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# A Technique for Broadbanding the CPW-Fed Bow-Tie Slot Antenna

Sung-Hak Kim[1] · Lijun Wen[1] · Han-Woong Ko[1] · Dong-Hee Park[2] · Bierng-Chearl Ahn[1]

## Abstract

In this paper, a technique is presented for broadbanding the bow-tie slot antenna fed by a CPW(coplanar waveguide). The bandwidth performance of existing bow-tie slot designs is greatly enhanced by optimizing the slot shape and properly adjusting the characteristic impedance of the coplanar waveguide feeding the slot. To connect the 50-ohm input coaxial line to the CPW feed line, a linear taper in the CPW is employed. The designed antenna shows a 3.5 ~ 10.0 GHz impedance bandwidth, a 3.5 ~ 6.0 GHz pattern bandwidth, and a 5.5 ~ 7.5 dBi gain over 3.5 ~ 6.0 GHz. Above 6.0 GHz, the antenna radiation pattern appreciably deviates from the typical dipolar pattern.

***Key words*** : CPW-Fed Antenna, Bow-Tie Slot, Broadband Antena.

## Ⅰ. Introduction

Broadband applications such as ultrawideband communications, impulse radar, and high-resolution time-domain reflectometry have prompted a great deal of interest in the design of broadband antennas. The slot antenna is one of many antenna types capable of broadband operation. Despite many favorable characteristics, slot antennas pose various difficulties to antenna engineers when it comes to feeding the antenna.

In 1976, Greiser proposed a slot antenna fed by a coplanar waveguide(CPW). The CPW is a transmission medium ideal for feeding bipolar slot antennas since electric fields between conductors in the CPW can be smoothly transformed into those in slot regions. Prompted by the original contribution of Greiser, many researchers investigated slot antennas fed by the CPW[2]~[10]. Liu, Horng and Alexopoulos presented a theoretical analysis for a slot loop and a rectangular slot dipole fed by a CPW[2]. Ding and Jacob investigated a CPW-fed wide rectangular dipolar slot[3]. They employed a capacitive coupling between the CPW and the slot to increase the impedance bandwidth, and metal strips along the slot length to suppress cross-polarized radiations.

The slot antenna of bow-tie shape fed by the CPW has been firstly investigated in 1998 by Huang and Ko [4]. They obtained a 36 % impedance bandwidth(VSWR $<2$) at 2.4 GHz using a bow-tie slot with 20° extended angle. Soliman and co-workers realized a similar performance with a bow-tie slot operating at 15 GHz[5]. Miao, Ooi and Kooi investigated a CPW-fed bow-tie antenna on a high-permittivity substrate($\varepsilon_r$=10.1)[6]. They used metal stubs in the slot region in order to control the impedance matching and the cross-polarized radiation. They obtained a 40 % impedance bandwidth. Zheng, Elsherbeni and Smith investigated a CPW-fed bow-tie slot antenna operating at 10 GHz[7]. Their slot has a 34.6° angle and operates over 9.5 ~ 10.5 GHz.

Zheng and co-workers investigated a bow-tie slot antenna fed by a CPW with tapered transition[8]. They used a tapered transition in the CPW simply for connecting the CPW to the input coaxial line, not for widebanding the antenna. Niu and Zhong studied a sector-shaped bow-tie slot fed by a CPW with a short linear transition at the slot-CPW junction[9]. They obtained a 37 % impedance bandwidth at 6 GHz. Niu and Zhong applied the same concept to a diamond-shaped bow-tie slot and obtained a 40 % impedance bandwidth at 6 GHz[10].

In this paper, we present a different technique for widebanding the bow-tie slot antenna fed by a coplanar waveguide. Our approach to the problem consists of 1) the optimization of the slot shape, 2) a proper choice of the characteristic impedance of the CPW feeding the slot, and 3) a wideband transition between the CPW and the input coaxial line. Using the commercial electromagnetic simulation software(CST MWS®), we designed a bow-tie slot antenna with a 96 % impedance bandwidth (3.5 ~ 10.0 GHz). Measured performances of the fabricated antenna are in good agreement with the simulation, confirming the validity of the proposed technique.

