Design of a Ring Probe-Fed Metallic Cavity Antenna for Satellite Applications

Kunpeng Wei, Zhijun Zhang, Yang Zhao, and Zhenghe Feng

***Abstract*—This communication presents the design of a novel ring probe-fed metallic cavity antenna with circular polarization for satellite applications. The motivation for this work is to propose a novel design that has the advantage of electrically large size and improved 3-dB axial-ratio bandwidth in the Ku-band and other higher-frequency bands as well as low cost and easy fabrication. The resonant mode and circular polarization of the proposed antenna is excited by a ring probe. To verify the design concept, a brass C-band antenna prototype of the proposed antenna is fabricated and measured. The measured impedance bandwidth for $|S_{11}| \leq -10$ dB and 3-dB axial-ratio bandwidth are 1.08 GHz (6.94 GHz to 8.02 GHz) and 0.80 GHz (7.11 GHz to 7.91 GHz), respectively. The 3-dB axial-ratio bandwidth of the antenna is 10.7%. The measured gain is about 8.3 dBic across the whole 3-dB axial-ratio bandwidth. Very good consistency between the measurement and simulation for the return loss and radiation patterns is achieved.**

***Index Terms*—Circularly polarized antenna, electrically large, ring probe-fed, satellite application, strong power-handling capability.**

I. Introduction

Because circularly polarized (CP) antennas are known for their capabilities of reducing polarization mismatch [1], [2] and moderately suppressing multi-path interferences [3], [4], they are commonly used in wireless communication systems such as radar and satellite systems. Circular polarization can provide better mobility and weather penetration than linear polarization [5]. Various CP antennas such as microstrip patch antenna [6], slot antenna [7], spiral antenna [8], and dielectric resonator antenna [9] have been developed as the typical types of CP antennas. The operating principle of these CP antennas is to excite two orthogonal filed components with equal amplitude but in-phase quadrature. Nowadays, the need for high-frequency band CP antenna designs is becoming increasingly more urgent because satellite communications are being developed from low-frequency bands such as the L-band and the S-band to high-frequency bands such as the Ku-band and the Ka-band to obtain broader bandwidths, higher data rates, and higher gains with the same radiating aperture. The performance of these CP antennas will deteriorate severely due to manufacturing deviation when scaled to high-frequency bands such as the Ku-band in which the wavelengths are only of a few millimeters. Moreover, their power-handling capability is limited.

With the advantage of unidirectional radiation characteristic, cavity-backed antennas have been considered as one of the widely used CP antennas for satellite applications. There are many air-filled metallic cavity-backed antennas [10], [11] or substrate-integrated cavity-backed antennas [12] proposed to achieve bandwidth enhancement and high-gain performances. However, because the cavities only serve as reflectors in cavity-backed CP antennas, separate circularly polarized radiators have to be developed for cavity-backed circularly polarized antennas. Open-ended waveguide antennas with linear polarization [13]–[15] are conventionally used to realize electrically large size antenna and strong power-handling capability. Three of the present authors recently proposed an electrically large metallic cavity antenna with circular polarization for satellite applications by introducing an inserted perturbation screw [16]. However, it suffers some problems such as narrow 3-dB axial-ratio bandwidths (4.7%) and complex perturbation mechanism. A novel ring-fed cylindrical metallic cavity antenna (MCA) with circular polarization is presented in this communication. Circularly polarized waves are excited by a ring probe without any additional perturbation mechanism. The 3-dB axial-ratio bandwidth of the proposed antenna has been improved to 10.7%. The dimensions of the presented cylindrical MCAs are generally larger than half a wavelength in the center operating frequency, which is easy to fabricate and low in cost for high-frequency satellite applications. Details of the considerations of the proposed designs and the experimental results of the prototype developed are presented and discussed.

