Design and Optimization of a Compact Wideband Hat-Fed Reflector Antenna for Satellite Communications

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***Abstract*—We present a new design of the hat-fed reflector antenna for satellite communications, where a low reflection coefficient, high gain, low sidelobes and low cross-polar level are required over a wide frequency band. The hat feed has been optimized by using the Genetic Algorithm through a commercial FDTD solver, QuickWave-V2D, together with an own developed optimization code. The Gaussian vertex plate has been applied at the center of the reflector in order to improve the reflection coefficient and reduce the far-out sidelobes. A parabolic reflector with a ring-shaped focus has been designed for obtaining nearly 100% phase efficiency. The antenna's reflection coefficient is below -17 dB and the radiation patterns satisfy the M-x standard co- and cross-polar sidelobe envelopes for satellite ground stations over a bandwidth of 30%. A low-cost monolayer radome has been designed for the antenna with satisfactory performance. The simulations have been verified by measurements; both of them are presented in the paper.**

***Index Terms*—Antenna feeds, Corrugated surfaces, Reflector antennas, Optimization, Satellite ground stations.**

I. Introduction

THE waveguide self-supported hat feed for reflector antennas has many advantages: low cross-polarization level due to its similar E- and H-plane radiation functions, low far-out sidelobes, low blockage as no struts are needed to support the feed, and low ohmic loss since the electronic devices, such as the transceiver, can be placed directly behind the reflector. Hat-fed reflector antennas have found use in terrestrial radio systems, gauge radars and other applications.

The idea of using a self-supported waveguide feed for reflector antennas in order to avoid strut blockage was proposed already in the 1940's by Cutler [1]. Later in 1987 a new self-supported feed, referred to as the hat feed, was presented by Kildal [2]. The hat feed used a corrugated brim surface (referred to as the hat) in order to reduce the cross polarization level, supported by a piece of dielectric (the head) located at the end of a waveguide (the neck), as shown in Fig. 1.

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]. One recent development is that the hat feed can be realized without the dielectric head for reducing the manufacturing cost and having the possibility of combining it with the Eleven feed [10]–[12] for dual band applications [13], [14] however at a cost of reduced BOR_1 efficiency (see Sect. II).

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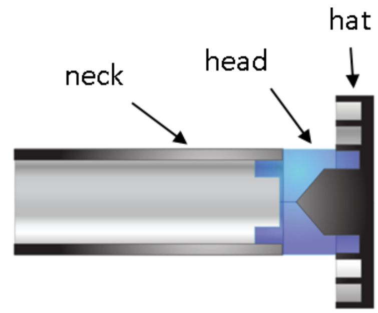

Fig. 1. Hat feed with corrugated brim (hat), dielectric support (head) and waveguide (neck).

The original hat feed [2] had a bandwidth of 10% for both impedance matching and radiation pattern performance. Then, the impedance matching bandwidth was improved to 33% after applying the Genetic Algorithm (GA) scheme for geometry optimization in [7], but the radiation performance within the band did not fulfill the requirements of the ETSI EN 302 standard for terrestrial fixed radio systems [15]. Nevertheless, this improvement showed the potential of hat-fed reflector antenna for wideband applications, such as in satellite communications (satcom) [16].

The purpose of this work is to design a wideband hat-fed reflector antenna with satisfied performance of both the impedance matching and the radiation patterns for satcom applications, focusing on the Ku-satellite band of 10.75-12.75 GHz (Rx) and 13.75-14.50 GHz (Tx). It should be noted that the requirements on co- and cross-polar sidelobe levels for satellite ground stations, defined by the ETSI EN 301 standard [17], are different from that for terrestrial radio systems [15]. Recently, the market for ultra small satellite ground stations has drastically increased. According to the less stringent nomenclature of standard M-x [18], antennas ready established for telecom applications are allowed to enter the market utilizing spread spectrum techniques. The goal of the antenna design in this work is to achieve an optimal performance of aperture efficiency and reflection coefficient,

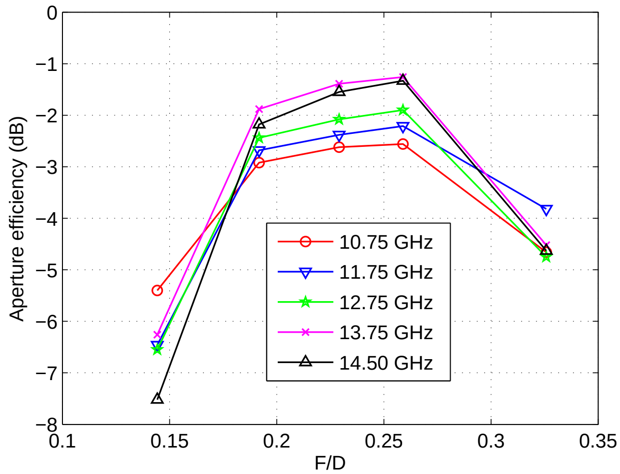

Fig. 2. Hat-fed reflector antenna simulated aperture efficiencies for various F/D-ratios.

