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Design of Compact Multiband Antenna for Triple-Band Cellular Base Stations

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***Abstract*—In this letter, a tapered slot antenna (TSA) which covers 1.5/2/2.4 GHz bands is designed for a 6-sector base station. It is shown that the TSA with desired half-power beamwidth and front to back (F/B) ratio at the frequency bands can be designed by loading the two pairs of slits and reflector. Results of numerical simulation show that the designed TSA radiates a sector beam with high F/B ratios over 20 dB at 1.5/2/2.4 GHz bands.**

***Index Terms*—tapered slot antenna, multiband antennas, base station, half-power beamwidth, F/B ratio.**

I. INTRODUCTION

IN recent years, mobile communication systems are widely used and various commercial mobile services which use different frequency bands have been started. Therefore, multiband base station antennas have much attention. The multiband base station antennas should have desired directivity over all frequency bands, i.e. a sector beam with high front to back (F/B) ratio. On the other hand, the size of the base station antennas should be compact to reduce antenna costs and wind pressure. Therefore, the design of the multiband base station antennas with desired directivity is difficult because the directivity of the antennas strongly depends on its relative size compared with wavelength.

Previously, various multiband/wideband antennas with desired directivity have been proposed as the base station antennas. A wideband stacked patch antenna has been proposed [1]. It has been demonstrated that the stacked patch antenna shows $65^\circ \pm 6^\circ$ of half-power beamwidth at 1.7/2.2/2.7 GHz bands. A wideband antenna, which is called a magnetoelectric dipole, has been proposed and stable half-power beamwidth has been achieved at the frequency range from 1.8 to 2.8 GHz [2]. However, F/B ratio of these antennas deteriorates at lower frequency. On the other hand, a patch antenna fed by a meandering probe [3] and folded printed dipole antenna [4] have been proposed. Moreover, antennas which cover 1710-2170 MHz band have been proposed [5]-[8]. These antennas radiate a sector beam with high F/B ratio in the frequency band. However, these papers mainly focus on wideband impedance matching but how to design the directivity of these antennas is not clarified in these papers.

To the best of our knowledge, most of the conventional base station antennas have been limited to dipole-type or patch-type antennas. Moreover, how to design the directivity of the wideband base station antennas under its size limitation has not been clarified in previous researches.

In this letter, we design a compact tapered slot antenna (TSA) for an application of 6-sector multiband base station at 1.5/2/2.4 GHz bands. In Japanese cellular system, 1.5 GHz band is assigned for HSPA (High Speed Packet Access), 2 GHz band is assigned for the 3G and LTE (Long Term Evolution), and 2.4 GHz band is assigned for WiMAX (Worldwide Interoperability for Microwave Access). Polarization diversity technique is employed for the proposed base station antenna and it has already known that a 6-sector beam in vertical polarization can be achieved using two element antenna array [9]. Therefore, we only focus on the design of the TSA for horizontal polarization in this letter. Due to the size limitation of the base station antenna, an array structure cannot be introduced to realize a sector beam with high F/B ratio in horizontal polarization. Therefore, another approaches are introduced to the TSA for horizontal polarization and desired 6-sector beam is realized. Results of numerical simulations show that the designed TSA for horizontal polarization radiates a sector beam with high F/B ratio over 20dB at the three frequency bands.

II. CONFIGURATION OF THE PROPOSED ANTENNA

Table I shows the desired performance of the proposed antenna. At 1.5/2/2.4 GHz bands, a sector beam with high F/B ratio over 20 dB is required for the proposed antenna. The proposed antenna is covered by a cylindrical radome. Therefore, the entire size of the antenna is limited by the size of the cylindrical radome and the antenna must be compact. In this letter, the effect of the radome is ignored in numerical simulation.

Fig. 1 shows the configuration of the proposed antenna, which is the TSA backed by a reflector. The TSA is fed by an L-shaped microstrip line on a polyphenylene ether (PPE) substrate which has a dielectric constant of 3.3, a loss tangent of 0.003, and a thickness of 0.8 mm. The TSA has elliptical shape and installation space in the cylindrical radome can be fully utilized. The major/minor radii of the ellipse of the TSA are R_x and R_y, respectively. The slot line behind the feed point is shorted directly by the reflector and the installation space of the TSA is saved. The shorted slot line has the width w_s and the length l_s. The tapered slot has exponential profile and has the width W. By specifying two points (x_1, y_1) and (x_2, y_2), the exponential profile $f(x)$ of the taper is expressed as

$$f(x) = c_1 \exp(Rx) + c_2, \quad (1)$$

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TABLE I
DESIRED PERFORMANCE OF THE PROPOSED ANTENNA.

