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Wide Band Hat-Fed Reflector Antenna for Satellite Communications

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Abstract—**This paper presents a new design of a hat-fed reflector antenna for satellite communication, where low sidelobe and cross polar levels are required for a wide band. The hat feed has been optimized in the design by using the genetic algorithm (GA) through a commercial FDTD solver QuickWave V2D together with own developed Matlab code. A return loss of 15 dB is obtained over a bandwidth of 1.47:1. The Gaussian vertex plate has been applied at the centre of the reflector in order to reduce back scattering. The simulations have been verified by measurements; both of them are presented in the paper.**

I. Introduction

The waveguide self-supported hat-fed reflector antenna is a robust antenna configuration with low blockage as no struts are needed to support the feed and the feed electronics can be placed behind the reflector as well. Low far-out sidelobes can be obtained by choosing a small F/D ratio.

The idea of using a self supporting waveguide feed for a reflector to avoid strut blockage was proposed already in the 1940s [1]. Later in 1987 a new self supported feed, referred to as the hat feed, was presented in [2]. The hat feed used a corrugated hat brim surface supported by a piece of dielectric to reduce the cross polarization level, as shown in Fig. 1. Fig. 2 shows the hat feed mounted in a reflector antenna.

Since then, several types of hat feeds have been developed for different applications at Chalmers University of Technology and by other researchers worldwide [3]-[9]. Another recent development is that the hat feed can be realized without dielectrics for reducing the manufacturing cost and for the possibility of combining it with the Eleven feed for dual band applications [10][11].

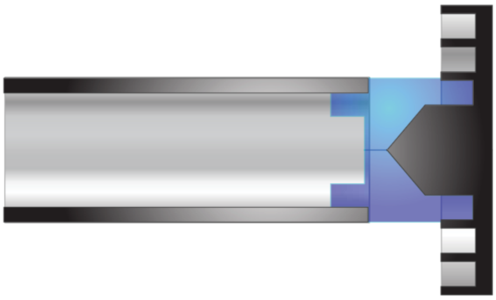

Fig. 1 Hat feed with corrugated brim (hat), dielectric support (head) and waveguide (neck)

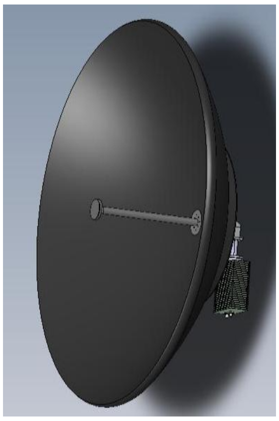

Fig. 2: Waveguide hat feed antenna with a ring focus reflector.

The original hat feed had a bandwidth of 10%. This was then improved to 33% using GA optimization [7], which opened new potential markets for the hat feed. The hat-fed reflector antennas have so far found most applications in radio links. With the increased bandwidth, the hat feed should also be suitable for satellite communication (satcom) applications. This work investigates this possibility, focusing on the Ku satellite band of 10.75-12.75 GHz (RX) and 13.75-14.5 GHz (TX). It should be noted that the requirement on sidelobes and cross polarization for satcom transmission, which is defined by ETSI [12], is different from that for terrestrial data links. Recently, the market for ultra compact satcom antennas has drastically increased and the less stringent nomenclature of standard M-x was presented in [13] to allow market entry also for small terminals, some being stabilized antennas for mobile applications.

In this work, the new design of a hat-fed reflector antenna for satellite communication is focused on low sidelobe and cross polar levels for a wide band. We have used the genetic algorithm (GA) together with a commercial software based on the FDTD method - QuickWave V2D to optimize the hat feed antenna for maximizing the efficiency and the return loss.

II. Hat Feed Optimization

The same GA scheme as one in [7] is used here to optimize the hat feed for maximising both the efficiency and return loss over the frequency band of 10.75-14.50 GHz. In the GA, one individual of a hat feed in a population is presented by chromosomes consisting of genes. The genes represent the dimensional parameters in the design and the chromosome includes all information of one antenna geometry. The initial population is randomly generated to get a good spread of start parameters. In order to produce the next generation, each individual is evaluated by a fitness value which determines the likeliness for the individual to pass its genes to the next generation. Two individual are selected as parents to produce two children in a crossover scheme. With a smaller likelihood a mutation will occur i.e. a gene generated in a random manner which is useful for avoiding local minima. The optimization is done towards a set of goals, resulting in numerous solutions with different characteristics. The fittest solutions are forming a pareto front, see Fig 3.

