Small and Low Side Lobe Beam-forming Antenna Composed of Narrow Spaced Patch Antennas for Wireless Sensor Networks

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***Abstract*—In order to reduce sensor node power consumption and interference, high gain antennas are required for the base station (BS) but this means multiple BS antennas are required for 360° area coverage. A high gain beam-forming antenna is the key to base stations covering "spotty service areas" more effectively and reducing interference, especially in the ISM bands. To solve the size and side lobe issues of conventional beam-forming antennas, this paper proposes the "narrowly spaced" patch antenna array. The measured performance of a prototype confirms that while being 2/3^{rds} smaller than conventional antennas, it has lower side lobe levels (-20dBc) and high antenna gain (10dBi).**

Keywords*— *Antennas, Linear antenna arrays, Planar arrays, Patch antennas, Wireless sensor networks

I. INTRODUCTION

In order to realize wide area sensor networks, low energy critical infrastructure monitoring (LECIM) has been attracting attention resulting in the 802.15.4k standard of the IEEE802 Standards committee. Since sensor nodes in wide area sensor networks are expected to offer long lifetimes with battery power, high gain base station antennas are required for reducing sensor node power consumption. High gain base station antennas are also a good solution to mitigating interference, a major problem in Industry-Science-Medical (ISM) band wireless communications systems [1-3]. Base station antennas that offer beam steering capability are also suitable for some wide area sensor networks, such as those for agriculture applications, where sensor nodes are closely located in multiple spots. Furthermore, 2-dimensonal (2-D) beam-forming is more suitable for multiple spot communications. The beam forming antenna composed of phased array antennas is a good candidate due to its high gain and electrical 2-dimensional beam steering. However, the traditional phased array antenna with more than λ/2 element separation is not suitable for wide area sensor network base station antennas since it is physically large and the antenna pattern side lobes are significantly high. The sheer size increases installation difficulties and decreases wind tolerances. Since conventional uniform distribution phased array antennas [4-6] have larger side lobe level than fixed directive antennas, such as sector antennas [7-9], the traditional phased array antenna increases interference to/from other systems. Resently, narrow beam phased array antenna were proposed [10-11] for radar applications. Since the narrow beam antenna required more than 10-elements with more than l/2 element separation, these antennas are not suitable for base satiation antennas due to antenna size issue. In order to realize small, low side lobe, and high gain beam-forming antennas for wireless sensor networks base stations, we have proposed a beam-forming antenna composed of narrowly-spaced patch antennas. Due to electromagnetic simulator advancement, the phased array antenna with less than l/2 element separation can be designed and simulated well. By using an unconventionally small element separation and balancing antenna gain against side lobe levels, we can realize small, low side lobe and high gain antennas.

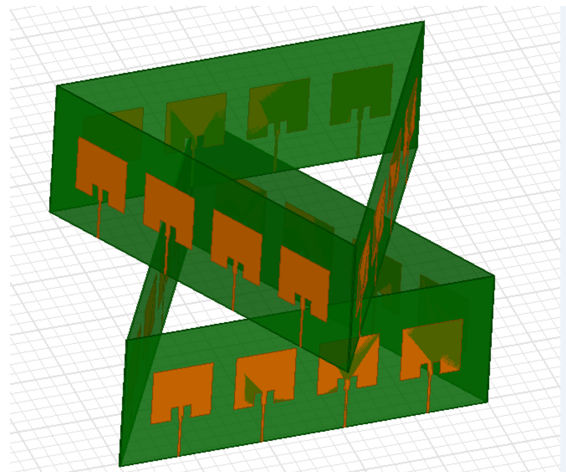

Fig.1. Antenna combination for 360 degree coverage

Since the proposed antenna offers a half power beam width (HPBW) of 60 – 80 degrees, 6 elements of the proposed antenna will be combined for 360 degree coverage as shown in Figure 1.

This paper is organized as follows. Section II proposes a 1-D low side lobe beam forming antenna to separate the service areas by horizontal degrees, such as 60 degrees per beam and Section III describes the corresponding 2-D beam forming antenna design which will be used to radiate the sensors by spots with horizontal and vertical beam-steering. Section IV summarizes our work on the proposed small, low side lobe and high gain beam-forming antennas

 ISBN: 978-1-61208-374-2

II. 1-DIMENSIONAL BEAM-FORMING ANTENNA

A high gain base station antenna is preferable to separate the service areas by horizontal degrees such as 60 degrees per beam. This creates following advantage against Omni base station antenna in star topology networks: (i) each sensor node needs to transmit less power by assuming up-link and down link budgets are balanced under maximum transmit EIRP is limited by radio regulation, (ii) the system will receive much less interference such as 1/6 when 6 element antenna is used, (iii) the system can achieve much higher spectrum efficiency such as 3 times when 6 element antenna is used.

