A phased array of switched-beam elements for angle-of-arrival measurement

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1. Introduction

Angle-of-arrival (AoA) is important in identifying the direction of radio signal to the receiving system in modern wireless communications. It enables the optimization of an adaptive antenna, locate and track the target, etc. [1]-[2]. The conventional AoA schemes are MUSIC [3] and ESPRIT [4] which are based on digital signal processing. Recently, Kamarudin *et al.* [5] proposed the use of switched-beam antennas to measure AoA. It accomplished the satisfactory results at the expense of less accuracy comparing with MUSIC and ESPRIT. It is suitable for a mobile unit which computation intensive is avoided. In such system, four beams were used and it is anticipated that the accuracy can be improved by using more number of antenna beams. Nevertheless, to obtain more number of antenna beams the more sophisticated feeding system and number of array elements must be increased. Ngamjanyaporn *et al.* [6] proposed the so called phased array of switched-beam elements (PASE) that provided a number of beams using only four array elements with four one-bit phase shifters. Therefore, it is a potential receiving antenna for a mobile unit.

This paper proposes PASE for AoA measurement in a mobile unit.

2. Time for AoA measurement

The AoA was estimated by comparing the ratio of the measured path gains obtained from the two beams with the greatest path gain to the ratio of the antenna patterns corresponding to the same beams [4]. The AoA can be obtained by finding the smallest difference between the measured maximum path gain ratio and the antenna pattern ratio for the corresponding regions. Let assume each beam of the array be identical. The time required for data acquisition (scanning time) per beam direction is m milliseconds. The time required for calculating gain ratio (searching) per direction is n milliseconds. Hence, for a 4-beam antenna, 12 regions are accomplished and each region accommodates 30°. The maximum time for searching is $30n$ milliseconds while the time for scanning 4 beams is $4m$ milliseconds. The total time required for AoA measurement is $4m+30n$ milliseconds. For the 8-beam antenna, there are 16 regions with the angle of 22.5° in each region and the total time required is $8m+22.5n$ milliseconds. The number of regions and time required for AoA measurement for the 12- and 16-beam antennas are 20 and 28, and $12m+18n$ and $16m+13n$, respectively. For illustration, Fig.1 shows radiation patterns of the 16-beam antenna. We can observe 28 regions around the azimuth plane. Table 1 compares time of each antenna when $m>n$, $m=n$ and $m<n$.

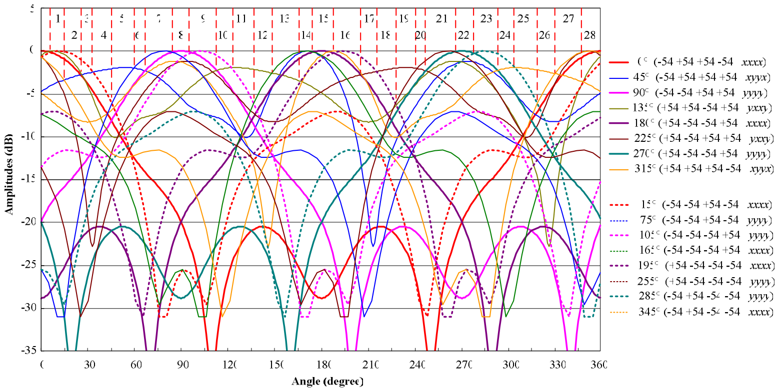

Figure 1: Radiation patterns of the 16-beam antenna

Table 1: Time for AoA measurement (t) and time difference from 4-beam antenna (Δt)

No. of beams (No. of regions)	4 (12)		8 (16)		12 (20)		16 (28)	
m, *n*	*t*(msec)	Δt (%)	*t*(msec)	Δt (%)	*t*(msec)	Δt (%)	*t*(msec)	Δt(%)
m=1, *n*=1	34	0	30.5	-10.3	30.0	-11.8	29.0	-14.7
m=2, *n*=1	38	0	38.5	+0.13	42.0	-10.5	45.0	-18.4
m=1, *n*=2	64	0	53.0	-17.2	48.0	-25.0	42.0	-34.4
m=1, *n*=3	94	0	75.5	-19.7	66.0	-29.8	55.0	-41.5
m=1, *n*=4	124	0	98.0	-21.0	84.0	-32.3	68.0	-45.2