The rest of this paper is organized as follows. Firstly we describe the design of the bow-tie slot integrated with the CPW feed line in Section Ⅱ. In section Ⅲ, we present the design of an optimum CPW-to-coax tran-

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[1]Department of Radio Engineering, Graduate School, Chungbuk National University, Cheongju, Korea.
[2]School of Electrical, Electronics and Information Engineering, Chungju University, Chungju, Korea.

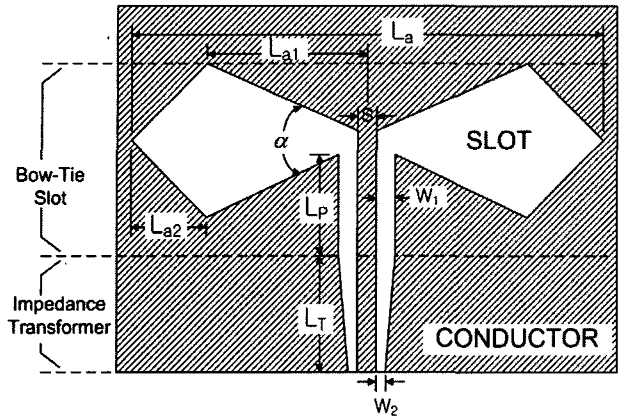


Fig. 1. Structure and design parameters of the CPW-fed bow-tie slot antenna.

sition. In Section Ⅳ, we describe the fabrication and measurements of the designed antenna. Finally in Section Ⅴ we draw conlcusions with suggestions for future work.

## Ⅱ. Design of the Bow-Tie Slot

Fig. 1 shows the antenna structure investigated in this paper. It consists of a bow-tie slot, a coplanar waveguide feeding the slot, and an impedance-matching transition between the coplanar waveguide and the coaxial input. The antenna circuit pattern is realized on a glass-fiber-reinforced Teflon laminate with the back-side conductor removed.

The antenna is designed in following steps. Firstly the shape of the bow-tie slot is optimized for wideband impedance matching with the coplanar waveguide feed line included. Secondly an impedance-matching transition between the coplanar waveguide and the input coaxial line is designed.

The size and shape of the bow-tie slot are primary design parameters determining the bandwidth performance of the antenna. In the initial design stage, the characteristic impedance of the coplanar waveguide is chosen to be 190 ohms based upon the fact that the input impedance of the frequency-independent antenna is about 190 ohms(=377/2 ohms). With a 190-ohm coplanar waveguide feed line in place, the shape of the bow-tie slot is optimized for the widest possible impedance bandwidth. When the optimum result is obtained, the input impedance of the bow-tie slot is calculated and the characteristic impedance of the coplanar waveguide is adjusted for better impedance matching.

The starting point in our design technique is realizing the fact that the input impedance of broadband antennas ranges from 140 ohms to 200 ohms so that the impedance bandwidth of the bow-tie slot is increased when a feed line with a proper characteristic impedance is used. For impedance matching with a 50-ohm input line, one might use a tapered impedance transformer. It is also important to note that the shape of the slot can be optimized for wideband performance.

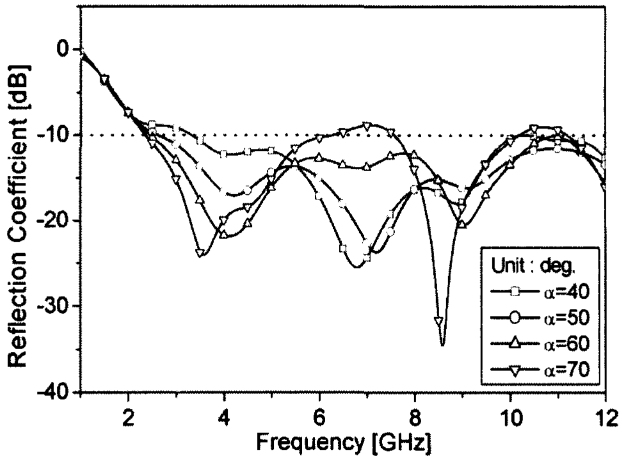


Fig. 2. Reflection coefficient of the bow-tie slot versus the slot angle.

Antenna design parameters are shown in Fig. 1. They are the total slot length($L_a$), the slot extended angle($\alpha$), the slot taper ratio($L_{a1}/L_{a2}$), the gap between slots($S$).

