Ultra-Wideband Tapered Slot Antenna with a Parallel Plate Waveguide

Satoshi YAMAGUCHI, Hiroaki MIYASHITA, Kazushi NISHIZAWA,
Yoshihiko KONISHI and Shigeru MAKINO
Mitsubishi Electric Corporation
5–1–1 Ofuna, Kamakura, Kanagawa 247-8501, Japan
E-mail:yamag@isl.melco.co.jp

1   Introduction

Tapered Slot Antennas(TSA)[1]-[2] are adequately applicable to wideband phased array antennas due to their ultra wide bandwidths[3]-[5]. Generally the TSA achieves its best performances when the width of the TSA aperture is greater than a half wavelength[6]. Significant degradation of VSWR performance is observed when a smaller aperture is adopted to suppress grating lobes for the phased array. On the other hand, it has been reported that E-plane mutual coupling effects between adjacent elements improve the VSWR performance in an infinite array environment because they can cancel most of the aperture reflection of element[7]. Although the mechanism is interesting, the VSWR performance cannot be improved for the radiating elements near the edge of the array aperture.

To overcome the difficulty, we propose a new tapered slot antenna. This is a Tapered Slot Antenna with a Parallel Plate Waveguide(PPTSA). The PPTSA is capable of providing the ultra-wide bandwidth even when the width of the aperture is less than a half wavelength. We propose a design procedure for the PPTSA through numerical simulations by using the FDTD method. Also, we verify its performances by the experiment.

2   Tapered Slot Antenna with a Parallel Plate Waveguide

Figure 1 shows a configuration of Tapered Slot Antennas with a Parallel Plate Waveguide(PPTSA). Both edges of TSA are shorted by the parallel plates. Fig.2 denotes VSWR performances calculated by the FDTD method for TSAs with/without a parallel plate waveguide. The dimensions of the PPTSA are as follows:

・Distance between parallel plates : D_{pp}=0.1643λ_L,
・Aperture width : W=0.1408λ_L,
・Taper length : L=0.4693λ_L,
・Width of feeding slot line : W_s=0.0023λ_L,
・Permittivity of dielectric substrate for the slot line : ε_r=10,
・Width of parallel plates : W_{pp}=3.52λ_L,
・Length of parallel plates : L_{pp}=1.0325λ_L,

where λ_L is the wavelength of the lowest operating frequency f_L. Fig.2 shows that the antenna impedance matching is hardly achieved without a parallel plate waveguide for wideband frequency because of significant reflections from the aperture. However, a remarkable improvement is observed for the PPTSA. The reasons are considered to be as follows: 1)The reflection current is concentrated on the slot line for the conventional TSA. On the other hand, the current flow spreads on the parallel plates for the PPTSA. Therefore antenna resonance for the PPTSA is weakened and the input impedance becomes close to constant. 2) The effective aperture width of the PPTSA becomes bigger than the conventional TSA and higher radiation efficiency is achieved. Therefore magnitude of the reflection itself becomes smaller.

3   Design of PPTSA

The effect of antenna parameter is studied using the FDTD simulation. The design procedure is shown as follows:

1. Aperture width W

   Let a distance between the parallel plates D_{pp} be less than a half wavelength of the highest operating frequency. Choose the width W of the aperture as wide as possible within the limit of D_{pp}.

2. Permittivity of dielectric substrate ε_r

   Fig.3 shows curves of VSWR of PPTSA with the permittivity ε_r for the slot line as a parameter. The impedance of antenna can be lowered to match the feeding line, e.g. to 50Ω, when relatively high ε_r is adopted.

3. Taper length L

   The effects of taper length L on VSWR are shown in Fig.4. Let the first peak point of VSWR be P1 which corresponds to a half wavelength resonance. Let the second point of resonance be P2. L can vary P1 and P2. Accordingly, L should be adequately chosen to achieve the worst VSWR becomes lowest.

4. Width of feeding point for slot line W_s

   Fig.5 shows the VSWR performances versus the width W_s of the feeding point for the slot line. W_s can vary the characteristic impedance of the slot line and should be adequately chosen to realize the impedance matching.

