Planar Dipole Array Antenna Design for Mobile Robot Communications at 5.6 GHz

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Abstract. Mobile robot communications are important in mobile robot systems, especially robot teamwork. Reliable communications are important for data transmission and control. Beamforming can improve communications performance to improve system’s reliability. This paper proposed beamforming array antenna at 5.6 GHz with 4 planar dipole elements. These antennas are arranged on azimuth plane. We conduct computer simulation of antenna design and beamforming scenarios. Beamforming is made by controlling power and phase of each antennas. We found that the designed antenna is suitable for beamforming at azimuth plane. It is confirmed by computer simulation of phased array antenna. The antenna has 1.3538 GHz bandwidth and more than 6 dB main lobe magnitude.

1. Introduction
Mobile robot communications enabling teamwork between robots for some missions, e.g., rescuing, surveillance, and carrying things [1–4]. It is possible by creating reliable communications between robots. It can be reached by using radio communications, e.g. wireless local area network (WLAN). There are some standards in use typically at 2.4 GHz and 5 GHz. IEEE 802.11an is one of the standards which can provide high performance WLAN communications [5–8]. In order to improve communications performance, multiple antenna technique is used, e.g. Multiple-Input Multiple-Output (MIMO) and beamforming.

Multiple-Input Multiple-Output (MIMO) is fifth telecommunication generation (5G) key technology [9]. Multiple antenna enables improvement on performances by making each antenna as independent as possible to maximize diversity. Dependency between antennas can reduce diversity. Dependency is measured by antenna’s correlations [10–12].

![Image](image.png)

Figure 1. Single antenna design: (a) front view, (b) back view.

Beamforming is multiple antenna technique that enables antennas direction control to adapt some conditions, e.g. user position and propagation characteristics. Smart antenna is a big concept of beamforming using smart adaptive radiation pattern [13–17]. This paper proposes beamforming of 4 elements planar dipole array antenna operates at 5.6 GHz. Beamforming performance is evaluated with s-parameter bandwidth and radiation pattern of each scenario.

The rest of this paper is organized as follows. Antenna designed is explained in Section 2 from single antenna to 4-elements antenna. Beamforming principles is explained in Section 3. Research
results are presented and discussed in Section 4. Finally, conclusions are presented in Section 5 and followed by future works in Section 6.

2. Antenna Design

We start the antenna design from single dipole antenna. After single antenna met working frequency requirement, the single antenna is extended into four elements array antenna with circular configuration in azimuth direction.

2.1. Single Antenna

Single antenna is important part of array antenna before expanded to array antenna. We use planar dipole antenna as basic design. Planar dipole antenna is chosen because of omnidirectional radiation pattern, relatively high bandwidth, and simplicity in design.

We consider Rogers RT-5880 with relative permittivity $r = 2.2$ and thickness $h = 1.6$ mm as printed circuit board (PCB) antennas material. This material is suitable for this design purposes [18–21] since its low permittivity compared to FR-4 material and its power characteristics.

Single dipole antenna is designed using simple basic formula of microstrip antenna and dipole antenna [22–24]. The simplified formula used is shown in equation (1).

$$l = \frac{143}{f_{MHz}}$$

where $l$ is length of each dipole element in meter and $f_{MHz}$ is frequency in megahertz (MHz). Reference impedance is set at 50 Ohm. The optimized single antenna design is shown in Fig. 1 with $w_f = 2.7$ mm, $l_f = 5$ mm, and $l = 12$ mm. We also set $L_x = 15$ mm and $L_y = 40$ mm.

Single antenna’s bandwidth at return loss (RL) below −10 dB reach 1.3538 GHz with working frequency between 4.8365 GHz and 6.1903 GHz as shown in Fig. 2. It meets requirement that antenna should works between 5.15 GHz and 5.85 GHz. Radiation pattern of single antenna is omnidirectional as shown in Fig. 3. It has omnidirectional radiation characteristics in xz-plane or azimuth direction. It means the designed single antenna can be used for next step of array antenna.