For practical applications, base station antenna beam forming capability is preferable to adjust the direction of each beam to radiate the power efficiently for where sensor nodes are located. For this beam-forming antenna, we propose a methodology to give mutual couplings between antenna elements intentionally contrast to the traditional antenna design. A small, high gain and planer antenna element is desired for the narrow-element-separation phased array. Patch type antennas are easy to connect to micro strip lines (MSL) and antenna size is reduced by using high relative permittivity substrates. The designed single patch element is shown in Figure 2. The patch antenna is fed by a MSL and radiates on the Z-axis. The antenna has 10mm wide notches for impedance matching. The substrate material is FR-4 whose permittivity is 4.12 and tan δ is 0.019 at around 900MHz. Patch antenna element width and height are set at 81.2mm to suit the working frequency of 920-928MHz that is allocated for sensor networks in Japan; MSL width is 6.95mm with input impedance of 50 ohm. The element size, 81.2mm (0.25λ) is suitable for small element separation arrangements. Gain and input reflection of the patch element were simulated by an electromagnetic simulator (HFSS v12.1). As shown in Figure 3, its peak gain is 6.28dBi and HPBW is 98degrees. Reflection is less than -10dB from 920MHz to 928MHz as shown in Figure 4. These characteristics confirm that the proposed single patch antenna is suitable for a beam-forming antenna element.

A four-element beam-forming antenna composed of narrowly-spaced linear array antennas was simulated and measured. The results confirm that the proposal offers small, low side lobe and high gain beam-forming antennas. The key design procedure is to determine the best element separation for more than 10 dBi gain, and -20dBc side lobe. This trade off was balanced by using an electromagnetic simulator. As shown in Figure 5, in order to achieve better than -20dBc side lobes, the element separation should be 113mm or smaller. For more than 10dBi gain, element separation should be 113mm or larger as shown in Figure 6. From these results, the separation of 113mm can realize small, high gain and low side lobe beam-forming antennas.

The beam-forming antenna composed of the resulting antenna is shown in Figure 7. When compared to traditional λ/2 separation designs, this structure reduces antenna size by 35 percent. The simulated reflections of each element

