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Corporate-Series Fed Microstrip Array Antenna with Yagi Elements for 5G

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Abstract

The present paper presents an array antenna of a microstrip patch for 5G applications. Four rectangular microstrip patch elements are arranged in parallel and series to form an array antenna. Two insets are made on both sides of each patch element to achieve a wide frequency bandwidth of 23.97-31.60 GHz. To attain a high gain and wider bandwidth, the microstrip patch antenna is fed using series and corporate feeding networks. Further, three director elements on top of the top-most patch elements, and one reflector element at the open end of each patch element, are added. The addition of the Yagi elements improved the overall gain and acquired a higher radiation efficiency throughout the operating frequency bandwidth, with the array antenna achieving a maximum peak gain of 8.7 dB. The proposed antenna is built on a low-loss and low-cost substrate of FR4-eproxy. The proposed antenna design with a simple structure is suitable for Internet of Things and 5G applications.

Index Terms: Microstrip patch, Corporate feed, Series feed, Yagi, 5G

I. INTRODUCTION

Fourth-generation (4G) technology is being implemented around the world in many different countries, and is bringing about a higher speed, faster network, low latency, and higher density. However, with the popularity of mobile communication and Internet of Things (IoT), the use of wireless devices is increasing daily. This will eventually create a global bandwidth shortage in the future. Thus, researchers are looking at the fifth-generation (5G) communication system as an answer to these demands, which is anticipated to provide an enormous volume of available spectrum, achieve a high data rate, and have an extremely high device density. 5G is expected to utilize the underutilized millimeter-wave bands [1]. Utilization of millimeter wave bands for wireless communication will help improve the communication experiences of users.

The basic element of any wireless communication system is an antenna. Thus, to develop 5G technology, it is necessary to design an antenna capable of operating at bands listed for 5G communication. There are various types of antennas. Among them, microstrip patch antennas are preferred for different commercial wireless applications owing to certain advantages. Antennas designed on microstrip patches are usually conformable, smaller in size, lighter in weight, and can achieve a high-density packaging. Microstrip antennas are also extreme easy to fabricate, and the cost of production is extremely low compared to that of other antennas. Furthermore, microstrip patch antennas can be converted into arrays to improve the antenna performance. Owing to these advantages, 5G microstrip patch antennas have also been studied and developed with good results. Numerous studies on microstrip array antennas have been conducted for 5G applications [2-6].

Among the advantages of microstrip patch antennas, it distinctly supports numerous types of feeding techniques. A microstrip array antenna can be fed using a single microstrip line or even through multiple and complex microstrip lines.

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A few popular feeding techniques include series feed networks, corporate feed networks, and corporate-series feed networks [7]. Among these feeding techniques, corporate-series feeding techniques have rarely been used for 5G communication. In a corporate-fed network, several power dividers comprising numerous breaks and extended lines for transmission are used, which causes substantial dielectric loss and spurious radiation to occur, whereas short lines for transmissions are utilized networks fed with a series-feed technique to enhance the efficiency of the antenna [8]. Corporate-series feed techniques combine corporate as well as series feeding techniques to distribute the power equally to the patch elements. A 16-element rectangular microstrip-patch array antenna is presented in [9] for 5G applications, which is fed by a corporate-series feed network and operates at 28 GHz. However, the antenna achieves a comparatively narrow bandwidth.

In this paper, an array antenna of a microstrip patch consisting of four rectangular patch elements connected by a corporate-series feed network is presented for wide bandwidth and high gain. The application of corporate-series feed technology, along with the addition of two insets on each side of the patch, and the implementation of Yagi elements improves the overall performance of the antenna. Moreover, the size of the patch antenna is reduced and the design of the antenna is simple, making the antenna suitable for IoT applications. Further, the antenna is designed using an FR4 substrate, which is of low cost compared to other materials used for patch antennas.

II. ANTENNA DESIGN

A single patch element operating at the desired frequency band was designed first. The following rectangular patch equation [10] was used to calculate the tentative width and length of the patch.

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}, \tag{1}$$

where c is the free space light velocity.

$$L = L_{eff} - 2\Delta L, \tag{2}$$

where

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{ff}}}, \tag{3}$$

and

$$\Delta L = 0.412h\frac{(\varepsilon_{ff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{ff} - 0.258)\left(\frac{W}{h} + 0.8\right)}. \tag{4}$$

After using the equations, the tentative width and length were roughly estimated as 3.37 and 1.76 mm, respectively. Because, the aim of this study was to design an array antenna with a wide bandwidth, single patch element parameters needed to be further optimized to 2.75 mm × 8 mm (LP × WP). The proposed antenna was designed on a low-loss substrate of FR4-eproxy, which has a dielectric constant (ε_r) of 4.4 and a loss tangent of 0.02.