Frequency Bands	1.5, 2, 2.4 GHz
$\|S_{11}\|$	$\leq -10\,\mathrm{dB}$
Front to Back Ratio	$\geq 20\,\mathrm{dB}$
Number of Sectors	6
Half-Power Beamwidth (Horizontal Plane)	$60^\circ - 70^\circ$
Size of Radome	$\phi\,200\,\mathrm{mm} \times 2500\,\mathrm{mm}$

TABLE II
GEOMETRICAL PARAMETERS OF THE PROPOSED ANTENNA.

Parameter	Value	Parameter	Value	Parameter	Value
R_x	95 mm	l_s	10 mm	w_{slit}	1 mm
R_y	95 mm	l_{m1}	10 mm	x_{slit1}	45 mm
w_s	2 mm	l_{m2}	30 mm	x_{slit2}	80 mm
W	135 mm	w_m	1.8 mm	l_{slit1}	55 mm
w_{r1}	128 mm	R	50	l_{slit2}	45 mm
w_{r2}	33.3 mm	α_1	150 deg.		
w_{r3}	30 mm	α_2	130 deg.		

$$c_1 = \frac{y_2 - y_1}{\exp(Rx_2) - \exp(Rx_1)}, \quad (2)$$

$$c_2 = \frac{y_1 \exp(Rx_2) - y_2 \exp(Rx_1)}{\exp(Rx_2) - \exp(Rx_1)}, \quad (3)$$

where R is the opening rate which indicates how steep tapered slots curve.

The TSA is backed by the bended reflector. The bended reflector is introduced to enhance the F/B ratio of the TSA. The bended reflector has two bend angles α_1 and α_2. The lengths of three parts of the bended reflector are defined as w_{r1}, w_{r2} and w_{r3}, respectively.

At the both edges of the TSA, the slits are loaded as shown in Fig. 1. Because the current distribution on the TSA is controlled by the slits, half-power beamwidth and F/B ratio of the TSA is controlled. Because the effect of the slit depends on its length compared with a wavelength, it is difficult to controll directivity of the TSA at three frequency bands with only one pairs of slits. Therefore, two pairs of slits are loaded to realize desired half-power beamwidth and F/B ratio at three frequency bands. The lengths of two pairs of slits are l_{slit1} and l_{slit2}, respectively. The spacings between the reflector and slits are x_{slit1} and x_{slit2}, respectively.

The values of the geometrical parameters were optimized by FEKO which is a numerical simulator based on the method of moments (MoM). The optimized geometrical parameters are listed in Table II.

III. ANTENNA DESIGN

A. Effect of Reflector Geometry on Antenna Directivity

The enhancement of the performance of the TSA by bended reflector is shown. In this section, w_{r1} and w_{r2} are fixed and w_{r3} is variable. The length of slits is fixed to zero ($l_{slit1} = 0$ and $l_{slit2} = 0$). All other parameters are shown in table II.

The effects of w_{r3} on half-power beamwidth and F/B ratio of the TSA are shown in Fig. 2 and Fig. 3, respectively. The variation of half-power beamwidth due to w_{r3} is no more than 20°. On the other hand, as shown in Fig. 3, it can be