II. Antenna Design

The basic geometry of the proposed antenna is shown in Fig. 1. As shown in Fig. 1(a), the antenna consists of an air-filled cylindrical cavity, a ring probe, and a thickened ring surrounding the outer wall of the cavity. Fig. 1(b) and (c) gives the top view and a sectional view, respectively. The thickened ring surrounding the outer wall of the cavity is used to fix the SMA connector. It is only an option of many ways to mount the SMA connector and not an intrinsic part of the design. The dielectric employed in the coaxial feed line is a small piece of Teflon with a relative permittivity ε_r of 2.2. The upper port of the cylindrical cavity is open, while the lower port is kept closed so as to radiate energy unidirectionally. The ring probe is used to excite the basic operating mode of the cavity and realize the circular polarizations. It is shown theoretically [17], [18] that by introducing a gap at the end of the probe, a traveling-wave current distribution on the probe. Because the perimeter of the ring probe is nearly a wavelength, the current phase on the y-axis part is behind that of the x-axis part by 90°. Therefore, a 90° phase difference between the polarization of E_x and E_y is achieved which can eventually generate the circularly polarized wave in the cavity without any additional perturbation mechanism.

The rotating direction of the circularly polarized waves is determined by the rotating direction of the probe as indicated in Fig. 1(b). As seen looking from the front of the cavity, right-hand circular polarized waves are realized when the ring probe rotates in the anti-clockwise direction, and left-hand circular polarized waves are obtained when the ring probe rotates in the clockwise direction. The basic operating mode is determined by the dimensions of the cylindrical cavity. The vertical height *H-FedHgt* and the diameter *D-FedProbe* of the ring probe determine the resonant frequency and the impedance matching of the designed antenna. The circularly polarized frequency and purity are mostly influenced by the parameter *angle* of the ring probe.

A metallic C-band prototype with right-hand circular polarization was designed to prove our design concept. It is designed and simulated using Ansoft HFSS full-wave simulator. The dimensions of the proposed antenna are finally optimized as shown in Table I. The size of the radiating aperture is 30 mm $(0.75\lambda_0) \times 30$ mm $(0.75\lambda_0)$ in the horizontal plane, and the overall height is 35 mm $(0.88\lambda_0)$, where λ_0

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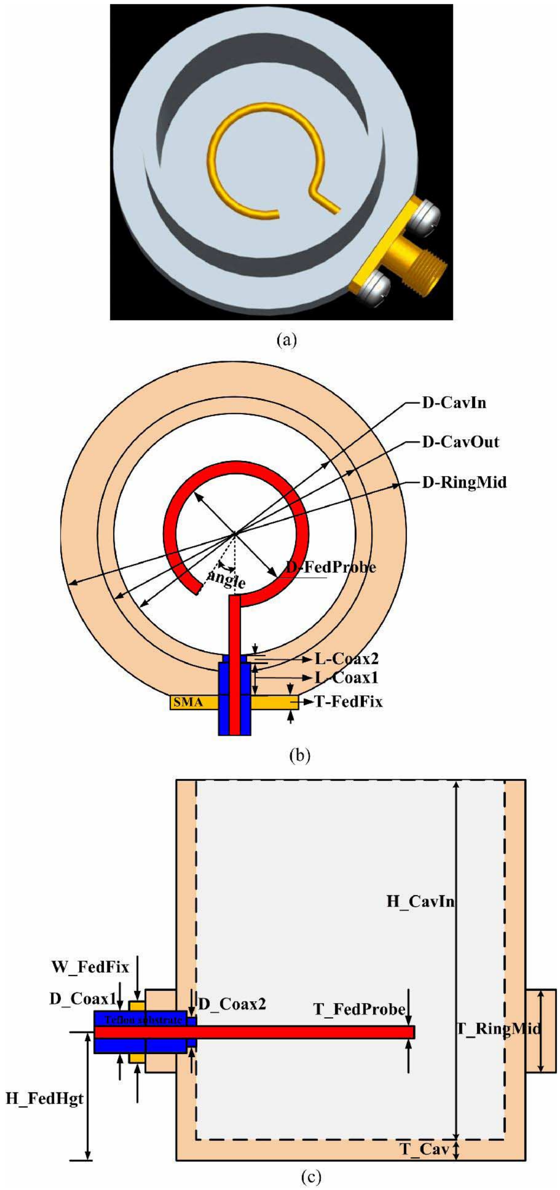

Fig. 1. Geometry of the proposed antenna: (a) 3D view; (b) top view; (c) sectional view.

