Smart Antenna:Weight Calculation and Side-lobe Reduction by Unequal Spacing Technique

M. N. Md Tan, S.K. A.Rahim, M.T. Ali and T.A.Rahman

Wireless Communication Center (WCC),
University Technology Malaysia (UTM),
Skudai Johor.
mnor1408@yahoo.com, sharulkamal@fke.utm.my, mizi732002@yahoo.com, tharek@fke.utm.my

Abstract - This paper is divided into two parts. The first part presents the study of smart antenna beam-forming where a single beam is shaped by weighting and summing the antenna outputs. In order to calculate the weight of the array elements, the conventional beam-former (known as delay and sum) has been chosen. MATLAB software is used to calculate the weights, and to obtain the array factor of 8 elements linear array antenna. The second part illustrates that, the side-lobe can be reduced by using unequal spacing technique, but the number of elements is remained unchanged. The comparison between symmetric and asymmetric arrangement for unequal spacing is also presented. The results show that by using the symmetrical arrangement, the side-lobe obtained is much better than asymmetrical arrangement. In fact, the side-lobe produced by asymmetrical arrangement is worse than the equal arrangement.

Keywords: Smart antenna; Beam-forming; symmetrical; asymmetrical

1. Introduction

Smart antenna is considered as an active area of research since the last few decades. This field can be applied into different areas such as radar, sonar, medical imaging and also communication, especially in wireless communications. Smart antenna system exploits the spatial diversity among different users and with proper signal processing techniques, this system has shown a convincing quality in terms of increasing the coverage and capacity, mitigate multi-path fading and enhance security and privacy. [1].

The smart antenna term is based on the system in which a system using an antenna array together with a processor that can adjust the radiation pattern to the desired user [2]. In other words, smart antenna is capable to direct the maximum radiation of the antenna pattern towards the signal of interest (SOI) and at the same time, place nulls towards the signal not of interest (SNOI), thereby increasing the performance of the wireless system. A block diagram for smart antenna system is shown in Figure 1.

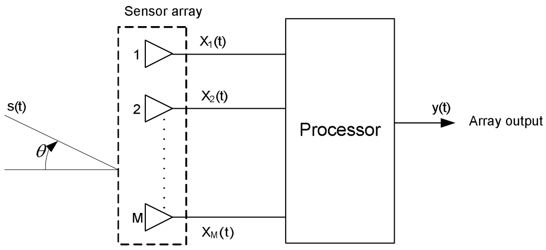


Figure 1: Block diagram of smart antenna system.

In Figure 1, the received signals, x(t), are multiplied by a complex weight in the processor. These weighted elements are then summed to form the array output, y(t).

Array output,

$$y(t) = \sum_{i=1}^{M} W_i^* x_i(t) \tag{1}$$

Where M = number of element
W=complex weight
$x(t)$ = antenna array output

The weight vector,

$$W = [W_1,.........,W_M]^T \tag{2}$$

Signal induced (signal vector) on all elements,

$$x(t) = [x_1(t),......, \ x_M(t)]^T \tag{3}$$

So, the output of the array become

$$y(t) = W^H x(t) \tag{4}$$

Where T and H denotes transposition and complex conjugate transposition.

For adaptive antenna, the values of these weights depends on the environment changes such as the location of the user, the signal to noise ratio and etc. These weights are important to ensure that the main beam is points to the correct direction.

The assumption made during the simulation was that the location (angle) of the desired user is already determined by on of the Direction of Arrival (DOA) algorithm at receiving site. In order to calculate the weight and obtain the radiation pattern, the user location is entered randomly in the programming using MATLAB.

