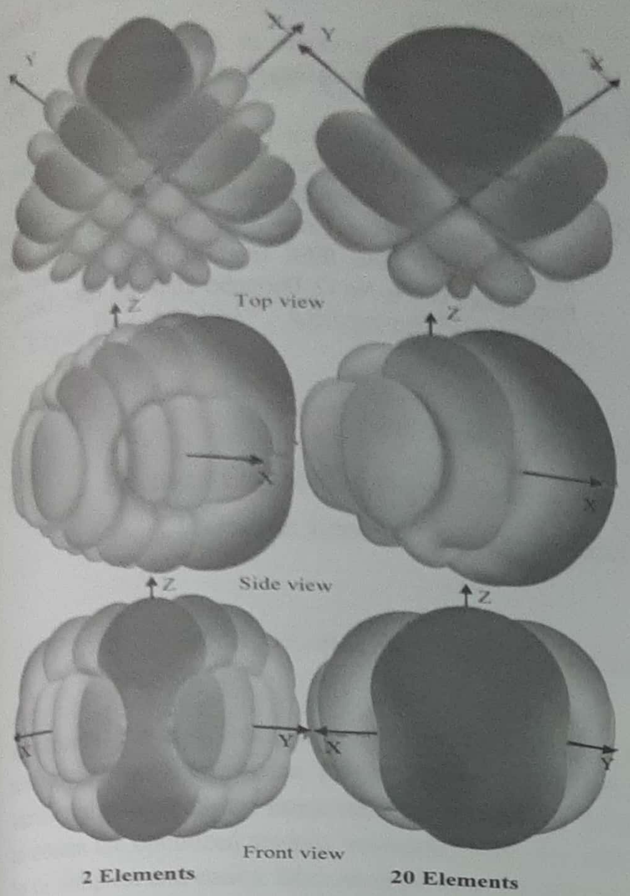

Fig.3 A 3D-patterns of the computed rectangular patch array antennas.

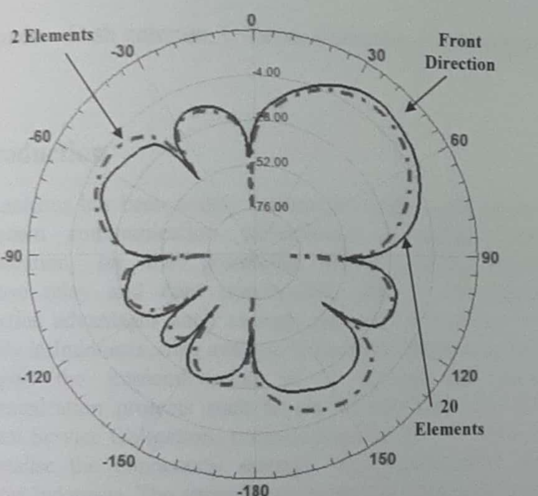

Fig.4 The azimuthal patterns comparison of the 2 and 20 elements array.

4. Results and Discussion

Some interesting computation results including the pattern properties, S_{11}, Axial ratio (AR) and gain are outlined in this paper. The comparison of 3D-pattern properties between 2 elements array and 20 elements array computed using FEM-HFSS algorithm is illustrated in Fig.3. Both antenna constructions generate the multi lobes of RF energy radiation where the main lobe is pointed to the angle direction 45^0 located in between X-Y axis. Based on Fig.3, it is clearly described that the two elements array configuration provides more lobes comparing with twenty elements. It looks that

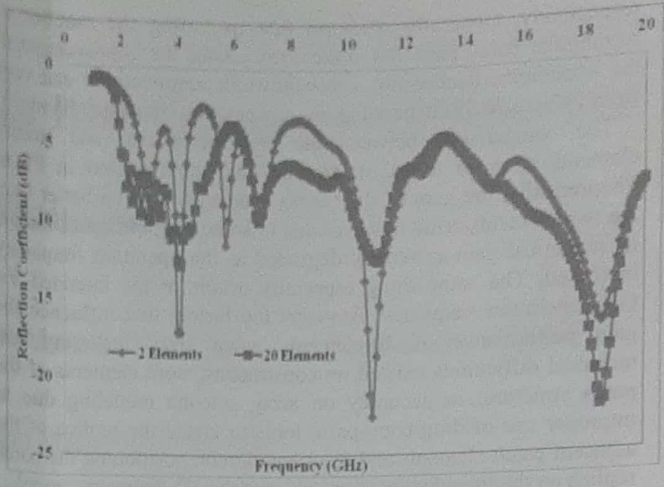

Fig.5 The reflection coefficients comparison of the 2 and 20 elements array.