After designing the single patch element, four single patches were connected using the combined corporate-series feed network to form an antenna array. A 50-ohm power source was fed to two rectangular patch elements in the form of a T-junction power divider through a network of microstrip lines. Subsequently, on top of each open patch element, one patch element was added using a quarter-wavelength transformer stub in series, creating an array of four rectangular patch elements.

The parameters of the rectangular element were kept constant. Further, Yagi elements were added, with three director elements placed on top of the top-most patch elements, and one reflector element placed below each patch element on the open side. Thus, the array antenna has a total of six director elements, (three on the top-left and three on top-right patch element), and four reflector elements (one below every patch element). However, the desired antenna performance was still not achieved. Thus, to improve the gain and directivity of the antenna, and to increase the bandwidth, optimization had to be made to the dimensions of the T-junction power divider. The optimization decreased the overall size of the antenna and enhanced the overall performance.

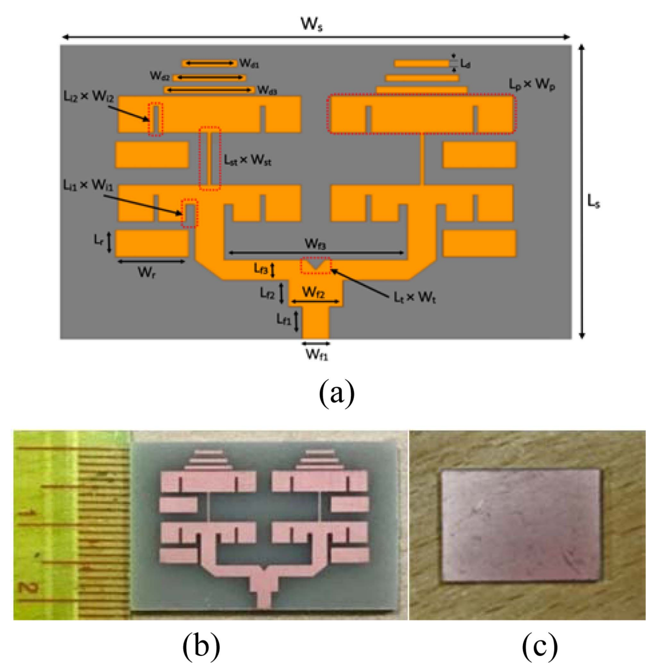

Fig. 1. Prototype of corporate-series-fed microstrip array antenna: (a) geometry of proposed array antenna, (b) top view, and (c) bottom view.

Table 1. Dimensions of the proposed array antenna

	Parameters	mm
Substrate	$L_s \times W_s \times H_s$	22 × 28 × 1.6
Patch	$L_p \times W_p$	2.75 × 10
Ground	$L_g \times W_g$	22 × 28
Insets	$L_{i1} \times W_{i1}$	1.25 × 0.5
	$L_{i2} \times W_{i2}$	2 × 0.25
Reflector	$L_r \times W_r$	2 × 4
Directors	W_{d1}, W_{d2}, W_{d3}	3, 4, 5
	L_d	0.5
Feedlines	$L_{f1} \times W_{f1}$	2.4 × 1.5
	$L_{f2} \times W_{f2}$	2 × 3
	$L_{f3} \times W_{f3}$	1.5 × 10.25
Triangular Slit	$L_t \times W_t$	0.75 × 1.5
Stubs	L_{st}	$3.9\{(l_g/2) + L_{i1}\}$
	W_{st}	$0.2\ (W_f/8)$

Finally, the combination of series and corporate feeding techniques led to the design of the proposed four-patch element array antenna. The corporate-series fed array antenna was able to obtain the desired antenna performance without compromising the overall size. The parameters of the proposed array antenna are shown in Table I, and the geometry is presented in Fig. 1.

