Design of Sector Antenna with Wideband 2D Hat-fed Reflector for Wireless Communications

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***Abstract*—We present the design of a new sector reflector antenna with 2-dimensional hat feed in order to avoid the radio link disconnection in point-to-point link communication systems due to the swinging of link antennas when there is a strong wind or vibration. The antenna has a 32% bandwidth for both the reflection coefficient below -17.8dB and the sidelobes of the radiation pattern in vertical plane below ETSI Class 3 envelope, based on the simulated results.**

***Keywords*—2D hat feed; sector reflector; point-to-point communication;**

I. INTRODUCTION

Reflector antennas with hat feed have been suggested and applied for wireless radio link systems for many years due to their very low far-out sidelobes, low cross-polar level and compact geometry [1],[2]. The analytical theory of the hat feed was presented in [1]. The return loss of the first practically usable hat feed was better than 15 dB over 6% bandwidth as reported in [3]. Then, the bandwidth of hat feeds was improved further by many developments, such as 15% 15dB-return-loss bandwidth by matching the feed with two irises using a mode matching method [4], 10% 20dB-return-loss bandwidth with numerical optimization in [5] by using the V2D code [6], 18% 15dB-return-loss bandwidth by employing the Chinese hat feed [7], 33% 17.7dB-return-loss bandwidth by genetic algorithm optimization [8], 26% both 15dB-return-loss bandwidth and ETSI Class-2 radiation pattern bandwidth without using dielectrics for low cost [9], and 30% both 17dB-return-loss bandwidth and sitcom M-x standard radiation pattern bandwidth for a Satcom hat feed [10].

In point-to-point communication systems, antennas are required to have high gain in order to have a sufficient long distance link. Thus, the beamwidth of the antennas is usually very narrow. Strong wind in bad weather days and vibrations from randomly uncontrollable sources may cause antennas swinging and therefore the link interrupt, which is unacceptable for most modern point-to-point communication systems.

The purpose of the present work is to find an optimal solution to this problem: an optimal trade-off between the link distance and the connectability of the link. A new sector reflector antenna with two-dimensional hat feed is proposed in this paper. Compared with commonly used link antennas, the new antenna has broader beamwidth in horizontal plane and narrow beamwidth in vertical plane, with simple geometry and low cost for manufacture. Simulated results are presented in the paper, and the prototype is under fabrication. Note that although only a linear polarized design of the antenna is presented in the paper, dual polarization can be realized with this new antenna by a similar design method.

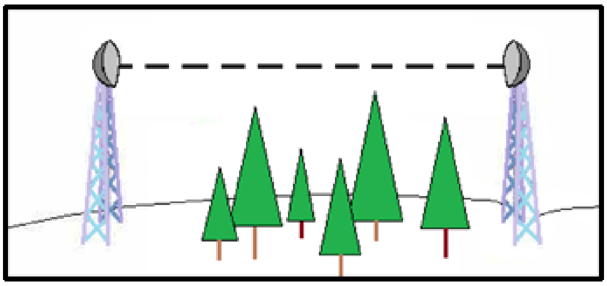


Fig. 1 Antennas in point-to-point communication systems

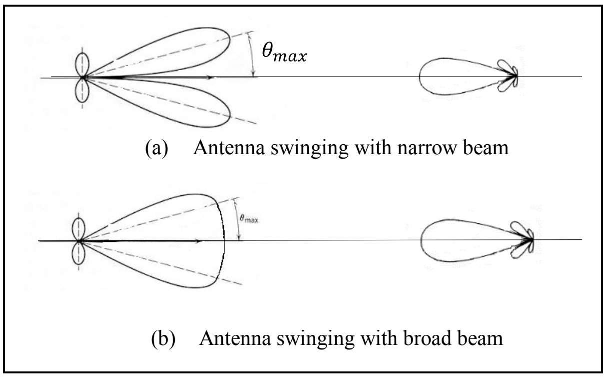


Fig. 2 Different connectability by using antennas with different beamwidth under the situation of strong wind or vibration.