4 Experiment on PPTSA

We fabricate a prototype of PPTSA and measure its performance. The dimensions of the PPTSA is the same as in the section 2 except for a permittivity of dielectric substrate $\varepsilon_r = 2.6$. An impedance matching circuit using a balan is placed near the feeding point. Fig.6 shows a comparison between calculated and measured VSWR. To guarantee the accuracy of the FDTD calculation within capability of an available computer, the comparison is made up to $4f_L$ here. 5:1 bandwidth is achieved for the PPTSA with the VSWR<3.

Figs.7 and 8 show the radiation patterns in E-plane and H-plane. A dip around -50 degree on the E-plane pattern at f_L is due to an experimental set up. Measured results are almost in good agreement with calculated ones for Figs.7 and 8. Wide beam width is obtained for the E-plane, that is suited for wide angle beam scanning for the phased array. It is expected that wider beam width would be also possible for H-planes when the antenna is arranged as an array where the width of the aperture is limited in the direction of the H-plane.

5 Conclusions

We proposed an ultra-wideband tapered slot antenna with a parallel plate waveguide. The antenna is suited for radiating elements of the phased arrays. The antenna has a good VSWR performance even when very small width of the aperture is adopted. We studied effects of the antenna parameters by using the FDTD method and showed a design procedure. Also, we verified VSWR performance and radiation patterns by the experiment. We confirmed the PPTSA could obtain wide beamwidth.

References

[1] P. J. Gibson, "The Vivaldi aerial," *Proc. 9th Eur. Microwave Conf., Brighton, U.K.,* pp. 101-105, June 1979.

[2] D. H. Schaubert, E. L. Kollberg, T. L. Korzeniowski, T. Thungren, J. F. Johansson, K. S. Yngvesson, "Endfire tapered slot antennas on dielectric substrates," *IEEE Trans. Antennas Propagat.,* vol. 33, pp. 1392-1400, Dec. 1985.

[3] J. Shin, D. H. Schaubert, "A Parameter Study of Stripline-Fed Vivaldi Notch-Antenna Arrays," *IEEE Trans. Antennas Propagat.,* vol. 47, no. 5, pp. 879-886, May 1999.

[4] H. Iizuka, M. Haneishi, "Radiation Properties of Triplate-Type Tapered Slot Antenna and Its Array," *1996 IEEE AP-S Int. Symp. Digest,* vol. 3, pp. 1916-19 1996.

[5] K. Mori, H. Arai, and Y. Ebine, "A 12-sector antenna using proximity coupled taper slot," *1999 IEEE Int. Antennas Propagat. Symp. Dig.* vol. 37, pp. 2412-2415, June 1999.

[6] K. S. Yngvesson, T. L. Korzeniowski, Y. S. Kim, E. L. Kollberg, J. F. Johansson, "The tapered slot antenna – A new integrated element for millimeter-wave applications," *IEEE Trans. Microwave Theory Tech.,* vol. MTT-37, pp. 365-374, Feb. 1984.