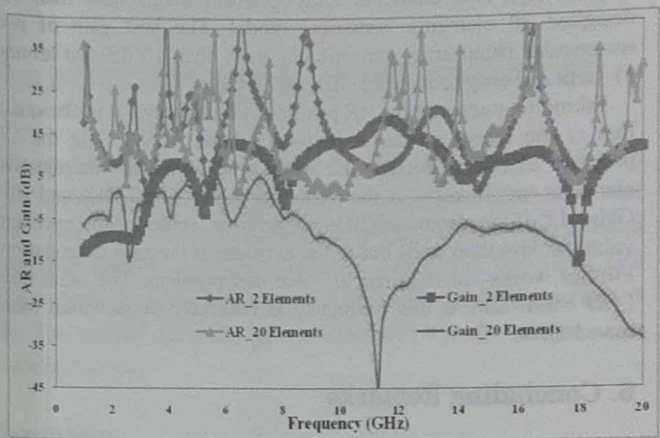

Fig.6. AR and Gain comparisons of the 2 and 20 elements array.

creating more rectangle patch elements to form an antenna array tends to minimize RF energy illumination to the unwanted directions, i.e. side lobes and back lobe directions. This phenomena also resembles that increasing the number of element array created significant efficiency improvement of the power pattern radiation mainly pointed to the front direction. The argumentation is analytically proveable by considering the power pattern properties, both the two and the twenty elements portrayed in Fig.4. The improvement of the quality of RF energy reception utilizing the 20-elements array antenna is indicated by the variation on some electrical parameters of the antenna. For instance, increasing the number of elements array affects the number of side and back lobes decreased. In contrary that increasing the number of elements array will improve the relative gain of abruptly 3 to 5 dBic and the directivity straightforwardly as well.

The reflection coefficient characteristics of both two elements and twenty elements array configuration were confirmed very close agreement. Both array generate three best resonant frequencies appeared in three bands, i.e. 4 GHz, 11 GHz, and 18.5 GHz. Considering the previous tested performance of the manufactured rectangular patch array antenna (twenty elements array) it can be demonstrated numerically that the array antenna is working excellent at the intended operation frequency 9.4 GHz. Based on Fig.5, it is shown that the impedance bandwidths of the above three bands are 0.2 GHz, 1.25 GHz, and 1.9 GHz, respectively, for two elements array. While, for twenty elements array the three impedance bandwidths are 0.85 GHz, 1.1 GHz, and 2.5 GHz, respectively. Generally speaking that increasing the number of rectangular patch elements in the array caused the improvement of the impedance bandwidth. The bandwidth improvement can vary from 24% to 76.5% depending on the operation frequency band.

The comparisons between the constructed two and twenty elements array in terms of *AR* and gain are depicted in Fig.6. Theoretically, the gain of the twenty elements must be better than the two elements array however due to some possible cause factors its numerical gain extremely degraded as the operation frequency increased. The same thing especially occurs at the intended 9.4 GHz operation frequency. Amongst the factors that influence the gain performance of 20-elements patch array including: the technical difficulties existed on constructing more elements of the patch structure; in accuracy on array antenna modeling due to improper use of drag-copy-paste tools to create the replica of the adjacent patch elements and disorientation on positioning the patch replica on the intended location set-up at the 3D-geometry model.

The best gain obtained at two bands, i.e. 4-5 GHz band and 6.5-7 GHz band, which are approximately 3-6 dBic and 2-6.5 dBic, respectively. Two elements array perform better gain than the designed 20 elements numerical model. The best gain of two rectangular patch array can produce more than 15 dBic at around 11 GHz and only provide 11 dBic at 9.4 GHz.

Taking into account the *AR* profiles of both arrays, it is obviously that at the target operation frequency band of 9.4 GHz the CP property of twenty rectangular patch array outperformed the two elements one. In between the frequency region of 8.7 GHz and 10.4 GHz, *AR* of the simulated-20-elements array achieved the excellent value far less than 3 dB but in the expense of the gain degradation. Further works are required to solve this problem. The axial ratio (*AR*) bandwidth at this frequency is relatively large which more than 1 GHz.

5. Concluding Remarks

The numerical computation to examine the fundamental electrical properties of the manufactured 20-elements rectangular patches array suitable for a particular 3D-weather radar application has been done. The detailed analytical study is also required to fully understand the practical operation of such kind of array antenna to obtain its comprehensive technical specifications for advanced development. To guarantee the numerical model was properly constructed two 3D-rectangular patch elements were built and used for the verification purpose. These include two and twenty patch elements configured in such away to include the edge RF-feeding technique and the insertion of passive phase shifter 90^0 to improve the performance of the designed antenna, especially to increase the efficient current distribution on the surface of the radiator patch structure and to achieve better CP property, respectively.

All in all, the electrical properties of two and twenty elements patch array were confirmed very close agreement. However, further study must be carried-out to solve the gain degradation of the simulated 20-elements patch array especially around the operation frequency 8.7 – 10.4 GHz and above.

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