II. SYSTEM CONFIGURATION AND ANTENNA CONSIDERATION

Fig. 1 shows a general antenna setup in point-to-point wireless communication systems. It is very common that two narrow beam antennas (therefore high gain) are used to set up a long-distance channel link. However, under the situation when there exists strong wind or vibrations, the antennas will be swinging, which may cause the interruption of the connection.

As shown in Fig. 2a, if the swinging angle θ_{max} of the antenna is bigger than its half 3dB beamwidth, the link would be interrupted. This interruption is unacceptable in the most modern communication systems, so we need to find a solution to solve this problem.

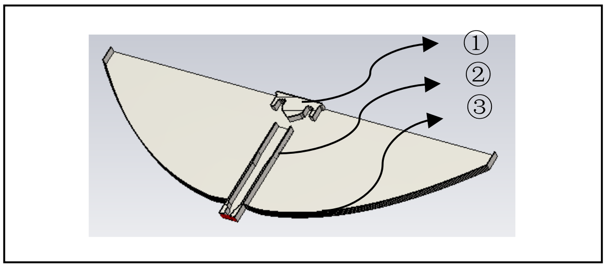


Fig. 3 Geometry of the sector antenna with 2-Dimensional hat feed: ① Hat feed; ② Feeding waveguide; ③ Main reflector. Note that the top plate is hidden in the figure for clarifying the geometry.

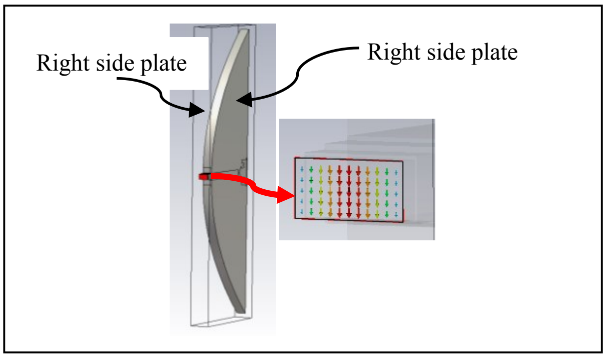


Fig. 4 Vertical polarization of the sector antenna.

From our experience, the swinging is more significant in horizontal plane which is the main reason for the disconnection, while the vertical swinging is much less and hardly causing the disconnection due to the configuration of mounting posters or mounting towers commonly used. Therefore, a sector reflector antenna (as shown in Fig. 3), instead of the previous paraboloidal reflector, is proposed to tackle this problem, where the 3dB half beamwidth in horizontal plane is broadened to an angle larger than the expected swinging angle θ_{max} while the 3dB half beamwidth in the vertical plane is kept narrow to have a high gain. Fig. 2b shows the wide 3dB beamwidth in the horizontal plane with the new sector antenna, which quarantines the connection when the antenna is swinging.

From Fig. 3, it can be seen that the proposed sector antenna has a simple and compact geometry which leads to a low cost for manufacture and lightweight.

Table I shows the specifications for the new sector antenna.

TABLE I. SPECIFICATIONS

Frequency band	10.5—14.5 GHz	Reflection coefficient	≤ -17.7 dB
Swinging angle θ_{max}	±30°	Antenna gain	20 dBi
3dB beamwidth in horizontal plane	90°	3dB beamwidth in vertical plane	2°

III. Linear Polarized Antenna Design

Hat feed is known for its excellent side-lobe suppression and low cross polarization for paraboloidal reflectors. In the design of a linear polarized sector antenna, we would like to have the same advantages as the standard hat feed has in the vertical plane. The polarization of the proposed antenna in this paper is shown in Fig. 4: the vertical polarization when the sector reflector is vertically amounted. Therefore, the E-field vector is parallel to the parallel plates (right and left side plates as in Fig. 4) of the reflector. The distance between the two plates is determined by the required 3dB beamwidth in the horizontal plane, which should be also larger than the half wavelength at the operating frequency in order to avoid the cut-off frequency in the parallel plate waveguide. In this work, we choose the spacing H between the parallel waveguides in the antenna by

$$H = \frac{67 * \lambda}{\theta_{3dB}^2} \quad (1)$$

where λ is the operating frequency, θ_{3dB} is the 3dB beamwidth in horizontal plane.