2. Beamforming Modelling

In smart antenna system, a lot of different processors (beam-former) can be used in order to study the performance of the system. The processors include conventional beam-former, null-steering beam-former, optimal beam-former and side-lobe beam-former. Beam steering is the simplest form of beam-forming that can be achieved by a delay and sum beam-former. It is also well known as conventional beam-former. The weight of the beam-former are all made equal in magnitude, whereas the phases are selected to steer the main beam of the array in a particular direction θ_i [3]. The array weights (W) can be obtained by

$$W = \frac{1}{M}[a(\theta_i)] \tag{5}$$

where M = the number of a linear array antenna
$a(\theta_i)$ = steering vector at direction θ_i

$$a(\theta_i) = [1, e^{-j\frac{2\pi d}{\lambda}\sin\theta_i}, ..., e^{-j(M-1)\frac{2\pi d}{\lambda}\sin\theta_i}]^T \tag{6}$$

where d = distance between the array elements

The far-zone field of a uniform linear array of identical elements is equal to the product of the field of a single element and the array factor of that array [4]. That is

E_{total}= E (single element x Array Factor (AF)) (7)

where $AF = W'*a(\theta_i)$ (8)

The results for weight calculation, the radiation pattern and their performance in term of the Half Power Beam-width (HPBW) and First side-lobe (FSL) for equal and unequal spacing are presented. Table 1 and 2 shows the weight values for each element at different angles for both equal and unequal spacing array elements respectively. These tables show that the weight values will change automatically when the angle of users or the spacing between the elements are changed.

Table 1: Weight values at different angle of users with 8 array elements (equal spacing)

Weight (W)	Angle of desired users		
	$\theta = 0^0$	$\theta = 30^0$	$\theta = -30^0$
W_1	0.1250	0.1250	0.1250
W_2	0.1250	0.0000 + 0.1250i	0.0000 - 0.1250i
W_3	0.1250	-0.1250 + 0.0000i	-0.1250 - 0.0000i
W_4	0.1250	-0.0000 - 0.1250i	-0.0000 + 0.1250i
W_5	0.1250	0.1250 - 0.0000i	0.1250 + 0.0000i
W_6	0.1250	0.0000 + 0.1250i	0.0000 - 0.1250i
W_7	0.1250	-0.1250 + 0.0000i	-0.1250 - 0.0000i
W_8	0.1250	-0.0000 - 0.1250i	-0.0000 + 0.1250i

Table 2: Weight values at different angle of users with 8 arrays elements (unequal spacing)

Weight (W)	Angle of desired users		
	$\theta = 0^0$	$\theta = 30^0$	$\theta = -30^0$
W_1	0.1250	0.1250	0.1250
W_2	0.1250	0.0000 + 0.1250i	0.0000 - 0.1250i
W_3	0.1250	-0.0386 - 0.1189i	-0.0386 + 0.1189i
W_4	0.1250	0.0735 + 0.1011i	0.0735 - 0.1011i
W_5	0.1250	-0.1011 - 0.0735i	-0.1011 + 0.0735i
W_6	0.1250	0.1189 + 0.0386i	0.1189 - 0.0386i
W_7	0.1250	-0.1250 + 0.0000i	-0.1250 - 0.0000i
W_8	0.1250	-0.0000 - 0.1250i	-0.0000 + 0.1250i

Figure 2 shows the array factor pattern for 8 elements linear array antenna with equal spacing (optimum spacing is 0.5 λ). The result showed that the beam can be directed correctly up to $\pm 60^0$ only. The pattern alters when the angle approaces 90^0 or 270^0 [5]. This is the disadvantages of using linear array since the coverage is less than 180^0.

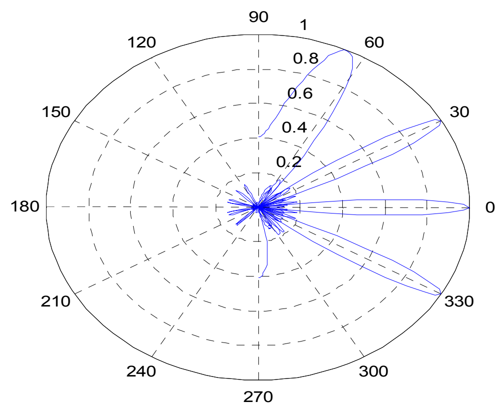


Figure 2: Radiation pattern of 8 elements at different angle of users with equal spacing

3. Unequal Spacing Array Element Analysis

If the array elements are arranged on the y-axis with a uniform spacing between elements, d, this arrangement is called uniform linear array as shown in Figure 3.