The total slot length is chosen to be approximately a half wavelength at the lowest operating frequency neglecting the effect of dielectric backing. To determine the optimum value of the slot extended angle $\alpha$, we initially let $L_a$, $L_{a1}/L_{a2}$ and $S$ be 7.5 mm, 2:1 and 1.5 mm, respectively. Then we calculate the input reflection coefficient of the antenna with various values of $\alpha$ as shown in Fig. 2. From Fig. 2, we choose the optimum slot angle $\alpha=50°$ for which the reflection coefficient is less than $-10$ dB over 2.5～12.0 GHz.

In order to optimize the slot taper ratio $L_{a1}/L_{a2}$, we calculate the reflection coefficient for various values of $L_{a1}/L_{a2}$ with $\alpha=50°$ as plotted in Fig. 3. With $L_{a1}/L_{a2}$ greater than 1, we obtain a reflection less than $-10$ dB over 3～12 GHz. With $L_{a1}/L_{a2}$ approaching infinity, the slot shape becomes a triangle occupying more space. Considering this fact we have chosen =2.

With the slot shape optimized, we adjust the characteristic impedance of the coplanar waveguide feed line, which is initially chosen to be 190 ohms. We calculated the input impedance of the bow-tie slot and plotted it in Fig. 4.

The real part of the slot impedance ranges from 80 to 180 ohms while the imaginary part ranges from $-50$ ohms to 70 ohms. From this analysis we choose 130 ohms for the characteristic impedance of the CPW

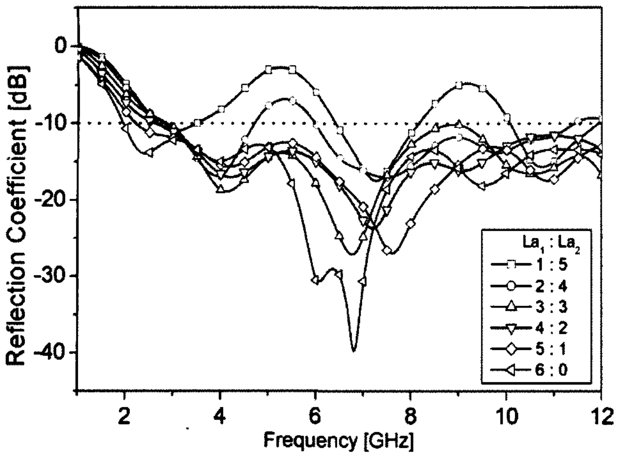


Fig. 3. Reflection coefficient of bow-tie slot for various values of the slot taper ratio.

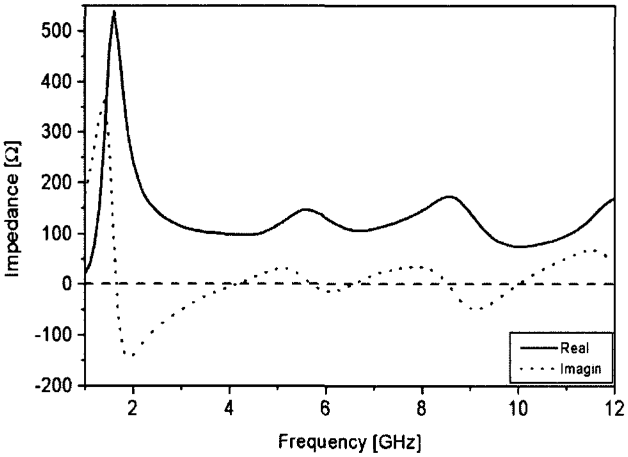


Fig. 4. Input impedance of the bow-tie slot versus frequency.

feeding the slot. The length($L_p$) of the coplanar waveguide feeding the slot is chosen to be 3.7 mm, a minimum value for which the input reflection coefficient is not degraded as $L_p$ is gradually reduced.

## III. Design of a CPW-to-Coaxial Transition

The final step in antenna design is to optimize a tapered transition between the coplanar waveguide and the input coaxial line. The widely-used SMA connector is employed as an antenna input interface. Diameters of inner and outer conductors of the SMA connector are 1.27 mm and 4.1 mm, respectively. A Teflon dielectric fills the space between inner and outer conductors yielding a 50-ohm characteristic impedance.