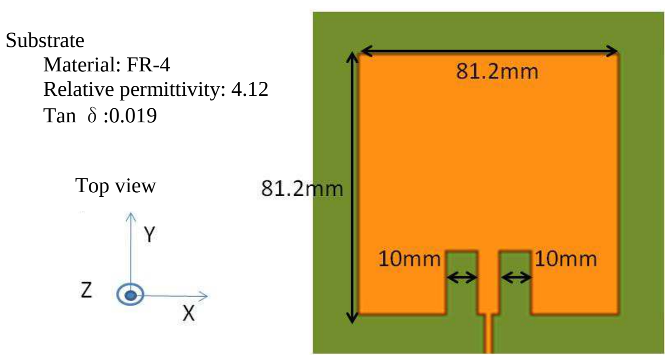

Fig.2. Single patch antenna

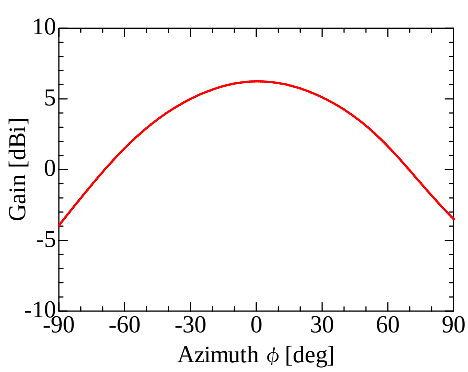

Fig.3. Single patch antenna gain

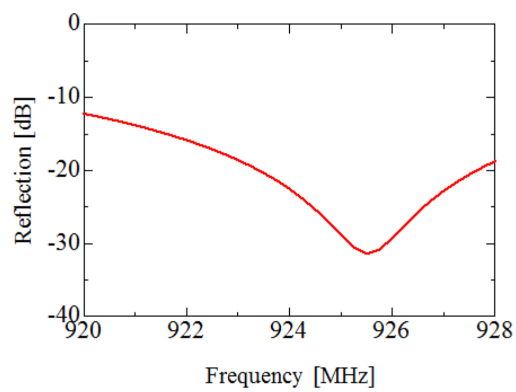

Fig.4. Single patch antenna reflection

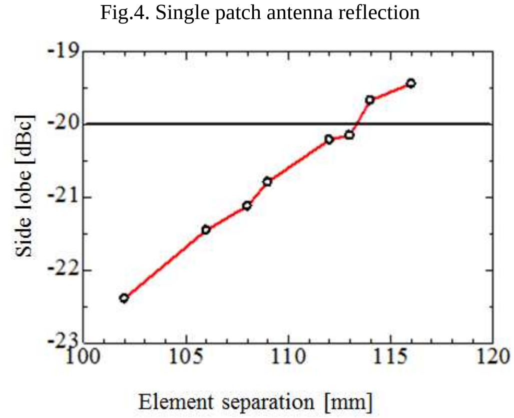

Fig.5. Element separation optimization for side lobe (4-element 1-D beam-forming antenna)

 ISBN: 978-1-61208-374-2

is shown in Figure 8. Element reflection is less than -10dB from 920MHz to 928MHz. The proposed antenna has more than 10dBi gain and -20dBc side lobe as shown in Figure 9. Based on electromagnetic simulation results, a prototype was designed, fabricated and measured. Measured reflection results are shown in Figure 10. The measurement results show the resonance point shift by 1MHz from the simulation and this is caused by fabrication error. The designed antenna gain / directivity have been measured in an anechoic chamber by comparing with an Omni antenna as shown in Figure 11. The prototype antenna is connected with the phase shifter (PS) board and signals are fed from a signal generator (SG) (The measured frequency is 923MHz). Receiver antenna, which is a sleeve antenna with 2dBi gain, is set at 4.8m from the transmitter antenna and received signals are fed to a spectrum analyzer (SA). The difference from the Omni transmission antenna shows the performance of the prototype antenna. A comparison of simulated and measured directivity is shown in Figure 12. Measured reflection is less than -10dB. The measured peak gain is 8.1 dBi, smaller than simulated value, and the measured side lobe level is -15.3dBc. Since the difference between measured and simulation results is small,

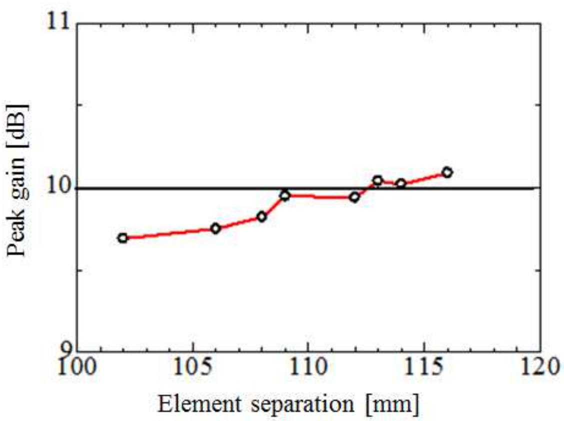

Fig.6. Element separation optimization for side lobe
(4-element 1-D beam-forming antenna)

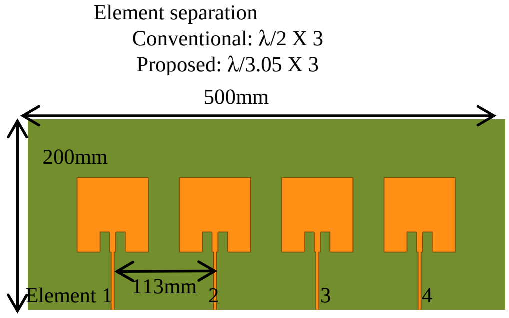

Fig.7. Beam-forming antenna composed of
4-element patch phased array antenna

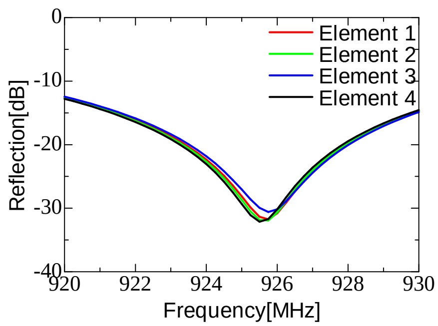

Fig.8. Simulated reflection
(4-element 1-D beam-forming antenna)