Table 1 indicates that for the case of scanning time equals searching time, 8-beam requires 30.5 milliseconds. It is 10.3% less than 34 milliseconds of the 4-beam counterpart. When the system utilizes longer scanning time than searching time (m=2, n=1) the 8-beam system spends 38.5 milliseconds while those of 4-beam system spends 38 milliseconds. The 8-beam antenna is not suitable for this case. It is relevant that the 8-beam system outperforms the 4-beam one when the system utilizes longer searching time. The system with n equals 2, 3 and 4 spends less time than the 4-beam system by 17.2, 19.7 and 21.0%, respectively. Note that when the number of beams is increased to 12 and 16, the regions for AoA measurement are markedly increased to 20 and 28, respectively. Consequently, time required for AoA measurement is significantly decreased. This enables the design with low cost searching devices. It should be noted that scanning time is dependent on analog to digital converter (ADC) and RF switch (RFSW) speed while searching time is dependent on CPU speed. In application, the fastest speed is required when the system is on a mobile unit. For the same processing time, the system consumes less processing time can provide more accurate AoA since angular step can be decreased.

3. PASE for AoA measurement

PASE arrangement in [5] aligned array elements of square patches of $\lambda\times\lambda$ in which array dimension is $3\lambda\times3\lambda$. To miniaturize its dimension, this work proposes the arrangement in Fig.2 which dimension can be reduced by 20%. In addition, the less array radius improves front-to-back ratio of the array. Each element produces bidirectional pattern with maximum points toward ±x or ±y direction.

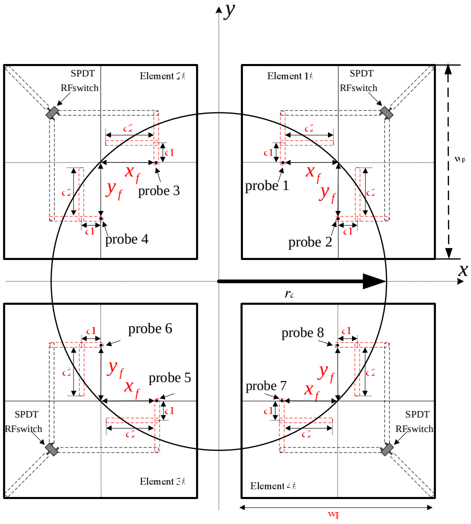

Figure 2: Proposed array configuration

Table.2 shows array configuration with dimensions of the feeding system. The parameters are patch width w_p, probe positions (x_f, y_f), stub position and length d_1 and d_2, respectively. The probes are switched to provide maximum in ±x or ±y direction by an RF switch. The array can switch its radiation patterns in different directions simply by switching probe positions and one-bit phase shifters. The phase shifters are adjusted to ±54° when elevation pattern has maximum at 45°.

Table 2: Dimensions of an array element

Symbols	Parameters	values
ε_r	Dielectric constant of substrate	10.0
$\tan\delta$	Loss tangent of substrate	0.0035
h	Height of substrate, for antenna (mm)	1.58
hf	Height of substrate, for feeding system (mm)	0.76
wp	Width of patch antenna (mm)	15.4
wl	Width of microstrip transmission line (mm)	0.76
fp	Position of feeding probe (mm)	3.9
d1	Position of stub (mm)	0
d2	Length of stub (mm)	3.0