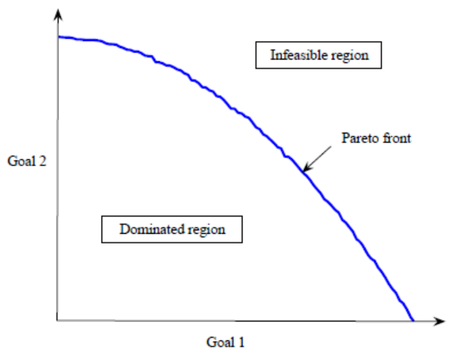

Fig. 3: The solution from a GA optimization. Each point along the pareto front represents the performance of a chromosome which contains the information of that particular antenna geometry.

The GA implemented in Matlab calls the QuickWave V2D simulator and feeds it with input data. In the FDTD code, the structure is meshed and a cell size of 1 mm is chosen, leading to 11 000 cells and a RAM requirement of 1 MB for the simulation of a hat feed. An iteration of 10 000 is found sufficient for consistent results and it takes approximately 10 seconds on a 2 GB RAM computer. A population size of 500 and 40 generations requires 56 hours simulation time. The chromosome in this optimization consists of 24 different genes for a hat brim with three corrugations.

In this work, several parameters are given and fixed. First, the F/D ratio, i.e. subtended flare angle from feed to reflector, is set to 88˚, based on initial results with varied F/D ratios. This value is smaller than the subtended half angle of 105˚ used in [7] where far-out sidelobes and backlobe performance were more critical than the main lobe area. Second, the hat diameter is fixed to 58 mm (2.4λ at the centre frequency 12.6 GHz) in order to avoid too much blockage from the hat in the reflector. Third, the waveguide diameter is constant to fit standard components in the band in order to reduce the manufacture cost. The crossover probability was set to 0.8 and mutation rate to 0.06. The optimization was stopped after 40 generation runs. The optimization goals are 1) more than 20 dB return loss in the TX band; 2) more than 17 dB return loss in the RX band; 3) sidelobe performance under the ETSI envelope and 4) aperture efficiency better than -2 dB.

The feed efficiency is factorized into the sub-efficiencies of spillover, cross polarisation, illumination and phase as factorised in [14]. The calculated feed efficiency and its sub-efficiencies after optimization are shown in Fig. 4. The phase efficiency is not included here as it can be compensated by using a ring focus reflector [15].

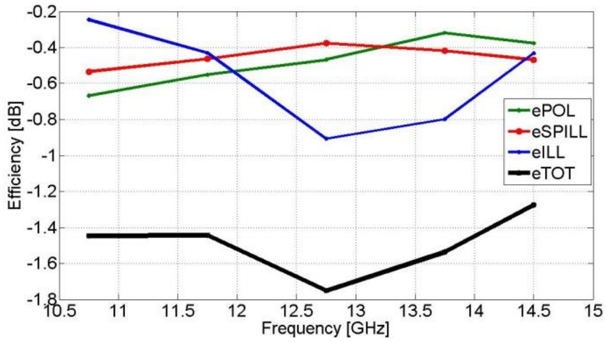

Fig. 4: The calculated efficiencies from the hat feed presented as part efficiencies and total efficiency.

The simulated reflection coefficient of the optimized hat feed when feeding a 53 cm diameter ring focus reflector antenna is shown in Fig. 5. It can be observed that the bandwidth of the reflection coefficient below -15.5 dB for this new hat feed antenna reaches to 47.5%, which presents an improvement from the previous 33% bandwidth in [7].

The simulated gain and aperture efficiencies over the full 47.5% frequency band are shown in Table 1.

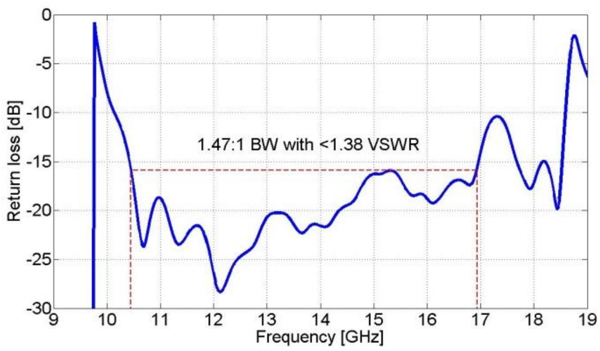

Fig. 5: Simulated return loss of hat-fed reflector antenna over extended frequency band.