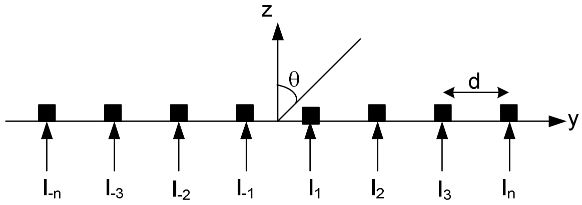


Figure 3: Uniform linear array elements

Where I = excitation current amplitude
d = spacing between element

The side-lobe level of this arrangement can be reduced by changing the arrangement in Figure 3 into non-uniform linear array. There are two techniques to form non-uniform linear array antenna. The first technique is by varying the spacing between elements but excitation amplitude is uniform. The second technique is by varying the excitation amplitude but the spacing between elements is uniform. Unluckily, the second method requires a complicated feed system and at the same time the beam-width also increases [6].

In this paper, the first method is chosen. The side level will be compared between equal and unequal spacing elements. The optimum equal spacing is 0.5λ. The radiation pattern for 8, 16 and 32 elements with equal spacing array element at 0 degrees user angle is shown in Figure 4. Table 3 shows the details of the differences between different numbers of elements for equal spacing. It shows clearly that when the number of elements is doubled, the beam-width is reduced by almost 50%. The side-lobe also shows some improvement when the number of elements increased.

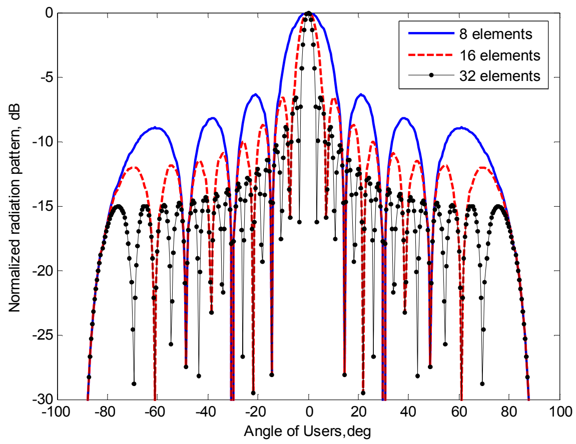


Figure 4: Radiation pattern with different number of elements with equal spacing at 0^0.

Table 3: Comparison between different numbers of elements for equal spacing

Number of Elements	First side-lobe (FSL) (dB)	Half power beam-width (HPBW)
8	-6.3991	17^0
16	-6.5871	9^0
32	-6.6452	3^0

The arrangement of the elements for unequal spacing basically can be made into two techniques, either in symmetrical arrangement or asymmetrical arrangement. These arrangements are shown in Figure 5.

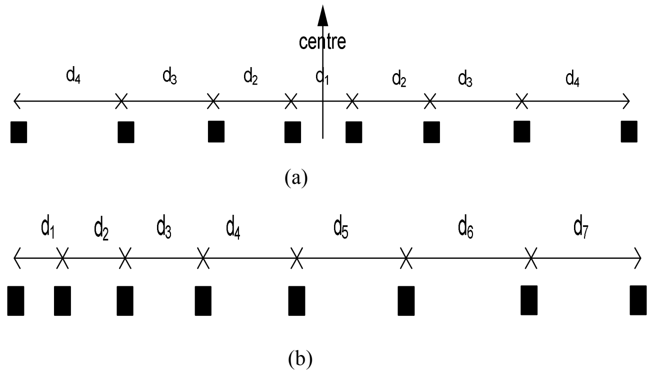


Figure 5: The arrangement of the element for unequal spacing; (a) Symmetric (b) Asymmetric

3.1 Equal spacing Vs Unequal Spacing (asymmetrical arrangement)

First comparison made is between equal spacing with unequal spacing with asymmetrical arrangement. The results shown in Figure 7 were based on the asymmetrical arrangements shown in Figure 6.