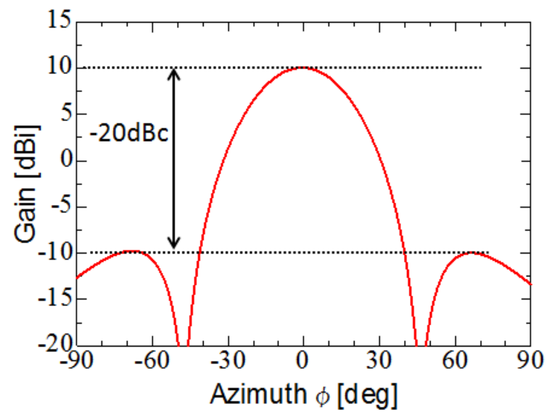

Fig.9. Simulated directivity
(4-element 1-D beam-forming antenna)

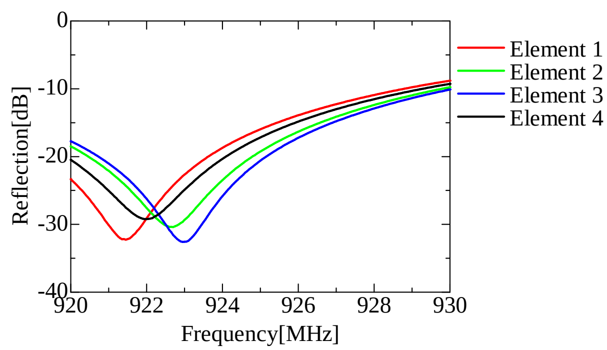

Fig.10. Measured reflection
(4-element 1-D beam-forming antenna)

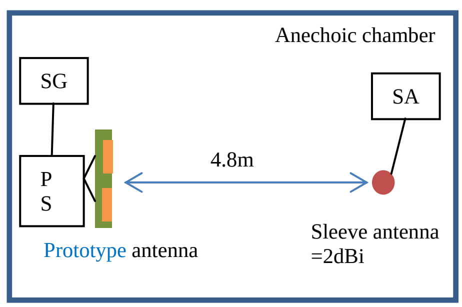

Fig.11 Measurement setting

the results show that proposed concept is suitable for creating 1-dimensional beam-forming antennas

III. 2-DIMENSIONAL BEAM-FORMING ANTENNA

For wide area sensor networks, 2-D beam-forming antennas are more useful and size reduction is more important than is true for 1-D ones. In order to design 2-D beam forming antennas composed of 16-element narrowly-spaced patch antenna arrays, the element separation was optimized by using an electromagnetic simulator. As shown in Figure 13, in order to achieve better than -20dBc side lobes, the element separation is 98mm or smaller. Since the 2-D phased array antenna can emit narrow beams in E-plane and H-plane, the gain at the element separation of around 98mm exceeds 10dBi as shown in Figure 14. From these optimization results, the element separation is set at 98mm. The resulting beam-forming antenna is shown in Figure 15. The substrate permittivity is 4.12 which is same in Figure 2 and 7. The antenna elements are separated by 98mm (λ/3.38). When compared to the traditional λ/2 separation, this structure reduces the antenna size by 41 percent. The simulated reflections of elements 1, 2, 5, and 6 are shown in Figure 16. Since the antenna is symmetrical, these four plots are enough to show overall reflection performance. All reflection values are less than -10dB from 920MHz to 928MHz. The antenna gain exceeds 13dBi and side lobes are at most -20dBc as shown in Figure 17. A matching prototype was designed, fabricated and measured. Measured reflection results are shown in Figure 18, and a comparison of simulated

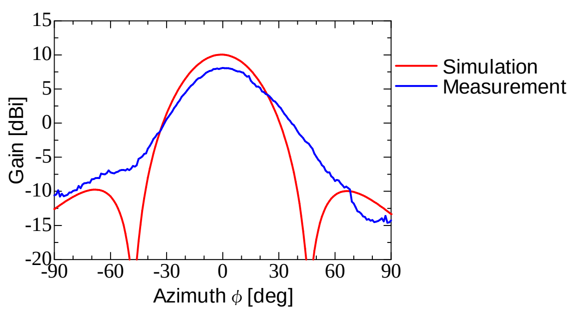

Fig.12. Measured directivity
(4-element 1-D beam-forming antenna)

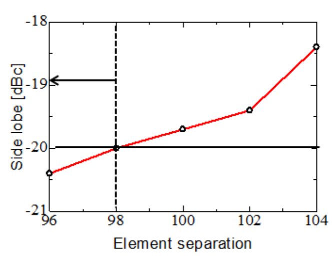

Fig.13. Element separation optimization for side lobe
(16-element 2-D beam-forming antenna)