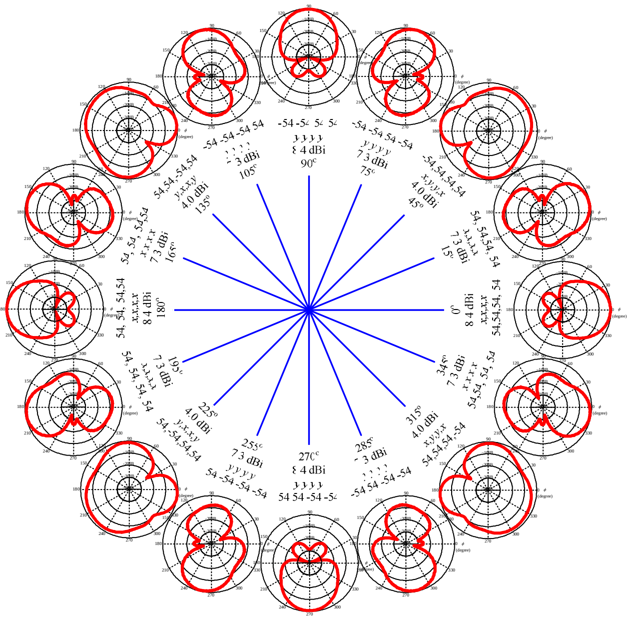

Figure 3: Azimuth radiation patterns

Fig.3 shows some radiation patterns from the proposed array antenna which can be controlled by element patterns (i.e., *y*,*x*,*x*,*y*), phase (i.e., 54,54,-54,54) and array radius. The array radius was fixed to 0.3λ. It is relevant that we can produce variety of beam directions. The gain varies from 4.0 to 8.4 dBi. These patterns can be utilized in AoA measurement. For instance, for the 8-beam antenna, we may choose phase shifters of ±54° and appropriate switching of element patterns. This enables us to switch 8 beams and yields 16 regions for AoA measurement.

4. Measurement results

By varying patch and array parameters, the suitable dimensions that provide matching and bidirectional patterns are listed in Table 2. The antenna was fabricated on Taconic (CER-10) substrate and tested. Fig.4 shows S_{11} of each element and of the array. They are well matched at 5.86 GHz which is slightly higher than the design frequency at 5.8 GHz. The measured patterns are plotted in rectangular coordinate as shown in Fig.5 where 16 regions are obtained. Some discrepancies from simulations are from imperfect element matching and phase shifters. However, this antenna provides 8 beams for AoA measurement.

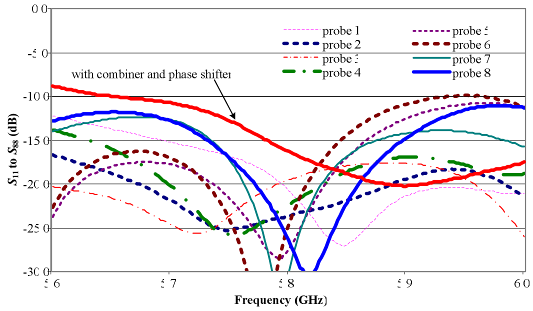

Figure 4: Measured S_{ii} (i =1, 2,…8) versus frequency of the elements and the array

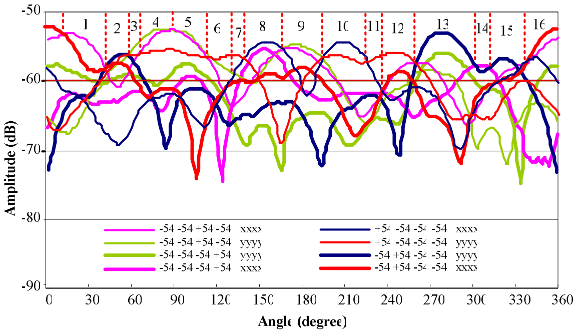

Figure 5: Measured radiation patterns of phased array of switched-beam elements

5. Conclusions

A new configuration of PASE was proposed. It possesses 20% smaller size than the previous configuration. It is apparent that the large number of beams yields large number of regions and spends less time required for AoA measurement than the four-beam antenna. A prototype antenna was fabricated and tested at 5.8 GHz. The AoA measurement will be validated in the future work.

Acknowledgment

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