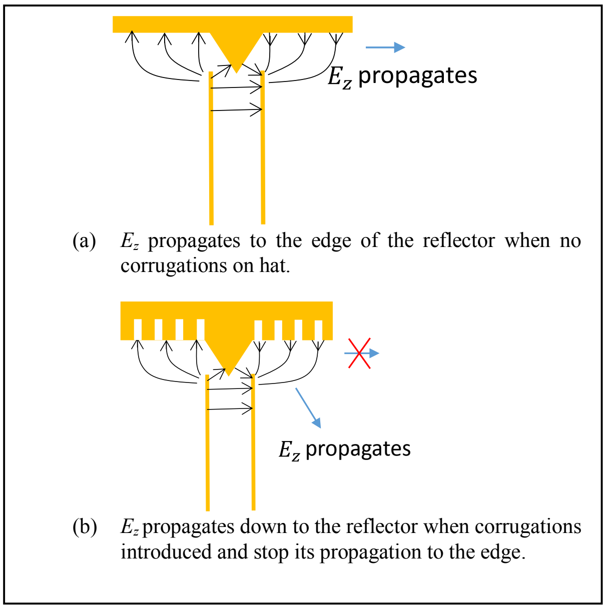


Fig. 5 The working principle for corrugation introduced on hat.

The reason that we use the two-dimensional corrugated hat feed for a sector reflector, as shown in Fig. 5, can be described briefly as below. The E-field out from the waveguide has z and ρ components. The z component can propagate along the hat surface if only the smooth metal surface without corrugation is used for the hat, as shown in Fig. 5a, which will make the field illumination high on the edge of the reflector and increase the far-out sidelobes' level. With the corrugation on the hat, the surface becomes a soft one to the z component of the E-field, which will stop the propagation of the z component, and therefore make the field illumination with a proper taper at the edge to reduce the far-out sidelobe level, as shown in Fig. 5b.

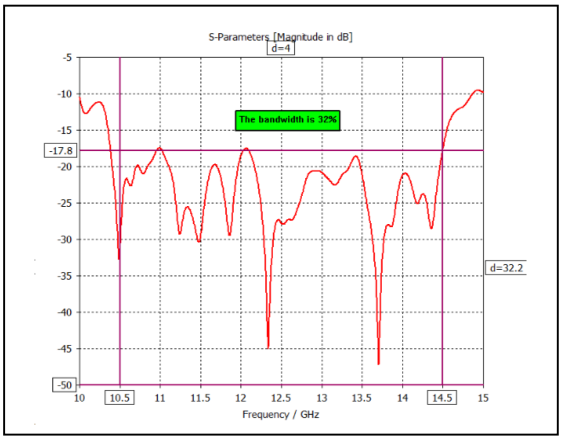


Fig. 6 Simulated reflection coefficient of the 2D hat feed when it is mounted in the sector reflector.

The design is through the optimization on reflection coefficient [11], aperture efficiency and radiation pattern in vertical plane via CST MS. The one-dimensional aperture efficiency in vertical plane can be calculated by several sub-efficiencies, in a similar way as in [12][13], as:

$$e_{ap} = e_{pol} e_{sp} e_{ill} e_{\emptyset} \tag{2}$$

where e_{pol} is the polarization efficiency, e_{sp} the spillover efficiency, e_{ill} the illumination efficiency and $e_{\emptyset}$ the phase efficiency. e_{pol} is almost 100% in our case. e_{sp} and e_{ill} are mainly determined by the size of the hat brim and the subtended angle of the reflector in use. $e_{\emptyset}$ is the phase efficiency. The 2D hat feed should have a square shaped phase center [14], similar to that the Body-of-Revolution (BOR) hat feed has a ring shaped phase center [15]. In this work, we try different radius and *z* position of the phase center to get the highest phase efficiency. We are working on the formula to calculate the square phase center and will report later.