Firstly we simulated the transition between a uniform coplanar waveguide and the coaxial SMA connector as shown in Fig. 5. The width of the center strip conductor of the CPW is chosen to be 1.6 mm, which is same as that of the CPW feeding the slot.

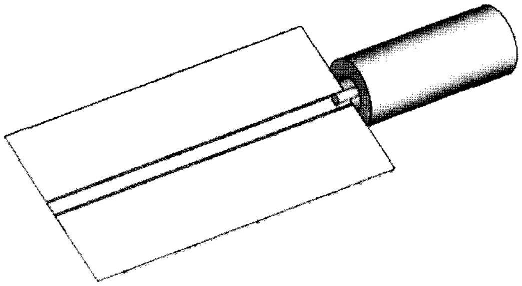


Fig. 5. Transition between a uniform CPW and a coaxial line.

The reflection coefficient is calculated for various values of the gap width between the center strip and the ground conductor of the CPW. The result is shown in Fig. 6. An optimum performance is obtained when the gap width is 0.3 mm. In this case, the characteristic impedance of the CPW is 68 ohms, which is different from 50 ohms. The departure from 50 ohms can be understood by noting that combined effects of the mismatch in characteristic impedances and parasitics at the junction between the CPW and the coaxial line could be minimum for a particular value of the gap width.

Secondly we design a tapered transition between a 68 -ohm CPW and a 180-ohm CPW as shown in Fig. 7, where a simple linear taper of the gap is employed. The 68-ohm CPW is connected to the coaxial line. We calculated the reflection coefficient for various values of the transition length and plotted the result in Fig. 8. As expected, the reflection coefficient is decreased as the transition length is increased. We have chosen 25 mm

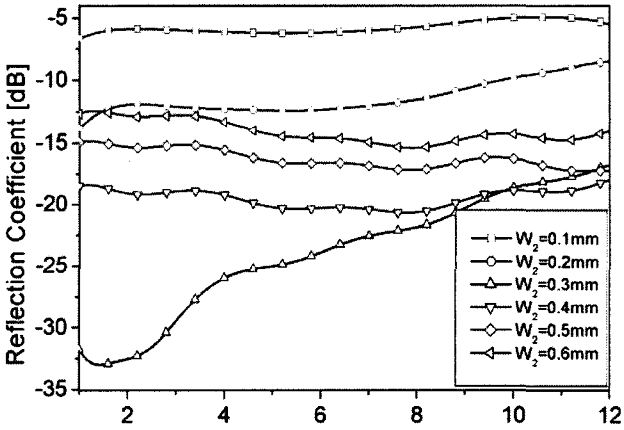


Fig. 6. Reflection coefficient of the transition between a uniform CPW and a coaxial line for various values of gap widths of the CPW.

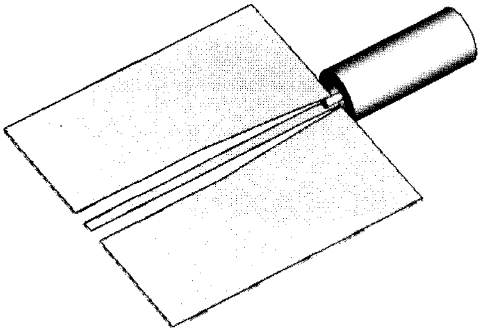


Fig. 7. Linearly-tapered transition between a 68-ohm CPW and a 130-ohm CPW.

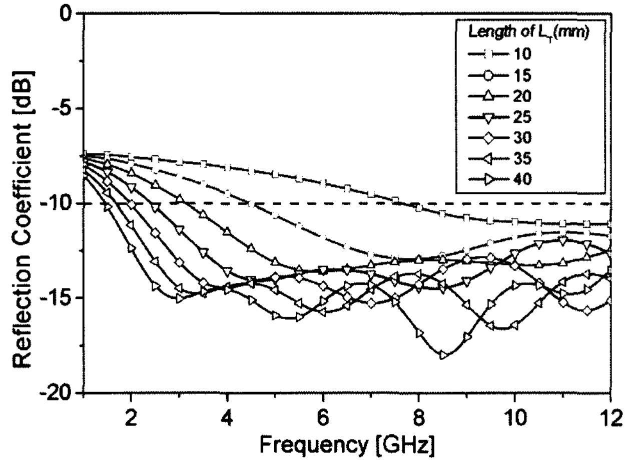


Fig. 8. Reflection coefficient of the 68-ohm to 130-ohm CPW transition for various values of the transition length.

for the final value of the transition length. In this case, the reflection coefficient is less than − 10 dB over 2.5 ~ 12 GHz.