III. RESULTS AND DISCUSSIONS

The antenna was designed using a finite element method based on a high-frequency structure simulator (HFSS). The simulated and measured S-parameters (S11) of the proposed array antenna are presented in Fig. 2. As shown in the figure, the antenna achieves a return loss of below -10 dB from 23.13 to 30.21 GHz. The return loss shows a matched behavior at approximately the measured band. From the measurement result, the maximum return loss is approximately -20 dB at 28 GHz, whereas the return loss is as low as -40 dB at the same frequency in the simulated result. The differences in the results between the real environment measurement and the antenna simulation could be due to losses owing to the nature of the substrate, connector condition, and manufacturing defects. However, the return loss measurement shows that the proposed array antenna operates within the frequency band proposed for 5G communication. Similarly, as shown in Fig. 3, the radiation efficiency of the antenna is presented. The antenna performs well with an efficiency of greater than 80% throughout the operating frequency bandwidth.

Fig. 4 shows the simulated realized gain of the proposed microstrip patch antenna. As indicated in the figure, the proposed array antenna has a higher realized gain over the operating frequency bandwidth, and achieved a maximum peak

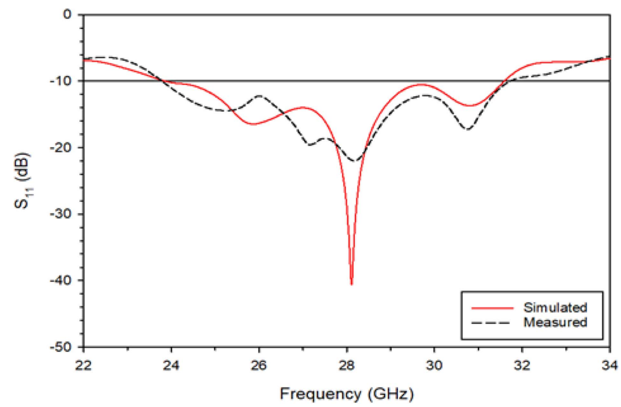

Fig. 2. S_{11} (measured and simulated) of the proposed corporate-series-fed array antenna.

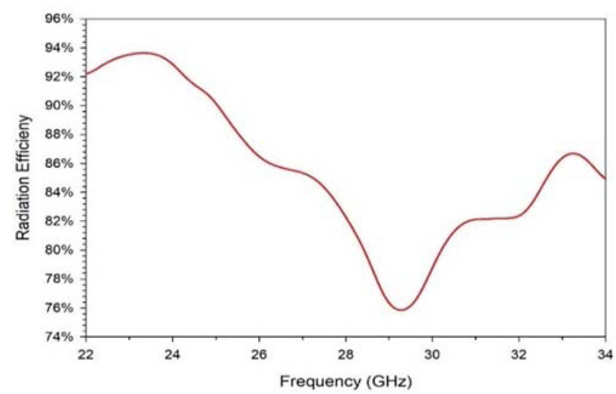

Fig. 3. Radiation efficiency of corporate-series-fed microstrip array antenna.

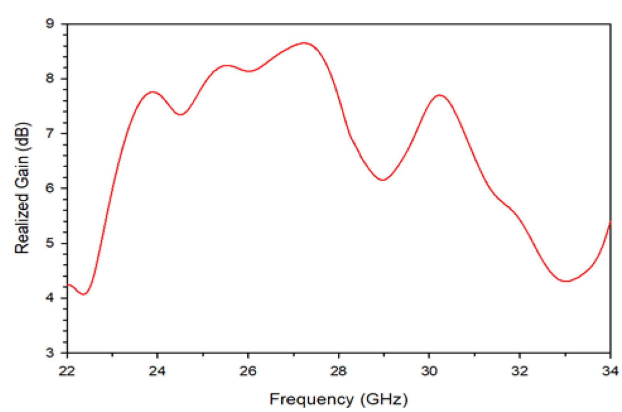

Fig. 4. Peak realized gain of corporate-series-fed microstrip array antenna.

gain of 8.7 dB. The simulated and measured radiation patterns of the proposed array antenna are shown in Fig. 5. The radiation patterns were recorded at 27, 28, and 29 GHz. As shown from the plots, the presented antennas exhibit a slightly directional nature. The proposed antenna achieved a high gain because the power fed to the antenna is equally split at each junction and transmitted to the patch array with