TABLE I
DIMENSIONS OF THE PROPOSED C-BAND MCA

Parameter	*D-CavOut*	*D-CavIn*	*D-RingMid*	*D-Coax1*
Value(mm)	34.0	30.0	43.0	4.1
Parameter	*D-Coax2*	*H-FedHgt*	*H-CavIn*	*angle*
Value(mm)	3.0	10.0	35.0	40°
Parameter	*D-FedProbe*	*L-Coax1*	*L-Coax2*	*T-FedProbe*
Value(mm)	7.3	4.0	1.0	1.27
Parameter	*T-RingMid*	*T-FedFix*	*T-Cav*	*W-FedFix*
Value(mm)	8.0	1.6	2.0	6.0

is the wavelength at the center frequency 7.5 GHz. The dimensions of the proposed antenna are electrically larger than those of traditional antennas, which can reduce the stringent requirement for machining precision and alleviate the severe performance degradation caused by processing deviation.

The effect of the key-geometrical parameters on the performance of the antenna has been studied. The other parameters were kept unchanged as the values in Table I when the influence of a particular parameter was investigated. The simulation software HFSS has been used in the study. Fig. 2 shows the reflection coefficient S_{11} for the different vertical heights *H-FedHgt* of the probe. As shown in Fig. 2, the impedance matching and optimum bandwidth of the proposed antenna are mainly determined by the parameter *H-FedHgt*. Fig. 3 shows the reflection coefficient S_{11} of the antenna for different diameters *D-FedProbe* of the probe. It is observed that the resonant frequency can be accurately tuned by the diameter *D-FedProbe* of the probe. As mentioned above, circular polarization is realized by the traveling wave of the probe. Therefore, the circularly polarized frequency and purity are mostly influenced by the rotating angle of the ring probe. As shown in Fig. 4, the parameter *angle* of the probe can be tuned to obtain an optimum axial ratio after the impedance matching is achieved. The optimum axial ratio can be achieved which is about 0.32 dB at the center frequency 7.5 GHz when the parameter *angle* of the ring probe is 40°.

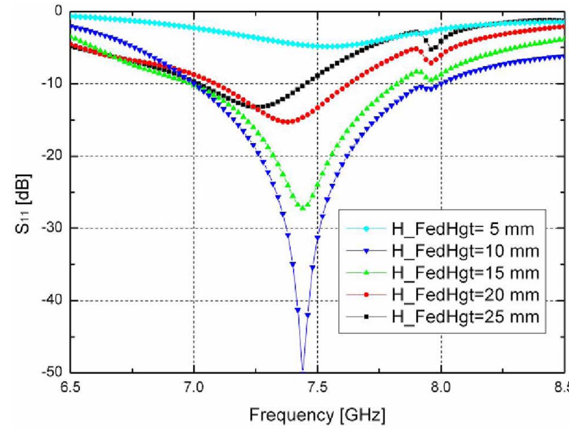

Fig. 2. Simulated reflection coefficient S_{11} for different vertical heights *H_FedHgt* of the ring probe.

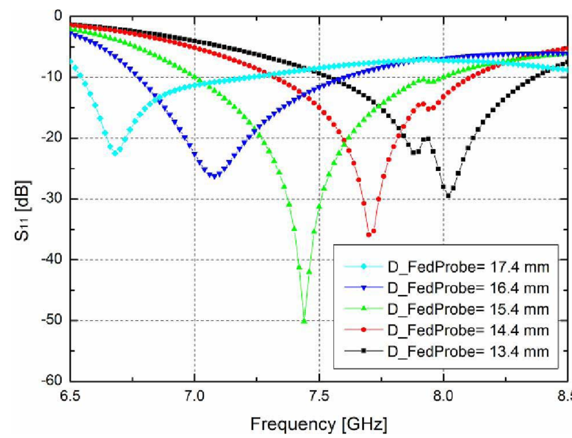

Fig. 3. Simulated reflection coefficient S_{11} for different diameters *D_FedProbe* of the ring probe.