[7] M. Kragalott, W. R. Pickles, M. S. Kluskens "Design of a 5:1 Bandwidth Stripline Notch Array from FDTD Analysis," *IEEE Trans. Antennas Propagat.,* vol. 48, no. 11, pp. 1753-1741, Nov. 2000.
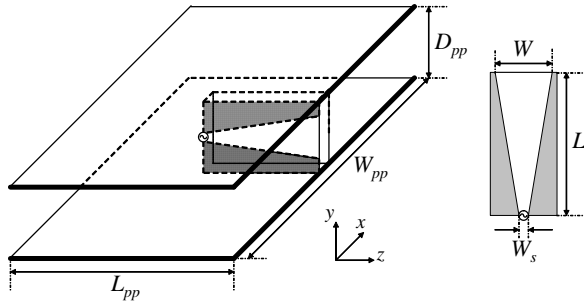
Figure 1: Configuration of PPTSA
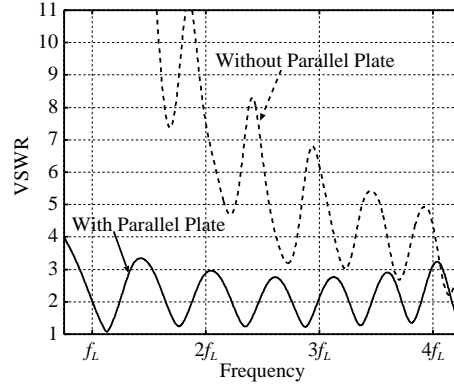
Figure 2: Comparison with/without parallel plate on VSWR
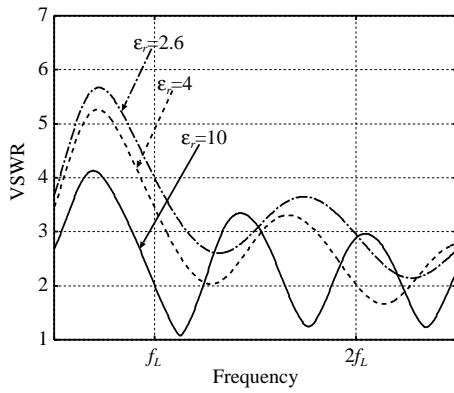
Figure 3: Effect of permitivity of dielectric substrate ε_r on VSWR
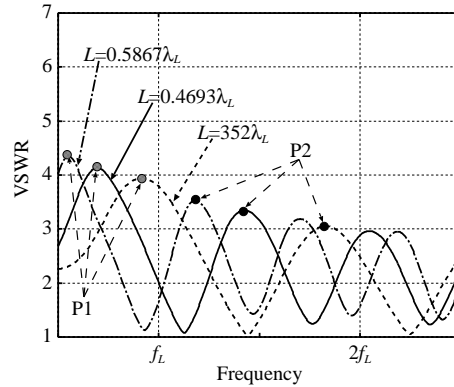
Figure 4: Effect of taper length L on VSWR
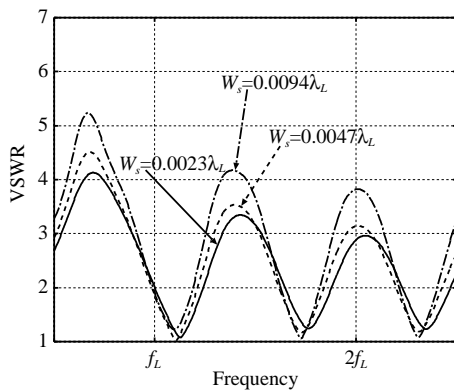
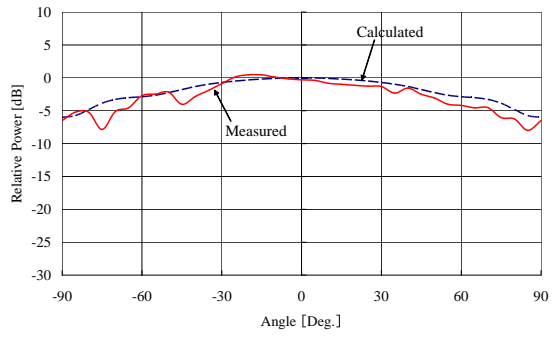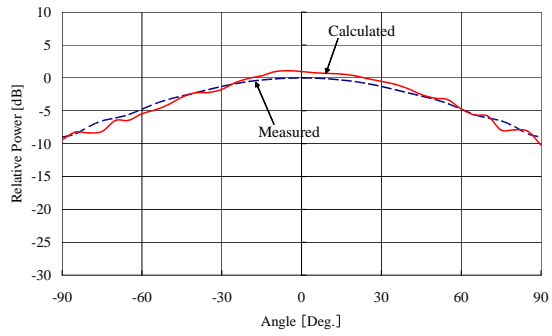Figure 5: Effect of feeding slot line width W_s on VSWR
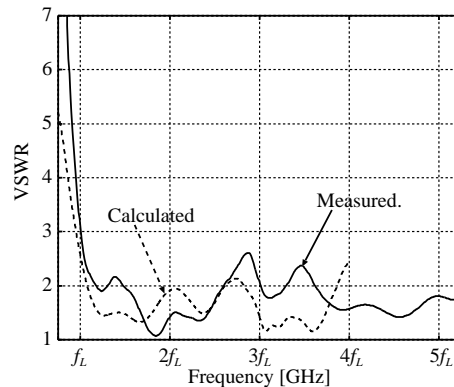
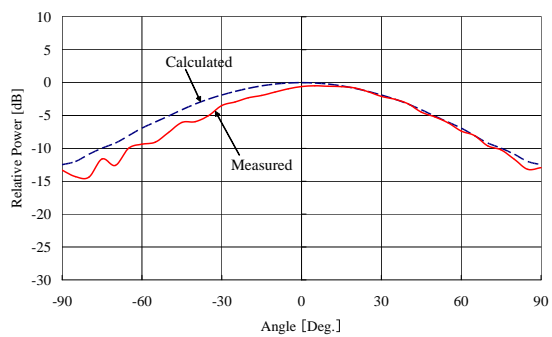Figure 6: Comparison experimental result with numerical result by using the FDTD method