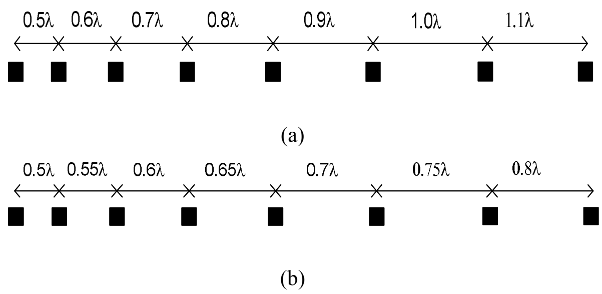


Figure 6: Different unequal spacing arrangements for asymmetrical technique: (a) design a (b) design b

The radiation pattern in Figure 7 shows that for both asymmetrical arrangements, the side-lode obtained is worse than the side-lobe produced by equal spacing array, but the HPBW for both designs **a** and design **b** are reduced from 17^0 to 11^0 and 13^0 respectively.

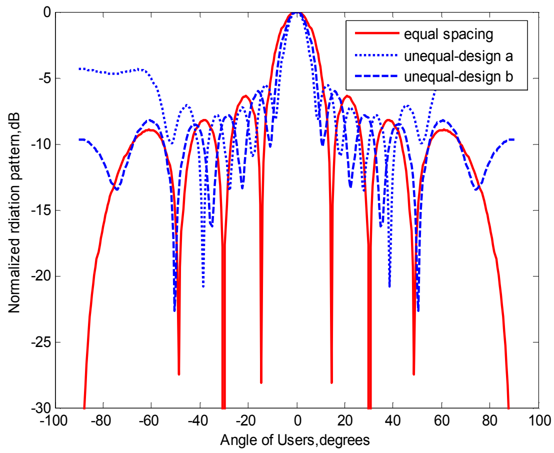


Figure 7: Radiation pattern of 8 elements for equal and unequal asymmetrical arrangement

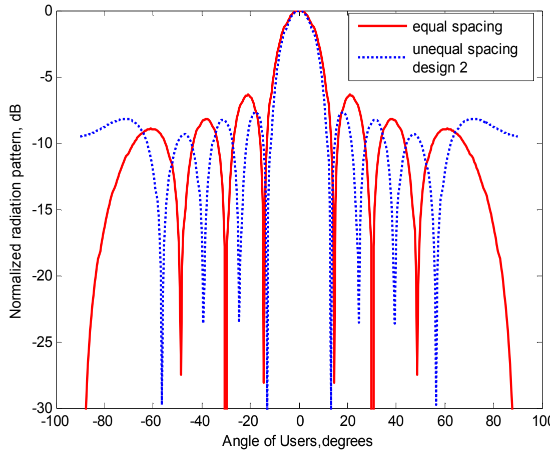
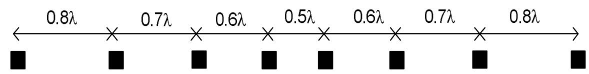


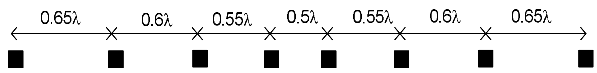
Figure 9: Radiation pattern of 8 elements for equal and unequal spacing at 0^0

3.2 Equal spacing Vs Unequal Spacing (symmetrical arrangement)

Figure 8 and Figure 9 shows the comparison made between equal and unequal (symmetrical arrangement) spacing for 8 elements. The arrangements of the elements were based on the even number arrangement as given in Figure 5(a) and equation (6) in [6]. The graph plotted in Figure 8 and Figure 9 were based on the position given in Figure 10 below.