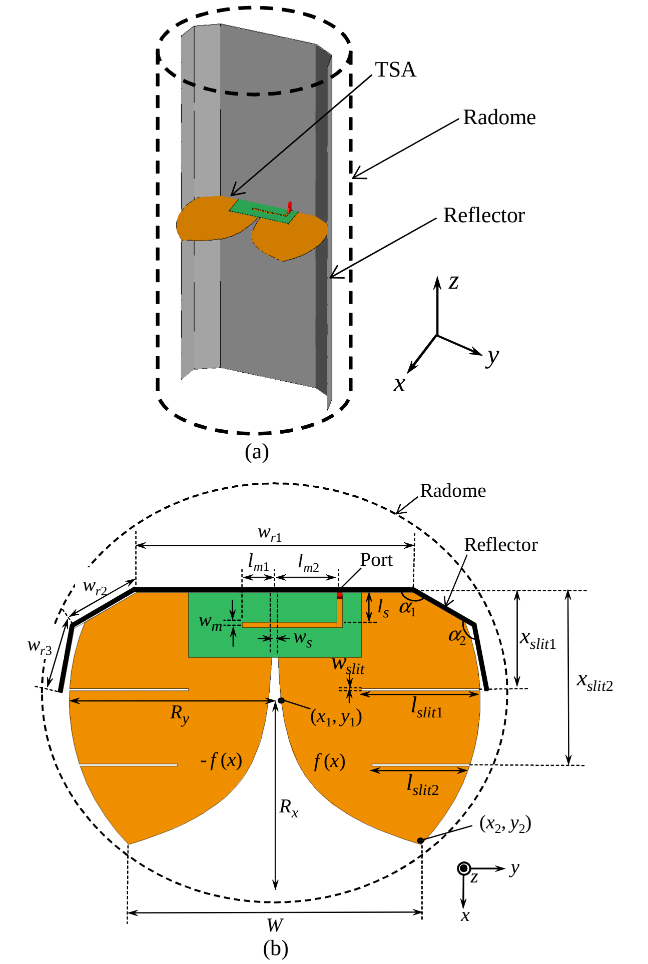

Fig. 1. Configuration of the proposed antenna. (a) Perspective view. (b) Top view.

seen that F/B ratio at each frequency is enhanced as w_{r3} increases. Therefore, it is found that w_{r3} largely affects the F/B ratio of the proposed TSA while the effect of w_{r3} on the half-power beamwidth is relatively small. As a conclusion, it can be said that the bended reflector is one of the promising techniques for the design of the wideband base station antenna with high F/B ratio under the size limitation. However, desired F/B ratio ($\geq 20\,\mathrm{dB}$) still cannot be realized at all frequency bands in this configuration simultaneously. Moreover, desired half-power beamwidth still cannot be realized at all frequency bands. Therefore, an another remedy is required for further enhancement of half-power beamwidth and F/B ratio.

B. Effect of Slits on Antenna Directivity

As an another remedy, the slits are loaded at the both edges of the TSA as shown in Fig. 1. Fig. 4 shows the effect of the slit length l_{slit2} on the half-power beamwidth of the TSA. Based on the discussion in the previous section, the reflector length w_{r3} is set to maximum size (i.e. 30 mm). It is found that half-power beamwidth of the TSA at each frequency is strongly affected by the slit length l_{slit2}. As can be seen in Fig.

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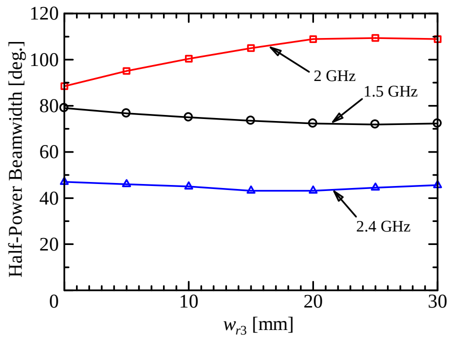

Fig. 2. Effect of w_{r3} on half-power beamwidth.

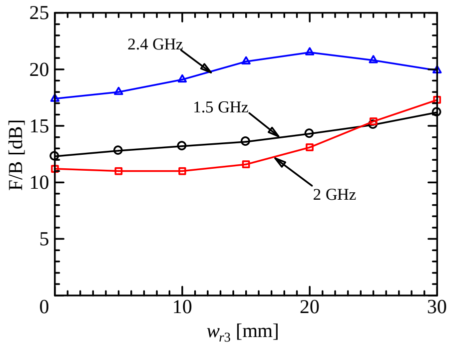

Fig. 3. Effect of w_{r3} on F/B ratio.