The whole antenna structure including the input SMA connector is simulated using CST MWS®. Results are presented in Section IV where they are compared with measurements.

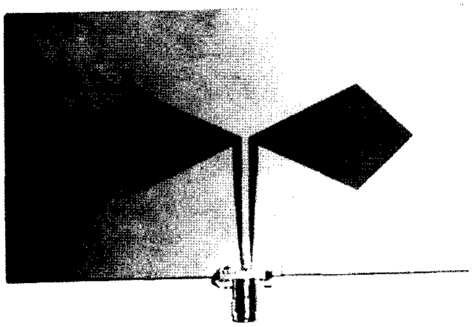


Fig. 9. Fabricated antenna.

## Ⅳ. Antenna Fabrication and Measurements

The designed antenna is fabricated on a Teflon laminate(thickness 0.787 mm, dielectric constant 2.50, loss tangent 0.002 @ 10 GHz). Fig. 9 shows the fabricated antenna. The ground plane size is 102 mm × 60 mm. The SMA connector is connected to the CPW by soldering.

Fig. 10 shows the reflection coefficient of the fabri-

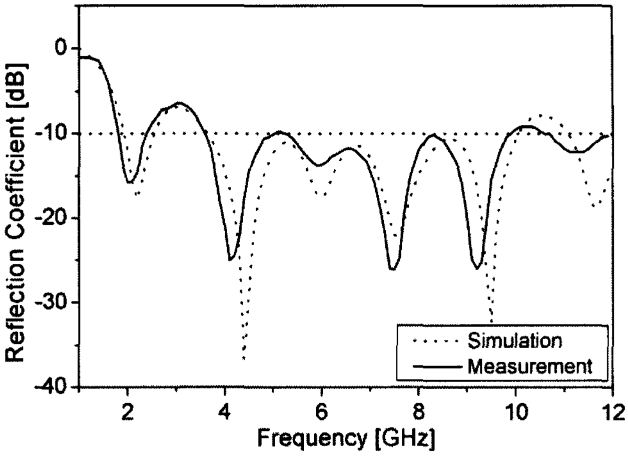
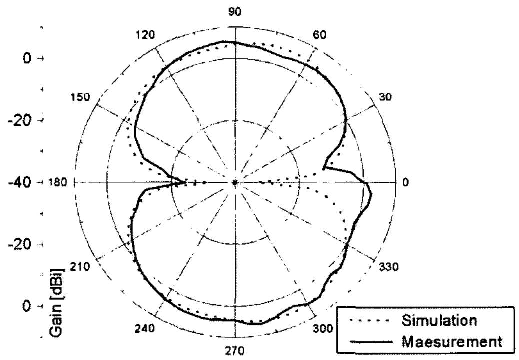
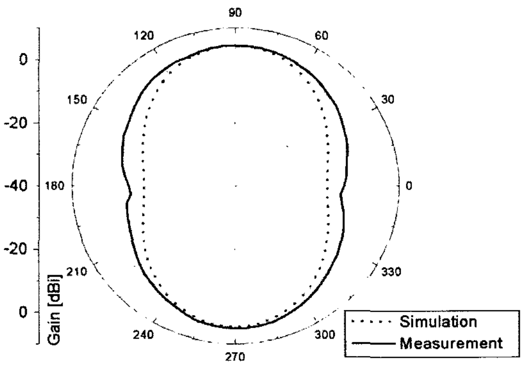


Fig. 10. Measured and simulated reflection coefficients of the fabricated antenna.



