

# A Hybrid Method to Calculate Far-field Pattern of Bow-Tie Antenna on Extended Hemispherical Dielectric Lens

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**Abstract**—This paper presents a novel hybrid method to simulate complex antenna system, which comprises a planar bow-tie antenna and an extended hemispherical lens. It utilizes Ansoft High-Frequency Structure Simulator (HFSS) to simulate the planar antenna, which is preferred for complicated structure. Ray-tracing is used to illuminate the lens surface with the radiation from the planar antenna (computed via HFSS), and Fresnel transmission coefficients is employed to compute the fields across the boundary between lens and the air. The rebuilt far-field pattern after lens is calculated by integrating the current distribution on lens surface. The comparison between this hybrid method and commercial software, such as HFSS and CST, are made at 100GHz. For higher frequency, which is difficult to simulate using HFSS or CST, the hybrid method shows a potential to predict the far-field pattern by comparing with test results.

**Keywords**—planar antenna; hemispherical lens; millimeter wavelength; hybrid method.

## I. INTRODUCTION

At millimeter and THz wavelength, the planar antenna mounted on dielectric lens is well used to couple the radiation from free space to detection sensor [1-3]. It has the advantages of high gain and broadband performance by using self-complementary broadband planar antennas [4]. High dielectric constant lenses are preferred to use as a focused components to provide high gain. Therefore, in millimeter range, the electrical dimension of lenses is far-larger than the operating wavelength. This provides a challenge for simulation of the planar antenna mounted of dielectric lens. In order to calculate the complex antenna system, several different methods are used. A double-slot antennas on silicon lenses are calculated by using ray-tracing and physics optics over 200GHz [5]. Moment of method is applied to calculate the planar antennas at sub-millimeter range [6]. In this paper, we presented a simpler way to calculate the bow-tie antenna mounted on extended hemispherical silicon lens. It utilizes HFSS to simulate the radiation of bow-tie antenna in the silicon medium which is used as a source for calculating the electromagnetic field distribution by Ray-tracing. Far-field pattern of the whole antenna system can be achieved by integrating the current distribution outside the lens surface. In the following, we will describe the hybrid method and the evaluation by comparing commercial software and tests results.

## II. HYBRID METHOD

### A. Bow-tie antennas mounted on extended hemispherical silicon lenses

Bow-tie antenna is designed as a dipole antenna according to the operating frequency. The length of the arm should be closed to a quarter half wavelength to resonant, the width of the arm is optimized according to the expected impedance. The extended hemispherical silicon lens, dielectric constant:  $n \approx 11.7$ , is using to couple the radiation from free space to bow-tie antenna. It has an extended length  $L$ , with a radius of  $R$ . The structure of the bow-tie antenna mounted on extended hemispherical silicon lens is shown in Figure 1. This kind of antenna was borrowed into millimeter wave field from optics and it was found that it could effectively increase the gain of the planar antenna by  $n$ . For silicon lens, it can provide an increasing gain of about 10 dB.

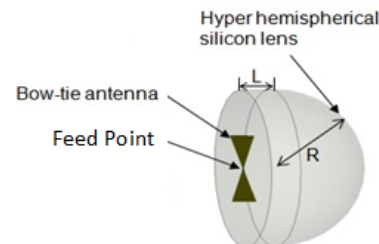


Figure 1. The structure of the bow-tie antenna mounted on extended hemispherical silicon lens

### B. Hybrid method

At millimeter wavelength, taking into account of the silicon medium wavelength, the bow-tie antenna is very small comparing with the diameter of the lens. The radiation of the bow-tie in the silicon medium could approximately works as a source to illuminate the lens surface. This step is done by using Ansoft High-Frequency Structure Simulator (HFSS).

After achieving the radiation pattern of the bow-tie antenna, ray-tracing technique is used to illuminate the inside surface of the silicon lens [7]. In order to calculate the electromagnetic field outside the lens surface, Fresnel diffraction is used to calculate the transmission coefficient of the silicon / air interface, as shown in Figure 2.

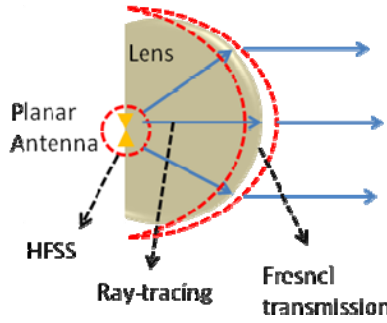


Figure 2. The hybrid method using ray-tracing and field-integration technique.

For a given ray, the field can be divided into parallel and perpendicular components at the interface. The corresponding transmission formulas are displayed for each mode [8]:

$$R_{\parallel} = \frac{n\sqrt{1 - n^2 \sin^2 \theta_t} - \cos \theta_t}{n\sqrt{1 - n^2 \sin^2 \theta_t} + \cos \theta_t} \quad (1)$$

$$T_{\parallel} = (1 + R_{\parallel}) \frac{\cos \theta_t}{\sqrt{1 - n^2 \sin^2 \theta_t}} \quad (2)$$

$$R_{\perp} = \frac{n \cos \theta_t - \sqrt{1 - n^2 \sin^2 \theta_t}}{n \cos \theta_t + \sqrt{1 - n^2 \sin^2 \theta_t}} \quad (3)$$

$$T_{\perp} = 1 + R_{\perp} \quad (4)$$

where  $n$  is the dielectric constant,  $\theta_t$  is the incident angle from normal to the spherical lens.  $T$  and  $R$  are the transmission coefficient and reflection coefficient. ( $\parallel$ ) and ( $\perp$ ) denote the parallel and perpendicular components. Once the electric and magnetic fields are found outside the lens surface, the equivalent electric and magnetic current densities can be calculated using [8]:

$$J_s = \hat{n} \times H \quad (5)$$

$$M_s = \hat{n} \times E \quad (6)$$

where  $\hat{n}$  is the normal to the interface. The far-field pattern of the bow-tie antenna mounted on silicon lens can be achieved by integration of the equivalent electric and magnetic current.