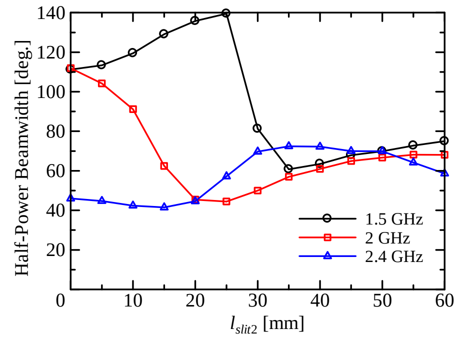

Fig. 4. Effect of slit length l_{slit2} on half-power beamwidth.

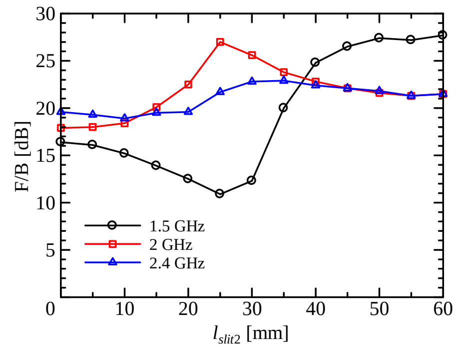

Fig. 5. Effect of slit length l_{slit2} on F/B ratio.

4, desired half-power beamwidth is achieved at all frequency bands when $l_{slit2} = 45\,\text{mm}$.

Fig. 5 shows the effect of the slit length l_{slit2} on the F/B ratio. It can be seen that F/B ratio at each frequency is affected by l_{slit2}. Moreover, F/B ratio at each frequency tends to increase as the slit length l_{slit2} increases. When the slit length l_{slit2} is greater than $40\,\text{mm}$, it is found that the F/B ratio over $20\,\text{dB}$ is realized at all frequency bands. Therefore, the TSA realizes desired half-power beamwidth and F/B ratio at all frequency bands when the slit length $l_{slit2} = 45\,\text{mm}$. Therefore, it is found that the length of slits largely affects both F/B ratio and half-power beamwidth of the proposed TSA. As a conclusion, it can be said that loading the slits is one of the promising techniques for the design of the directivity of the wideband base station antenna under the size limitation.

From the physical point of view, how two pairs of slits affect the directivity of the TSA is clarified. Fig. 6 and Fig. 7 show the current density distribution of the TSA at 2 GHz. Fig. 6 shows the distribution of the magnitude of the x-component of current density and Fig. 7 shows that of the y-component of current density. It is observed that the x-component of current density on the TSA is partly suppressed by introducing slits while y-component current is partly increased by introducing slits. In general, the x-component of current density on the TSA contributes to radiation in $\pm y$ direction. Therefore, half-power beamwidth of the TSA deteriorates when the x-component of current density on the TSA is large. On the other hand, two pairs of slits at both edges of the TSA perform as two open transmission lines. The length of two pairs of slits determines the resonant frequency of the slits. Because the pair of slits are extended to y-direction, the x-component of current density on the TSA is only suppressed. As a result, half-power beamwidth of the TSA with two pair of slits can be enhanced.

IV. Performance of Designed TSA

Finally, the reflection coefficient and the directivity of the designed TSA is verified. The dimensions of two pairs of the slits and reflectors are optimized. The reflection coefficient of the proposed antenna is shown in Fig. 8. It is found that the bandwidth of the proposed TSA becomes narrow when two pairs of the slits are loaded. However, the S_{11} of the TSA with two pairs of the slits is still less than $-10\,\text{dB}$ over the three frequency bands due to the broadband impedance matching performance based on tapered structure. The directivity of the designed TSA at 1.5 GHz, 2 GHz and 2.4 GHz are shown in Fig. 9. It is found that the designed TSA radiates a sector beam in three frequency bands. Moreover, it can be seen that backward radiation is fully suppressed by loading two pairs of slits to TSA. As a result, the gain of forward or side radiation increases. Half-power beamwidth and F/B ratio at three frequencies are shown in Table III. Designed TSA satisfies desired half-power beamwidth and F/B ratio at all three frequencies. Therefore, it is concluded that the TSA which is suitable for a 6-sector wideband base station can be designed by using reflector and slits without violating the size limitation.