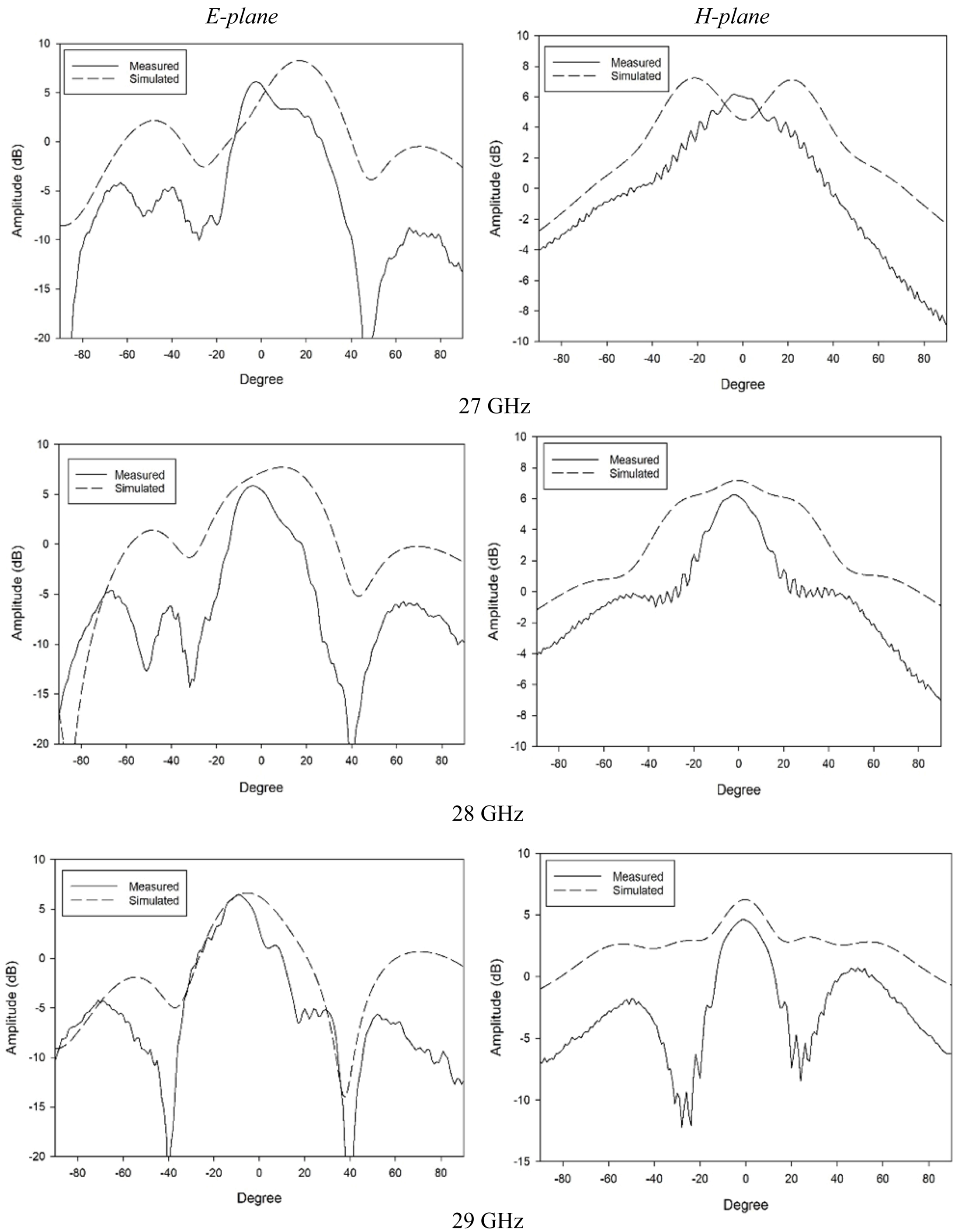

Fig. 5. Radiation patterns (measured and simulated) of the proposed corporate-series-fed array antenna (27, 28, and 29 GHz).

a uniform distribution. The equally split power is further transmitted through continuous lines, and the energy proportions are progressively coupled into each patch element arranged in series. There is a slight difference between the measured and simulated results. This is due to the losses caused by the nature of the substrate, errors during the measurement, and the defects caused during antenna fabrication.

From Table 2, it is clear that the proposed antenna has a much wider bandwidth than other microstrip antenna models fed with either series or corporate feeding techniques, as proposed by various researchers for 5G applications. The proposed array antenna is also smaller than that of all compared models.