![Figure 2. The obtained return loss of single antenna shown in Fig. 1.](image-url)
2.2. Array Antenna
Array antenna is constructed from 4 single antennas at Fig. 1. These 4 antennas are arranged on xz-plane using circle framework with radius \( r \) of 30 mm as shown in Figs. 4a and 4b. This configuration changes radiation pattern of each antenna from omnidirectional to bidirectional as shown in Fig. 5. The direction of antenna’s feeding is from the outer radius considering size of antenna’s port.

3. Beamforming
Beamforming uses principles of wave superposition. Usage of multiple antenna means multiple wave that can interfere each other. This interference makes maximal and minimal in specific direction. For isotropic antenna array, radiation pattern function in \( \theta \) is shown in equation (2).

\[
U_{\text{tot}} = \sum_{i=1}^{n} W_i e^{i\theta_i}
\]  

\( (2) \)
where $W_i$ is weighting amplitude of each antennas, $j$ is $\sqrt{-1}$ and $\theta_i$ is initial phase of each antenna. Basically, the superposition used for beamforming is affected by weighting (amplitude) and initial phase of each antenna.

4. Results and Discussions

The designed array antenna is used as beamforming antenna. It is possible by control amplitude and phase of each antenna’s element [25–27]. We use numbering of the antenna as seen in Fig. 4b to identify array’s element considering beamforming in xz-plane or azimuth direction.

4.1. 2 neighboring antennas

In this subsection, we use only 2 neighboring antennas and the other antennas are inactive. It means, there are only 2 active antennas. Fig. 6a shows array antenna’s radiation pattern if only antenna 1 and 2 are switched on with same phase. It has been shown that antenna’s mainlobe is at the middle between two antennas ($45^\circ$, $\phi = 180^\circ$) with 7.03 dB magnitude. Fig. 6b shows array antenna’s radiation pattern if only antenna 1 and 2 are switched on with $30^\circ$ phase leading at antenna 2. It has been shown that antenna’s mainlobe direction is shifted at $50^\circ$ ($\phi = 180^\circ$) with 6.93 dB magnitude and sidelobe of the antenna is expanded into bigger sidelobe.

4.2. With suppression from 2 other antennas

In this subsection, we modify the design from previous subsection by activating the 2 other antennas as suppressor. We set 2 other antennas with same power and $90^\circ$ phase difference compared to 2 other active antennas. Fig. 7a shows array antenna’s radiation pattern where antenna 3 and 4 is set as suppression of antenna 1 and 2. It has been shown that antenna’s mainlobe is at the middle between two antennas ($45^\circ$, $\phi = 180^\circ$) with 8.79 dB magnitude which is higher than Fig. 6a. Fig. 7b shows array antenna’s radiation pattern where antenna 1 and 2 are switched on with $30^\circ$ phase leading at antenna 2 and other 2 antennas is set as suppression antennas. It has been shown that antenna’s mainlobe direction is shifted at $51^\circ$ ($\phi = 180^\circ$) with 8.75 dB magnitude which is higher than Fig. 6b and sidelobe of the antenna is expanded into bigger sidelobe.

Figure 6. Array antenna’s radiation pattern: (a) $0^\circ$ phase difference, (b) $30^\circ$ phase difference.

Figure 7. Array antenna’s radiation pattern with suppression: (a) $0^\circ$ phase difference, (b) $30^\circ$ phase difference.
5. Conclusions
We have proposed planar dipole array antenna system at 5.6 GHz using 4 antenna elements. The antenna has 1.3538 bandwidth. Multiple antennas in this design supports beamforming in xz-plane or azimuth direction with main lobe magnitude above 6 dB. It can be achieved by control amplitude and phase of each antenna.

6. Future Works
Higher number of antennas will be considered to improve beamforming performances. It enables higher main lobe magnitude and smoother beamforming.

7. References
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