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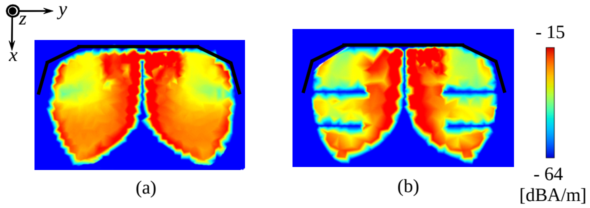

Fig. 6. x-component of the current density distribution at 2 GHz. (a) w/o slits. (b) w/slits.

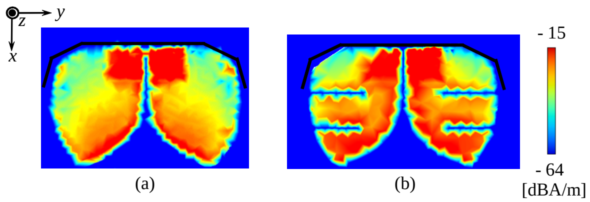

Fig. 7. y-component of the current density distribution at 2 GHz. (a) w/o slits. (b) w/slits.

V. Conclusion

The compact tapered slot antenna at 1.5/2/2.4 GHz bands for 6-sector base station was designed. Both bended reflector and slits were introduced to the TSA to realize a sector beam with high F/B ratio at the three frequencies under the size limitation. The designed TSA showed half-power beamwidth of 60° – 70° and F/B ratio over 20 dB at the three frequency bands.

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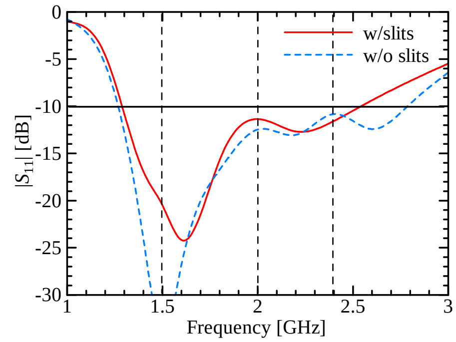

Fig. 8. Reflection coefficient of the proposed antenna.

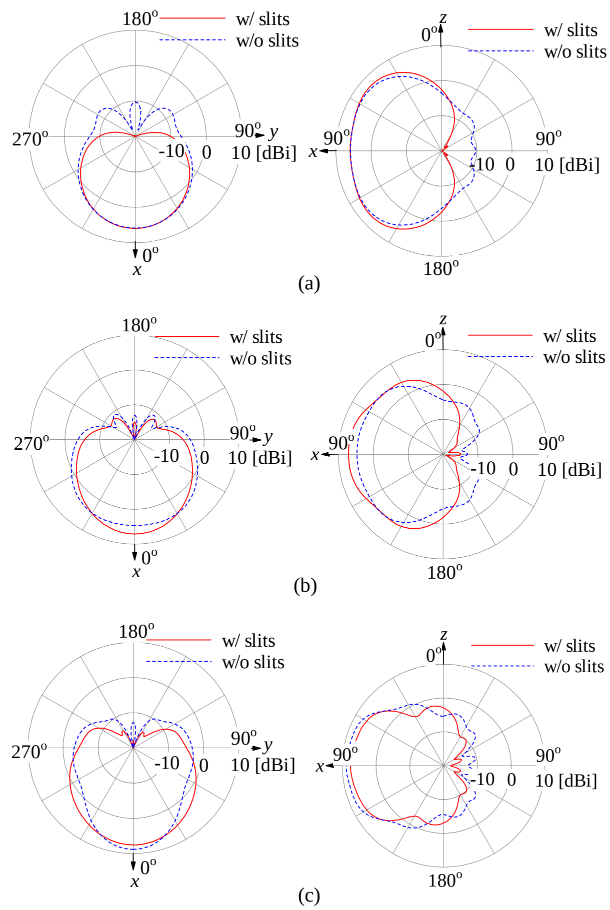

Fig. 9. Directivity patterns in xy plane and xz plane at (a) 1.5 GHz, (b) 2 GHz and (c) 2.4 GHz.

TABLE III
Half-Power Beamwidth and F/B Ratio.

Frequency [GHz]	Half-Power Beamwidth [deg.]		F/B ratio [dB]	
	w/slits	w/o slits	w/slits	w/o slits
1.5	67.9	72.3	26.7	16.2
2	65.0	108.8	22.1	17.5
2.4	70.0	45.6	22.1	19.9

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