III. MEASUREMENT RESULTS

According to the parameters given in Table I, a prototype of the proposed antenna was fabricated and measured. Fig. 5 shows a photograph of the fabricated C-band prototype. The measured and simulated reflection coefficient S_{11} of the constructed prototype are presented in Fig. 6. The data agrees with the simulated results in general. The measured impedance bandwidth ($S_{11} < -10$ dB) is 1.08

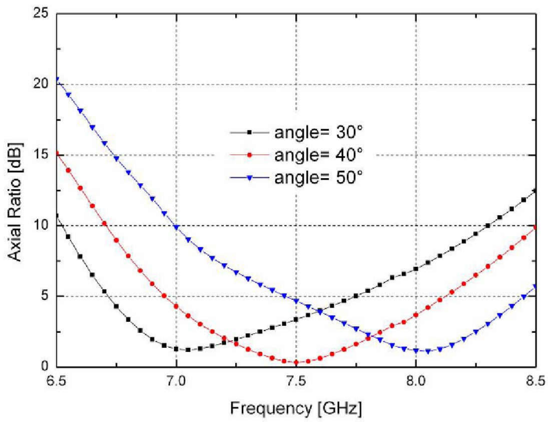

Fig. 4. Simulated axial ratio for different rotating angle of the ring probe.

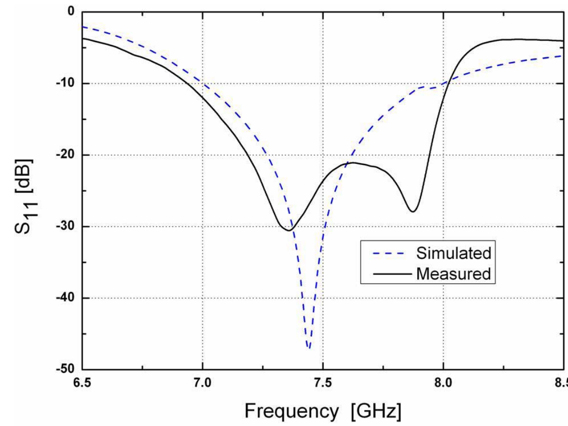

Fig. 6. Measured and simulated S_{11} of the proposed antenna.

Fig. 5. Photograph of the fabricated C-band prototype.

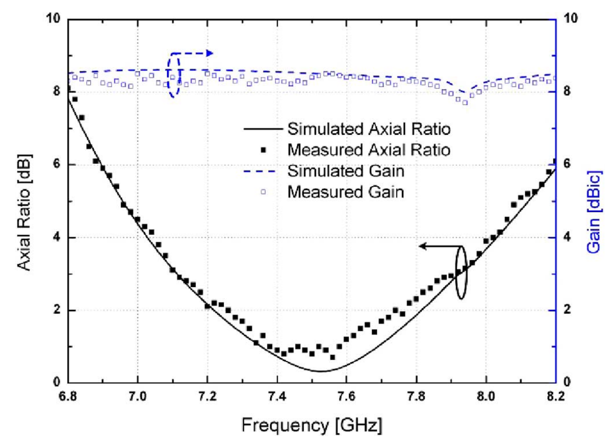

Fig. 7. Measured and simulated axial ratio and gain at the broadside.

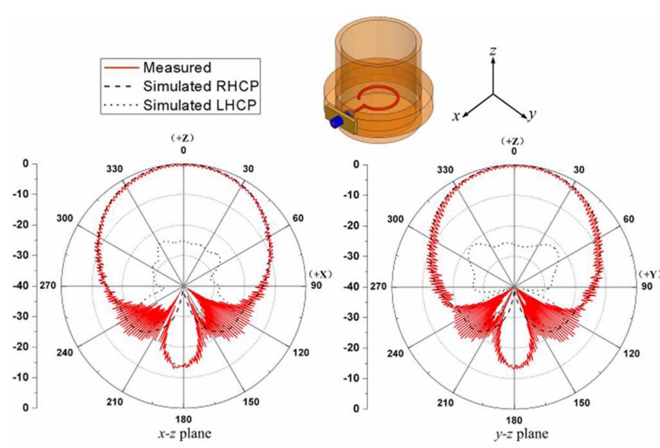

Fig. 8. Measured and simulated radiation patterns of the antenna at 7.5 GHz. (a) x-z plane and (b) y-z plane.