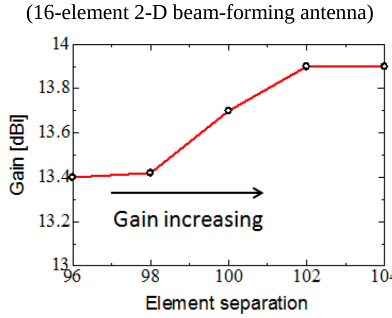

Fig.14. Element separation optimization for peak gain
(16-element 2-D beam-forming antenna)

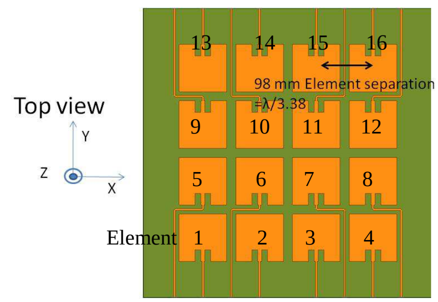

Fig.15 2-D beam-forming antenna

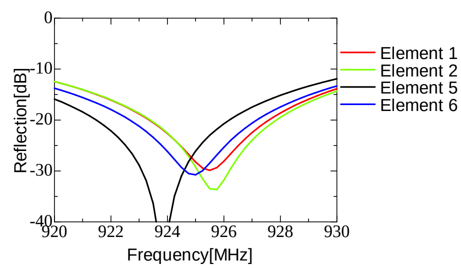

Fig.16. Simulated reflection
(16-element 2-D beam-forming antenna)

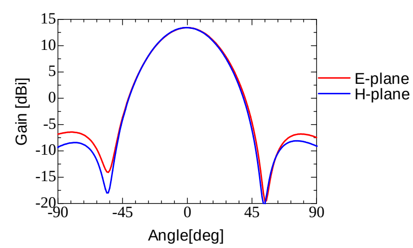

Fig.17. Simulated directivity
(16-element 2-D beam-forming antenna)

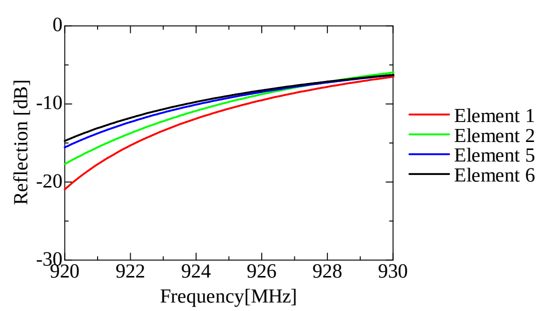

Fig.18. Measured reflections
(16-element 2-D beam-forming antenna)

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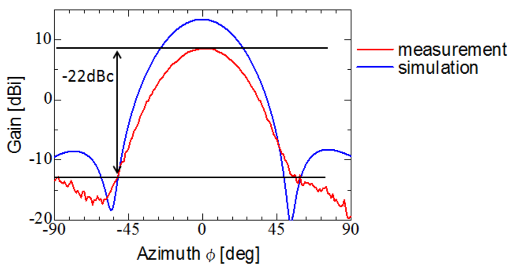

Fig.19. Measured directivity
(16-element 2-D beam-forming antenna)

and measured directivity is shown in Figure 19. Measured reflection values are better than -10dB from 920MHz to 928MHz. In the measurement reflection, the resonance point is out of measurement range. Since this difference is comes from substrate permittivity error, the difference can be canceled. The measured peak gain is 8.59 dBi, smaller than the simulation value, and the measured side lobe level is -22.3dBc

IV. Conclusion

This paper has proposed the low side lobe beam-forming antenna composed of narrowly-spaced patch antenna arrays. To validate the proposed antenna, 1-D and 2-D beam-forming antennas composed of patch antenna arrays were simulated and designed, and prototypes were measured The simulation results show that both antennas have, small (65 percent size reduction) and low side lobe level (better than -20dBc), and high gain (more than 10dBi). Measured results show close agreement with the simulation results and the 2-D beam-forming antenna achieved side lobe levels better than -20dBc. Thus, the proposed beam-forming antenna is a good candidate for base station antennas of wide area sensor networks.

Acknowledgment

This project is partially supported by Ministry of Internal Affairs and Communications, SCOPE and also partially supported by Japan Science and Technology Agency, A-STEP

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