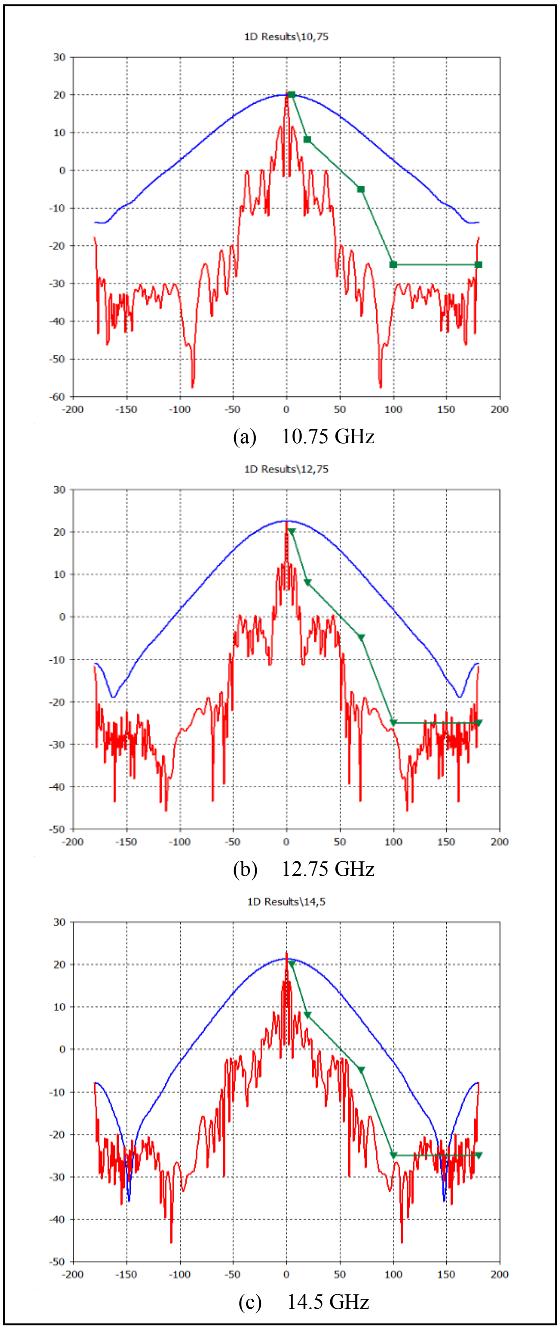
IV. Simulation Results

The simulated final reflection coefficient of this antenna is shown in Fig. 6. From the figure, we can see that the 17.8dB-return-loss bandwidth is 32%, a very wide one, from 10.5 GHz to 14.5 GHz. Fig. 7 shows the simulated radiation patterns in vertical and horizontal planes, where the radiation patterns in vertical plane can fulfill ETSI standard Class 3 requirement [16].The antenna directivity is higher than 20 dBi over the band. The 3dB beamwidth in horizontal plane and vertical plane is 90° and 2°, respectively.

V. Conclusions

A linear polarized sector antenna has been designed in order to keep the link connection in point-to-point communication system when the antenna is swinging due to strong wind or vibration. The simulated relative bandwidth has achieved to 32% for both the reflection coefficient below -17.8 dB and the sidelobe envelope below ETSI standard Class 3.

This antenna can be also used in point-to-multipoint communications systems and a dual-polarized version of this antenna is under design.



(a) 10.75 GHz

(b) 12.75 GHz

(c) 14.5 GHz

Fig. 7 Simulated radiation patterns in vertical plane (red line) and horizontal plane (blue line). The green line presents ETSI class 3 requirement.

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