(a)



(b)

Figure 10: Symmetrical arrangement for even number of elements: (a) design 1 (b) design 2

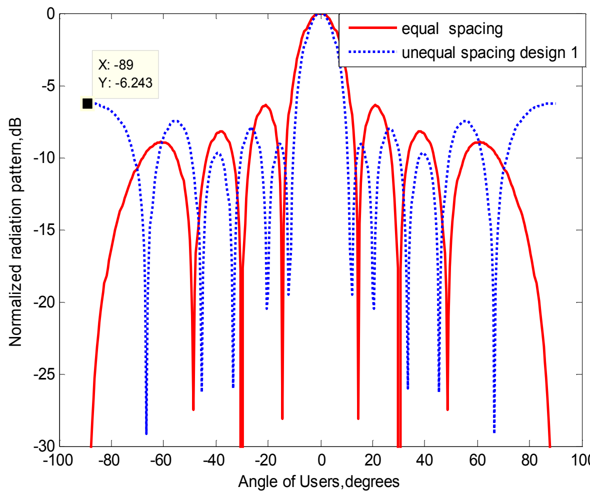


Figure 8: Radiation pattern of 8 elements for both equal and unequal spa

It can be seen obviously that between Figure 9 and Figure 10 if the arrangement is made carefully, the side-lobe of the linear array antenna can be enhanced easily. The HPBW and first side-lobe (FSL) for 8 elements with equal spacing is 17^0 and -6.399dB respectively. Meanwhile, the HPBW and FSL for design 1 are 15^0 and -9.0693dB and for design 2, the HPBW is 16^0 and FSL is -7.7073dB.

FSL in design 1 is better than design 2 where the main difference is that the side-lobe other than FLS in design 1 is higher than design 2. In fact, the ambiguity level in design 1 is improved from -6.248dB to -8.199dB in design 2. It is also shown that the result obtained in design 2 is better than the result obtained in [7]. In [7], the FSL showed a tremendous improvement but again, the side-lobe other than the FSL is much higher than the equal spacing.

Table 4 shows the comparison made between the equal spacing array element and unequal spacing for both design 1 and design 2. It can be seen clearly that although unequal spacing array required longer size, the FSL for both designs are improved and the beam-width reduced slightly.

Table 4: Comparison between equal and unequal spacing element

	Equal spacing	Unequal spacing	
		Design 1	Design 2
Beam-width	17^0	15^0	16^0
FSL	-6.399dB	-9.0693dB (41.73%)	-7.7073dB (20.45%)
Array length	3.5 λ	4.7 λ (34.28%)	4.1 λ (17.14%)

4.0 Conclusion

A study of the linear array antenna in term of their weight for each of the elements, the radiation pattern in both the equal and unequal spacing has been carried out. The first part of this paper shows that it is important to calculate the weight of each element correctly in order to direct the beam to the desired user.

The second part shows that considerable improvement of side-lobe level can be obtained by using symmetrical unequal spacing arrays arrangement in comparison with equal spacing arrays having the same number of elements and uniform excitation amplitude. In asymmetrical arrangement, the HPBW is reduced but the side-level is about the same level and in fact some results shows that the side-lobe obtained are worst than the symmetrical arrangement.

Acknowledgement

The authors would like to thank to everyone for their helps and supports in completing this project especially to University Technology Malaysia (UTM) and also to Wireless Communication Center (WCC).

References

[1] Roy,R.H, “An overview of smart antenna Technology: The next wave in Wireless Communication”, Vol 3, Mac 1998, pp. 339-345

[2] Godara,L.C., “ Smart Antenna”, CRS Press, 2004. pp.4

[3] Godara,L.C., “Application of Antenna Arrays to mobile Communications, Part II: Beam-forming and Direction of Arrival Considerations” Proceeding of the IEEE, vol 85, No 8, August 1997, pp. 1195-1245.

[4] C.A. Balanis, “Antenna theory analysis and design”, John Wiley and Sons, 1997. pp. 251

[5] Iclia Villordo-Jemenez, Ignacio E. Zaldivar-Huerta, G.M Galvan-Tejada, “An Overview of SDMA in Communications Systems”, Circuit and System, MWSCAS06’, 49th IEEE Conference, Midwest Symposium, 6-9 August 2006, pp.168-171.

[6] R.F.Harrington, “Side-lobe Reduction by Non-uniform Element Spacing”, IRE Transaction. On Antenna and Propagation, Vol. Ap-9, pp. 187, March, 1961.

[7] Cheng-Cheh Yu, “Side-lobe reduction of asymmetric linear array, Electronic Letter, Vol 33, No 9, 24th April 1997.