### III. COMPARISON WITH COMMERCIAL SOFTWARE AND TESTS RESULTS

#### A. Comparison with HFSS and CST

In order to evaluate the hybrid method, a bow-tie antenna mounted on extended hemispherical silicon lens is calculated. The bow-tie antenna has an arm length of 0.4mm and arm width of 0.3mm. The diameter of the silicon lens is 12mm, and extended length is 1.5mm. Far-field pattern of the bow-tie based on silicon lens is calculated by using hybrid method,

HFSS, and CST at 100GHz. Both E-plane ( $\phi=0^\circ$ ) and H-plane ( $\phi=90^\circ$ ) far-field is shown in figure 3 and figure 4. Since the structure of the bow-tie and silicon lens is symmetrical, only half of the plane is displayed with theta angle from  $0^\circ$  to  $90^\circ$ .

From the comparison of the simulated results, we can see it is difficult to achieve a unified far-field between different methods at such high frequency. However, the trend of the pattern is similar. The simulated results by using the proposed method are more closed to CST results on the main lobe, and have a same trend on the side lobe.

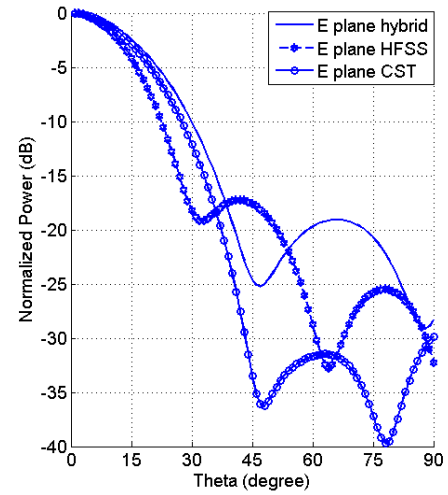


Figure 3. Far-field of E\_plane using different methods..

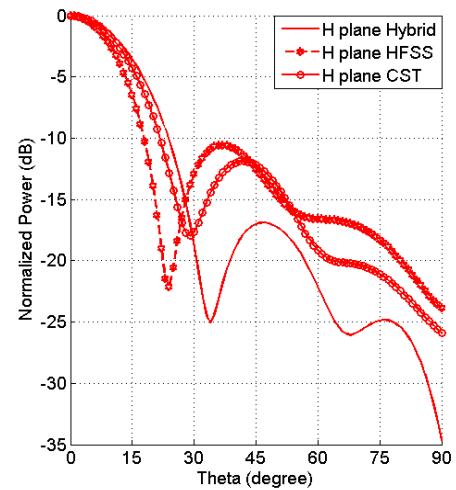


Figure 4. Far-field of H\_plane using different methods.

#### B. Comparison with tests results

In order to evaluate the hybrid method on higher frequency, which is difficult to simulate by using neither CST nor HFSS, a detector array using bow-tie antenna mounted on extended hemispherical silicon lens was made and tested on 300GHz [9]. It utilized 8 bow-tie elements array fabricated on 0.15mm thick quartz substrate. The

antenna array with quartz substrate is attached at the focal plane of the silicon lens. Schottky diodes are soldered at the feed point of the bow-tie antennas to detect millimeter wave or THz signal. The central element of the detector array is measured and compared with the simulation using hybrid method, which is shown in figure 5. As we can see, the measured results agreed with simulation on main lobe. The disagreement at the shoulder of main lobe is caused by the measurements errors. For side lobe, it is difficult to predict correctly considering the approximation of Ray-tracing.

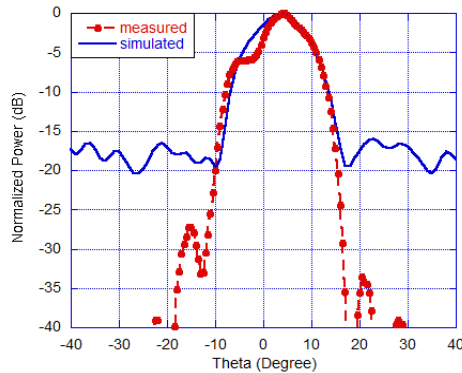


Figure 5. Far-field of detector and simulation using hybrid method

#### IV. CONCLUSION

This paper presented a hybrid method to simulate bow-tie antenna mounted on extended hemispherical silicon lens. It utilizes HFSS to simulate the bow-tie antenna, and Ray-tracing to illuminate the lens surface with the radiation from the bow-tie antenna (computed via HFSS), and compute the fields across the boundary between lens and the air using Fresnel diffraction. The rebuilt far-field pattern after lens is calculated by integrating the current distribution on lens surface. It is important to note that this method is not limited

to bow-tie antennas and is applicable to any planar antennas, such as spiral / log-periodic antennas. The comparison with different commercial software and real tests shown that the hybrid method can provide good prediction on the main lobe at 300GHz. More work will be done to improve the accuracy on the side lobe at high frequencies.

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