TABLE I

SIMULATED GAIN AND EFFICIENCY OF THE NEW HAT FEED WITH 53 CM REFLECTOR ANTENNA OVER 47.5% FREQUENCY BAND.

Frequency [GHz]	Gain [dBi]	Efficiency [dB]
10.50	32.78	-2.52
11.50	33.93	-2.16
12.50	34.99	-1.82
13.50	36.21	-1.28
14.50	36.79	-1.31
15.50	37.35	-1.33
16.50	36.72	-2.52

III. GAUSSIAN VERTEX PLATE

A significant contribution to the return loss of a hat fed reflector comes from the multiple reflections between the reflector and the feed. This type of resonance was described in [16] and it was found that they occur at multiples of half wavelengths. This was analysed further in [17] with a multiple reflection (MR) approach based on the moment method to calculate the radiation and scattering patterns of the feed. Physical optics (PO) and uniform geometrical theory of diffraction (UTD) was used to include the reflector and to account for the multiple reflections between reflector and feed using the expression for the sum of infinite geometric series.

The effect of multiple reflections can be minimized by introducing vertex plates of either flat shape or preferably Gaussian form. The vertex plate reduces the centre blockage and has a positive effect on both gain and sidelobe levels. The contribution from the reflector to the reflection coefficient was initially studied in [18]. The Gaussian vertex plate for a hat fed antenna with the derived mathematics is presented in [19]. The shape of the vertex plate is depending on the wavelength (λ) and focal distance (F) and we find numerically, according to Fig. 6

$$t_0=0.15\lambda \quad \rho_0=0.5(F\lambda)^{0.5} \qquad (1)$$

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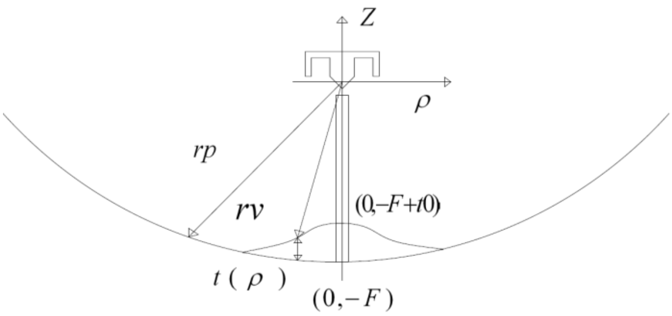

Fig. 6: Hat fed reflector antenna with (exaggerated) Gaussian vertex plate.

The return loss for a parabolic reflector with Gaussian vertex plate has been simulated and is presented with the same reflector without vertex plate in Fig. 7.

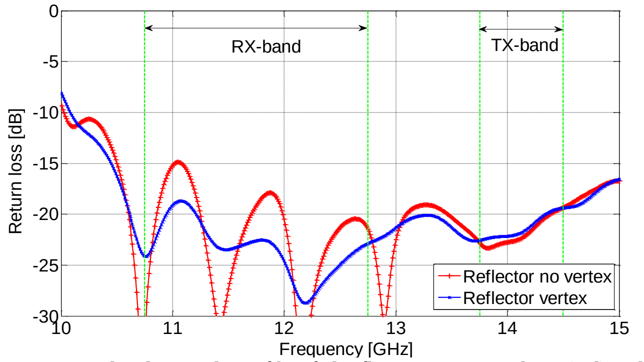

Fig. 7: Simulated return loss of hat-fed reflector antenna without (red) and with (blue) Gaussian vertex plate.

We can clearly see the effect of multiple reflections between the feed and reflector resulting in periodically appearing fluctuations in the return loss. The improvement is most apparent in the RX band where the radiated field along the waveguide is stronger than in the TX band.

IV. MEASUREMENT RESULTS

The optimized hat feed was manufactured by Arkivator AB and measured with a HP Vector Network Analyser. The feed with reflector antenna is shown in Fig. 8.