GHz (6.94 GHz to 8.02 GHz). The measured simulated axial ratios at the broadside are shown in Fig. 7. It indicates that the measured and the simulated 3-dB axial-ratio bandwidths are 0.80 GHz (7.11 GHz to 7.91 GHz) and 0.81 GHz (7.12 GHz to 7.93 GHz), respectively, which shows good agreement. Compared to the previous work by a perturbation mechanism [16], the 3-dB axial-ratio bandwidth of the antenna has been improved to 10.7%. The measured and the simulated gains at the broadside are also compared in Fig. 7. The measured gain varies from 7.9 dBic to 8.5 dBic across the 3-dB axial ratio bandwidth. The efficiency is defined as the ratio of radiated power versus the total available power from the power source. Thus the efficiency value includes all impacts from mismatch loss, dielectric loss, and conductor loss. The efficiency of the antenna varies from 88% to 95% within the operating band.

The radiation characteristics of the fabricated prototype were also studied. The simulated CP radiation patterns are shown in Fig. 8. The antenna excites right-hand circular polarized (RHCP) waves, and the cross polarization is left-hand circular polarization (LHCP). It is observed that the radiation patterns in the two principal planes show similar symmetrical characteristics. Fig. 8 also shows the measured radiation patterns of the proposed antenna in both x-z and y-z planes at 7.5 GHz with a spinning horn as the transmitting antenna. The peak and null of the zigzag curve in measured radiation pattern are the maximum and minimum record, respectively, when the spinning horn is rotated a circle. The magnitude of the ripple of the zigzag curve represents the purity of circular polarization. It is clear that a good right-handed CP radiation is observed. In practice, >0 dBi gain beamwidth is frequently used as the specification for low earth orbit (LEO) satellite applications. The measured >0 dBi gain beamwidths at the central frequency of 7.5 GHz are 126° and 122° in the x-z and y-z planes, respectively. The measured 3-dB axial-ratio beamwidths at the central frequency of 7.5 GHz are 180° and 142° in the x-z and the y-z planes, respectively. Therefore, the 3-dB axial-ratio beamwidth is wide enough to cover the >0 dBi gain beamwidth for practical engineering applications.

IV. Conclusion

The design of a novel ring probe-fed metallic cavity antenna with circular polarization for satellite applications was described in this communication. The proposed design has the advantages of electrically large size and strong power-handling capability. Circularly polarized waves are excited by a ring probe without any additional perturbation mechanism. A C-band prototype with right-hand circular polarization has been designed and fabricated to validate the design concept. The dimensions of the proposed antenna are generally larger than half a wavelength in the center operating frequency, which can reduce the stringent requirement for machining precision and alleviate the severe performance degradation caused by processing deviation. The 3-dB axial-ratio bandwidth of the antenna has been improved to 10.7% compared with the 4.7% bandwidth of the author's earlier design. The experimental results show that this design is ideally practical for satellite applications.

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A Wideband Bond-Wire Antenna for Millimeter Wave Intra-Communication Systems

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***Abstract*—A compact and wideband millimeter wave bond-wire antenna (BWA) is proposed for consumer product intra-communications. The antenna consists of two 0.8 mm long wires in front of the ground plane. Its impedance bandwidth is 29 GHz (37 GHz to 66 GHz). It has 2 dBi average gain. After introducing the bandwidth widening solution to a wire antenna, the new BWA structure is presented. The antenna parameters including the impedance bandwidth, the radiation pattern and the gain versus frequency were simulated and compared with measured results. The proposed BWA was implemented in a CMOS integrated circuit (IC) millimeter communication system. 11 Gb/s wireless data transmission was achieved by using a part of the bandwidth of the proposed BWA.**

***Index Terms*—Bond-wire, bond-wire antenna (BWA), millimeter wave communications, monopole antenna, package antenna and wideband antenna.**

I. Introduction

It has been predicted that the desired data rate for short-range wireless communications will increase to 10–100 Gb/s in the very near future [1]. To achieve the super high speed with a reasonable modulation complexity, high carrier frequencies such as millimeter wave (30 GHz to 300 GHz) and terahertz (300 GHz to 3 THz) are preferred. In such high frequency wireless systems, the highly efficient wideband antenna is one of the critical issues.

This communication focuses on the antenna design for a CMOS IC based millimeter wave transceiver. Because of the low resistivity and the high permittivity of the silicon substrate of the IC, a typical on-chip antenna has low radiation efficiency [2], [3] although it has the merit of combining with IC process. On the other hand, for an external antenna, since the antenna size in this frequency range is small, some acceptable fabrication errors for low radio frequency designs could result in

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