

FMCW radar with butler matrix for beam steering of phased array for accurate localization

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Abstract—This work aims to investigate the feasibility of using 8×8 butler matrix on FMCW radar for accurate localization. The system is designed to operate at 5.8GHz frequency with the ability to locate the object precisely. Design is expected to provide reliable wireless positioning and security surveillance performance compared to the radar implemented with a single antenna, phased array radars and camera surveillance.

Index Terms—FMCW, Butler matrix, beam steering

I. Introduction

Wireless positioning and security surveillance have become two issues in the present days. Wireless positioning has definitive impact in the fields on medicine and manufacturing [1]. Security surveillance became very difficult, as the techniques to overcome the surveillance have increased drastically. General camera surveillance has very meager effect if the field of interest is filled with mist or fog and there are innumerable occasions where the cameras have been outfoxed and crime has taken place. These two issues can be addressed through the design of effective radar system for continuous monitoring of the space of interest. The implementation of radar system with butler matrix enables beam steering of the phased array of antenna facilitating the effective analysis of the field. Fig. 1 shows diagrammatic representation of model system. The antenna array system is initially developed with adjacent element spacing as $d=\lambda/2$ and studied for resolution. Reflectivity of the antenna pattern is studied by marking stationary clutters in the field of interest. The resolution of the system is defined to be the efficiency to distinguish between two adjacent targets with least possible angular separation. The study is then extended by varying the spacing between adjacent elements and observing for resolution of the system.

II. Results

In this work, radiation pattern of single antenna is established using equations and array pattern by using the following equations [2,3]. The width of the strip is calculated as:

$$W = \frac{v_0}{2f_r} \sqrt{\frac{2}{\epsilon_r + 1}} \quad \dots (1)$$

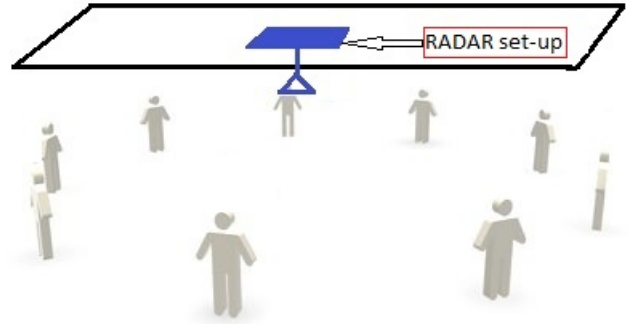


Fig. 1. Setup of FMCW radar with butler matrix for surveillance applications.

The effective dielectric constant can be calculated using

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \frac{h}{W} \right]^{-2} \quad \dots (2)$$

In order to calculate the effective length, the extension length of the strip is to be determined. Hence,

$$\Delta L = 0.412h \frac{(\epsilon_{reff} + 0.3) \left(\frac{W}{h} + 0.264 \right)}{(\epsilon_{reff} - 0.258) \left(\frac{W}{h} + 0.8 \right)} \quad \dots (3)$$

Thus arriving at the effective length of the antenna as,

$$L_{eff} = L + 2\Delta L \quad \dots (4)$$

The E-pattern is simulated using:

$$E_\phi = j \frac{k_0 h W E_0 e^{-jk_0 r}}{2\pi r} \left\{ \sin \theta \frac{\sin(X)}{X} \frac{\sin(Z)}{Z} \right\} \quad \dots (5)$$

where:

$$X = \frac{k_0 h}{2} \sin \theta \cos \phi \quad \dots (6)$$

$$Z = \frac{k_0 h}{2} \cos \theta \quad \dots (7)$$

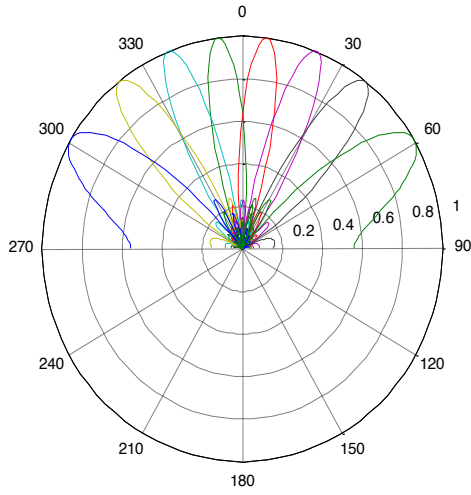


Fig. 2. Normalized E-pattern of the array for 8x8 Butler matrix with spacing between elements as $d=\lambda/2$