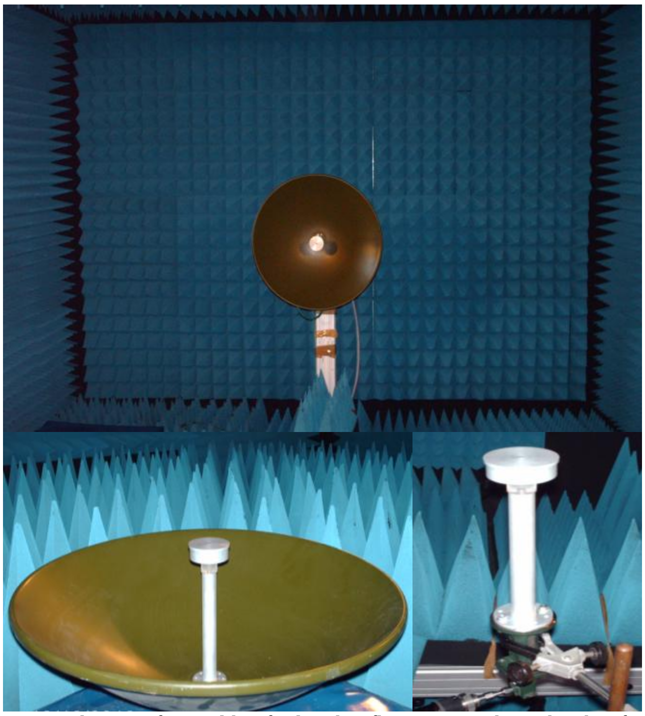

Fig. 8: The manufactured hat feed with reflector in anechoic chamber for measurements.

The return loss was measured with and without reflector and time domain gating was used to neglect reflections outside the area of interest i.e. apart from the hat and multiple reflections between the hat and reflector. The resulting return loss is shown in Fig. 9.

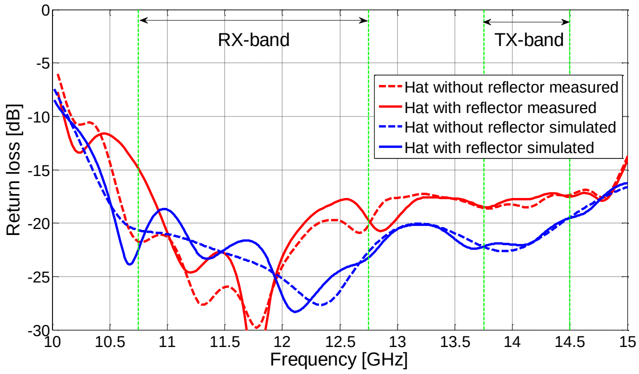

Fig. 9: Measured (red) and simulated (blue) hat feed with and without reflector with Gaussian vertex plate.

We see a reasonable agreement between simulated and measured results even if the level is about 3 dB higher for the measured hat in the TX band. The reflector is mainly influencing the RX band where multiple reflections between reflector and hat create fluctuations of S_{11}. The measured and simulated radiation patterns of a hat-fed reflector antenna of 53 cm diameter at 13.75 GHz are shown in Fig 10. The patterns agree rather well.

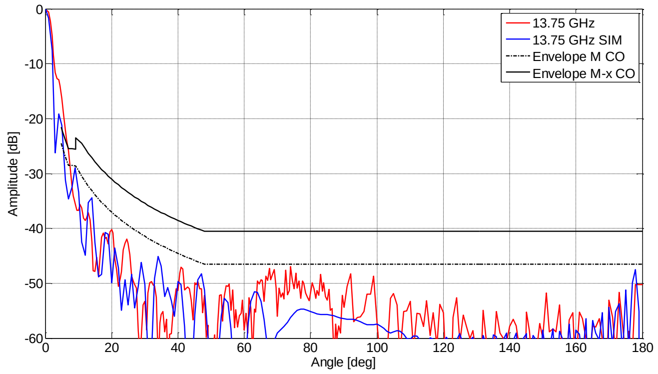

Fig 10: Measured (red) and simulated (blue) radiation patterns of hat-fed 53 cm reflector at 13.75 GHz.

V. Conclusions

A new hat feed design for satellite communication is presented in the paper. Through a GA optimization scheme, the efficiency and reflection coefficient of the hat feed over a wide frequency band have been optimized. By applying a Gaussian vertex plate in the reflector the reflection coefficient of the whole antenna is improved. Measurements on reflection coefficient and radiation patterns agree rather well with simulated values.

Acknowledgment

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