Table 2. Comparison between array antenna models

Antenna type	Max. return loss (dB)	Bandwidth (GHz)	Size ($L_s \times W_s$) mm^2
Corporate-series feed	-40	**23.13~30.21**	22 × 28
[11] (Series feed)	≈ -30	27.45~28.95	78.5 × 42
[12] (Corporate-series)	≈ -60	26.4~28.9	88 × 25

IV. CONCLUSION

In this paper, an efficient array antenna for 5G communications with a wide bandwidth covering most of higher 5G bands is presented. A combination of corporate and series feeding techniques was applied to develop an efficient corporate-series feed technique. The proposed array antenna is fed using a corporate-series feed network, which achieves a good gain, with a maximum peak gain of 8.7 dB and a wide bandwidth of 23.13-30.21 GHz. Yagi elements (three director elements on top of each of the top-most patch elements, and one reflector element on the open end of each patch element) were added, which improved the performance of the antenna. Overall, the simulation and measured results proved that the proposed microstrip array antenna is suitable for 5G applications.

REFERENCES

[1] T. S. Rapparport, S. Sun, R. Mayzus, H. Zhao, Y. Azar, K. Wang, G. N.Wong, J.K. Schulz, M. Samimi, and F. Gutierrez, “Millimeter wave mobile communications for 5G cellular: It will work!,” *IEEE access*, vol. 1, pp. 335-349, May. 2013. DOI: 10.1109/ACCESS.2013.2260813.

[2] S. F. Jilani, Q. H. Abbasi, and A. Alomainy, “Inkjet-Printed millimetre-wave PET-based flexible antenna for 5G wireless applications,” in *2018 IEEE MTT-S International Microwave Workshop Series on 5G Hardware and System Technologies (IMWS-5G)*, pp. 1-3, 2018. DOI: 10.1109/IMWS-5G.2018.8484603.

[3] Y. Rahayu and M. I. Hidayat, “Design of 28/38 GHz dual-band triangular-shaped slot microstrip antenna array for 5G applications,” in *2018 2nd International Conference on Telematics and Future Generation Networks (TAFGEN)*, pp. 93-97, 2018. DOI: 10.1109/TAFGEN.2018.8580487.

[4] H. A. Diawuo and Y.-B. Jung, “Broadband proximity-coupled microstrip planar antenna array for 5G cellular applications,” *IEEE Antennas and Wireless Propagation Letters*, vol. 17, no. 7, pp. 1286-1290, May. 2018. DOI: 10.1109/LAWP.2018.2842242.

[5] H. Aliakbari, A. Abdipour, R. Mirzavand, A. Costanzo, and P. Mousavi, “A single feed dual-band circularly polarized millimeter-wave antenna for 5G communication,” in *2016 10th European Conference on Antennas and Propagation* (EuCAP), pp. 1-5, 2016. DOI: 10.1109/EuCAP.2016.7481318.

[6] O. M. Haraz, M. M. M. Ali, S. Alshebeili, and A.-R. Sebak, “Design of a 28/38 GHz dual-band printed slot antenna for the future 5G mobile communication networks,” in *2015 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*, pp. 1532-1533, 2015. DOI: 10.1109/APS.2015.7305155.

[7] H. Errifi, A. Baghdad, A. Badri, and A. Sahel, “Design and analysis of directive microstrip patch array antennas with series, corporate and series-corporate feed network,” *International Journal of Electronics and Electrical Engineering*, vol. 3, no. 6, pp. 416-423, Dec. 2015.

[8] F.-Y. Kuo and R.-B. Hwang, “High-isolation X-band marine radar antenna design,” *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 5, pp. 2331-2337, 2014. DOI: 10.1109/TAP.2014.2307296.

[9] B. T. Mohamed and H. Ammor, “A 16-elements corporate-series feed rectangular patch antenna array at 28 GHz, for future 5G applications,” *2019 International Conference on Wireless Technologies, Embedded and Intelligent Systems (WITS)*. pp. 1-4. IEEE (2019). DOI: 10.1109/WITS.2019.8723750.

[10] C. A. Balanis, Antenna theory: *Analysis and design. John Wiley & sons*, pp. 811-876, 2005.

[11] T. Varum, A. Ramos, and J. N. Matos, “Planar microstrip series-fed array for 5G applications with beamforming capabilities,” *2018 IEEE MTT-S International Microwave Workshop Series on 5G Hardware and System Technologies (IMWS-5G)*, pp. 1-3, 2018. DOI: 10.1109/IMWS-5G.2018.8484697.

[12] B. T. Mohamed and H. Ammor, “A 16-elements corporate-series feed rectangular patch antenna array at 28 GHz, for future 5G applications,” *2019 International Conference on Wireless Technologies, Embedded and Intelligent Systems (WITS)*, pp. 1-4, 2019. DOI: 10.1109/WITS.2019.8723750.

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