(a) E-plane pattern



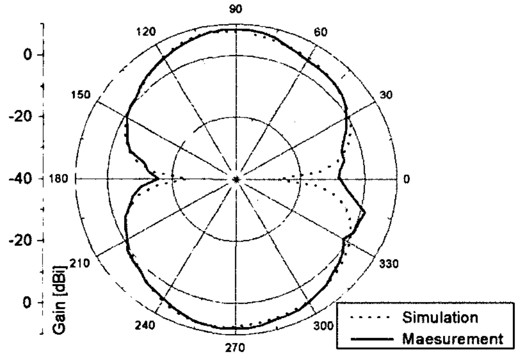
(b) H-plane pattern

Fig. 11. Far-field radiation pattern at 3.5 GHz.

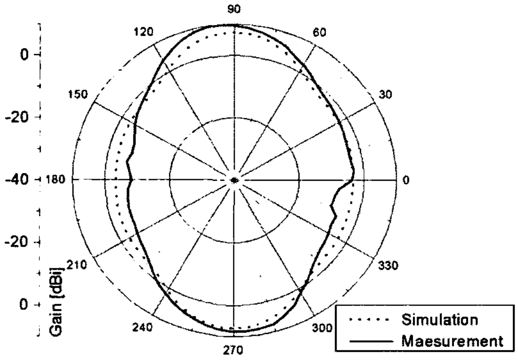
cated antenna over 1~12 GHz. The reflection coefficient of the whole antenna is increased above −10 dB at 3 GHz while those of the bow-tie slot and the CPW-to-coaxial transition are below −10 dB. This is due to a constructive addition of finite values of individual reflection coefficients. The measured reflection coefficient is below −10 dB over 3.5~10.0 GHz. The agreement between measurement and simulation is good.

Figs. 11~13 show measured and simulated far-field radiation patterns. Angles 0° and 180° correspond to a direction along the ground plane, while angles 90° and 270° correspond to a direction normal to the ground plane. The E-plane pattern of the bow-tie slot resembles that of a wire dipole, but has much narrower a beamwidth. Due to limitations in our far-field antenna instrumentation we present radiation patterns only up to 6 GHz.

At frequencies above 8 GHz, simulated radiation patterns contain multiple local maxima and minima, which is due to the fact that the slot length is greater than one wavelength. Also at frequencies above 8 GHz, the global maximum radiation occurs off the antenna normal due to uneven phase distributions across the slot width.

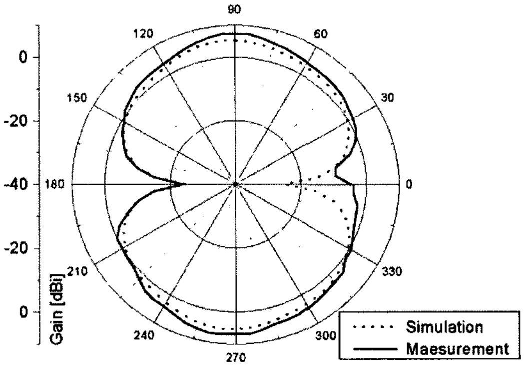


(a) E-plane pattern

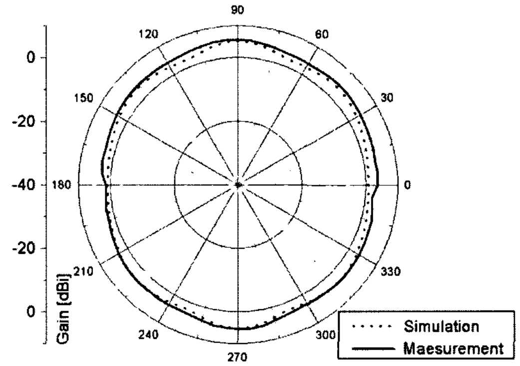


(b) H-plane pattern

Fig. 12. Far-field radiation pattern at 5 GHz.



(a) E-plane pattern



(b) H-plane pattern

Fig. 13. Far-field radiation pattern at 6 GHz.

Fig. 14 shows the measured gain of the antenna over 3.5~6.0 GHz. The antenna gain ranges from 5.5~7.5 dBi with the maximum value of 7.5 dBi occurring at 5.25 GHz. The agreement between simulation and measurement is excellent. Rather high values of the gain can be understood by noting that half-power beam widths in E- and H- planes are much smaller than those of the half-wave dipole antenna.