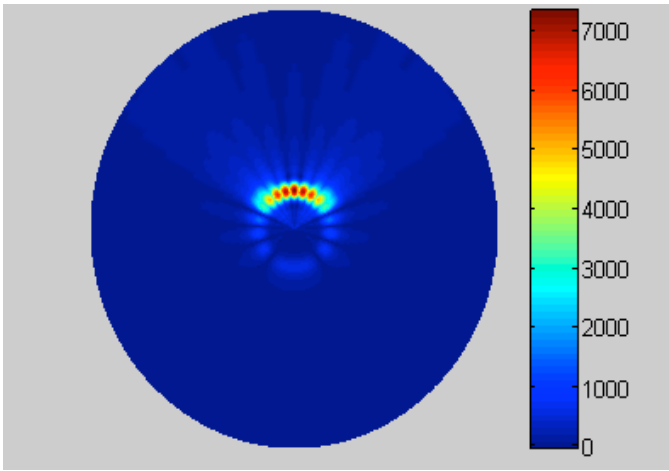


Fig. 3. RADAR performance with 14° distance between adjacent targets

and for E-plane $\theta = 90^\circ; 0^\circ \leq \phi \leq 90^\circ$ and $270^\circ \leq \phi \leq 360^\circ$. The array factor of butler matrix is simulated for an 8x8 array using:

$$AF(\theta) = \frac{\sin(N\pi \frac{d}{\lambda} \sin \theta - \beta_1)}{N\pi \frac{d}{\lambda} \sin \theta - \beta_1} \quad \dots (8)$$

where N = Number of elements in the linear array (2^n), and

$$\beta_1 = 1\pi$$

$$l = \pm \frac{1}{2}, \pm \frac{3}{2}, \dots, \pm \frac{(N-1)}{2} \quad \dots (9)$$

The E-pattern of the array is simulated by multiplying the E-pattern with the array factor. Fig. 2 indicates normalized radiation pattern of the array with spacing between elements as $d=\lambda/2$. The radiation pattern of the butler matrix is used to simulate for the identification of targets. As the target moves further from the center the ease of identifying the target decreases. Fig. 3 indicates response of pattern to 7 stationary targets existing in the field.

The study is extended by varying spacing between the elements in the array to $d=\lambda/1.33$ and $d=\lambda$. It is observed for the array pattern that, as spacing between antenna elements increases, directivity of the beams also increases.

III. Conclusion

It can be observed in the Fig. 3 that the antenna array with spacing $d=\lambda/2$ is effective in distinguishing two adjacent targets. But as the angular distance between the targets decreases the performance becomes poor. The overlapping of targets is observed in as spacing decreases which indicates poor performance of the system. Similar study is performed with antenna patterns obtained for spacing between elements as $d=\lambda/1.33$ and $d=\lambda$

Table 1: Observed results for spacing between elements V/S resolution

Spacing between antenna elements	Resolution observed
$d = \lambda/2$	14°
$d = \lambda/1.33$	9°
$d = \lambda$	7°

The resolution of the antenna system with different spacing conditions between the antenna elements can be observed in the above table. The proposed system has a much better resolution as the spacing between antenna elements increases. Another solution can be using an array with more number of elements but this can be more complex as it involves increased number of phase shifters and crossovers for the design of butler matrix architecture. Since the simulation is performed considering ideal phase shifters, couplers and crossovers the result from physical implementation can be much worse. The 8x8 architecture for butler matrix provided with reliable outputs and board-level implementation is less complex compared to a larger sized array.

Impact of MTT-S scholarship

I am grateful to IEEE MTT-S for providing the scholarship for my work. With fewer burdens on me to struggle for funding my education, I can spend more time focusing on my studies, which helped to achieve my academic goals. I am immensely thankful to Dr. Changzhi Li for mentoring me and dedicating his valuable time. The scholarship provided me a stage to express my idea, which is great for building my profile. It has been a great learning curve for me. I have successfully graduated from Texas Tech University with a degree in MS-EE. I will continue gaining more experience and skills by working at Freescale Semiconductor.

References

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