(a)f_L
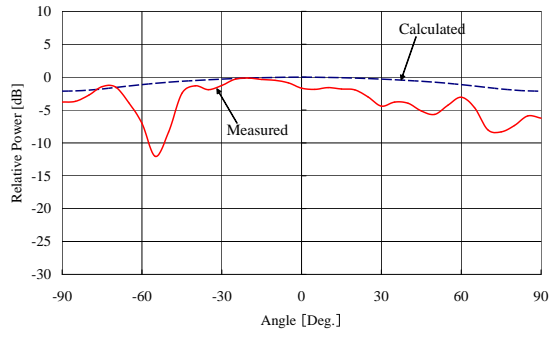
(b)$2f_L$

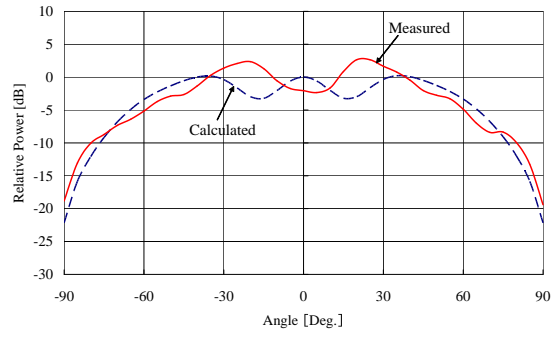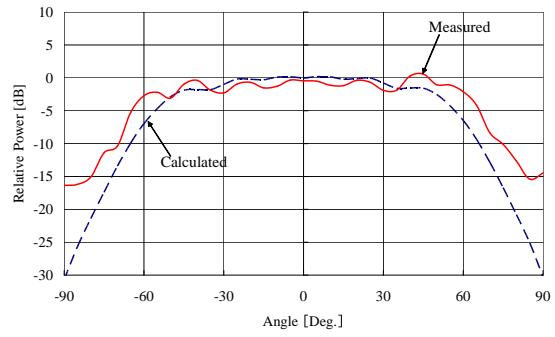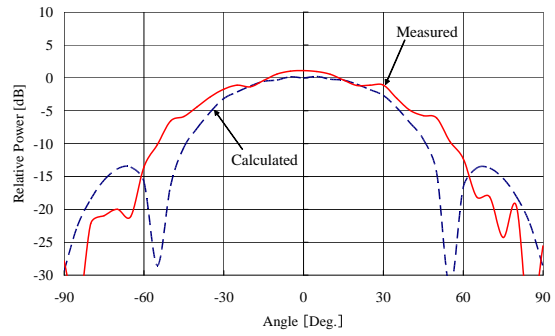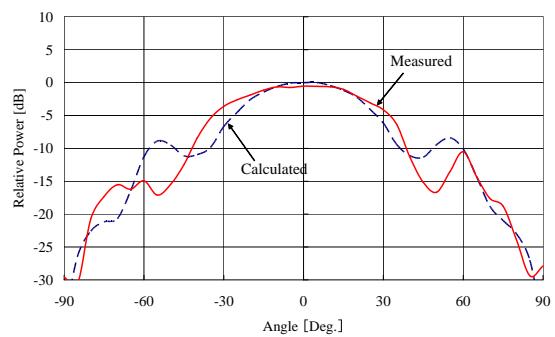(c)$3f_L$

(d)$4f_L$

Figure 7: E-Plane radiation pattern

(a)f_L

(b)$2f_L$

(c)$3f_L$

(d)$4f_L$

Figure 8: H-Plane radiation pattern