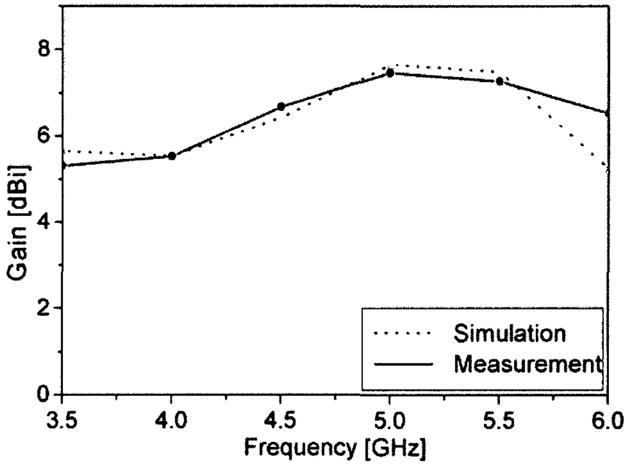


Fig. 14. Antenna gain.

## Ⅴ. Conclusions

A technique for broadbanding a bow-tie slot fed by a coplanar waveguide is presented. The core of our approach is 1) optimization of the slot shape, 2) choice of the coplanar waveguide feed line of optimum characteristic impedance, and 3) a proper design of a transition between the coplanar waveguide and the 50 ohm coaxial input.

The end region of the bow-tie slot is linearly tapered to zero width over the last third of the slot length. The optimum slot angle is found to be 50 degrees. The characteristic impedance of the coplanar waveguide feeding the slot is chosen to be 130 ohms. The input coaxial line is connected to a CPW with 68-ohm characteristic impedance, which is linearly tapered to have 130-ohm characteristic impedance. The length of the overall CPW is kept to a minimum value while maintaining the reflection coefficient less than $-10$ dB over 3.5～10.0 GHz.

The fabricated antenna shows good pattern characteristics over 3.5～6.0 GHz. Beyond 8.0 GHz, the maximum position in the radiation pattern is tilted in the direction opposite to the feed line, and multiple maxima and minima occur in the radiation pattern. The fabricated antenna shows 5.5～7.5 dBi gain over 3.5～6.0 GHz. The broadband bow-tie slot antenna design presented in this paper can be used in many wideband applications currently under intensive developments around the world such as ultra wideband systems and low-power impulse radars. Time-domain performances of the proposed antenna will be treated in our future article.

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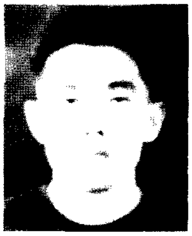
### Sung-Hak Kim

He received the B.E. degree in Electrical & Computer Engineering from Chungbuk University in 2003. He is currently working toward the M.E. degree in Radio Engineering Department, Graduate School, Chungbuk University. His research interests include antennas and EMI/EMC.

### Lijun Wen

He received the B.E. degree in Communications Engineering from Haerbin Industrial University in 1997 and the M.E degree in Radio Engineering from Chungbuk University in 2005. He is currently working toward the Ph.D. degree in Radio Engineering Department, Graduate School, Chungbuk University. His research interests include antenna, RF systems, microwave circuit design.

## Han-Woong Ko



He received B.E. degree in Electrical & Computer Engineering from Chungbuk University in 2003. He is currently working toward the M.E. degree in Radio Engineering Department, Graduate School, Chungbuk University. His research interests inclued antennas and microwave circuits.

## Bierng-Chearl Ahn

He received the B.E. degree in Electrical Engineering from Seoul National University in 1981, the M.E. degree in Electrical Engineering from Korea Advanced Institute of Science and Technology in 1983, and the Ph.D. degree in Electrical Engineering from University of Mississippi in 1992. From 1983 to 1986, he was with Goldstar Precision Company as a research engineer. From 1993 to 1994, he worked for Agency for Defense Development. Since 1995 he has been with Chungbuk University, where he is currently a Professor in the School of Electrical and Computer Engineering. His research interests include applied electromagnetics and antennas.

## Dong-Hee Park

He received the B.E. degree in Electronics Engineering from Cheongju University in 1985, the M.E. and Ph.D. degrees in Electronics Engineering from Chung-Ang University in 1987 and 1992, respectively. Since 1992, he has been with Chungju University, where he is currently a Professor in Electronics & Information Engineering Department. His research interests include antennas, electromagnetic scattering and EMI/EMC.