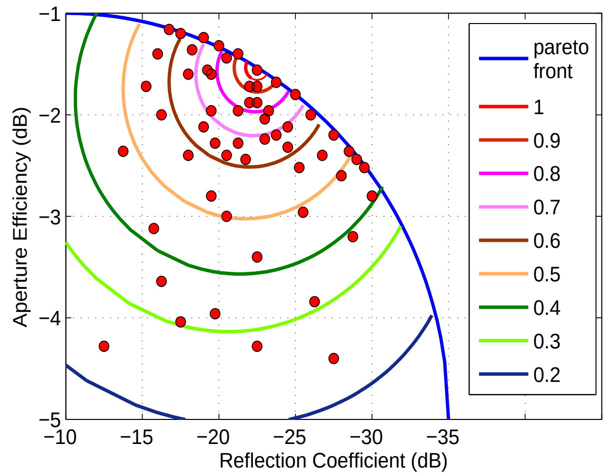

Fig. 4. Illustration of pareto front with individuals represented by the red dots. The curved lines are the fitness values for the GA optimization.

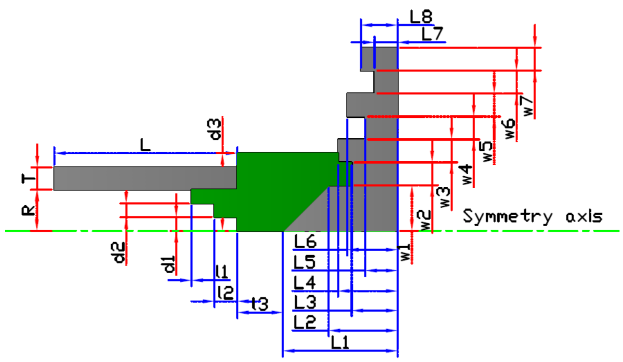

Fig. 3. Dimensions of the hat feed to be determined by optimization.

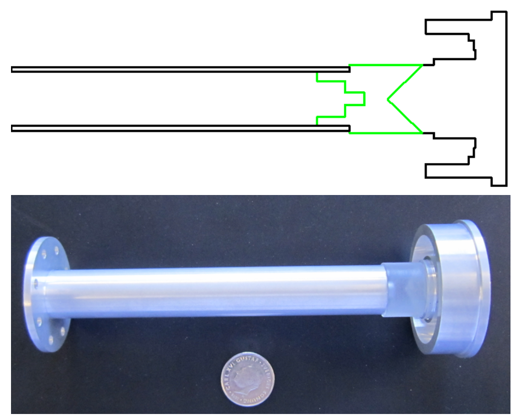

Fig. 5. The cross section of the optimized hat feed and a photo of the prototype hardware.

a relatively compact size, and the radiation patterns satisfying the M-x standard for satcom.

In this paper, we present a new design and optimization of a complete hat-fed reflector antenna for the Ku-satcom-band. The optimization is performed on the hat feed by using the GA with a commercial electromagnetic solver based on a two-dimensional FDTD method, QuickWave-V2D (QW-V2D) [19]. The Gaussian vertex plate, a technique to improve the reflection coefficient, is employed in the new design. A low-cost monolayer radome has been designed with satisfactory performance. Measurements on the antenna prototype enclosed by the radome, have verified the design, and show good agreement with the simulations.

The design can be extended to a reflector antenna with a larger diameter to satisfy the stricter ETSI EN 301 standard.

II. Characterization of Hat Feed for Optimization

The hat feed is characterized for the optimization in this work as follows.

A. Reflection Coefficient

The reflection coefficient Γ of the hat-fed reflector antenna is defined at the input port of the circular waveguide when the hat feed illuminates the reflector.

B. Aperture Efficiency

The aperture efficiency of a hat feed can be calculated by its sub-efficiencies [20] as

$$e_{ap} = e_{BOR1} e_{sp} e_{pol} e_{ill} e_{\phi} \, , \tag{1}$$

where e_{BOR1} is the BOR_1 (Body Of Revolution) efficiency [20], [21], e_{sp} the spillover efficiency, e_{pol} the polarization efficiency, e_{ill} the illumination efficiency and e_{ϕ} the phase efficiency. Since the hat feed is a BOR_1 antenna, $e_{BOR1} = 100\%$. It is also known that the hat feed has a ring-shaped phase center and the phase efficiency can be improved to almost 100% by using a ring-shaped focus parabolic reflector [22]. Therefore, the optimization is focused on e_{sp}, e_{ill} and e_{pol}, i.e.

$$e_{opt} = e_{sp} e_{pol} e_{ill} . \tag{2}$$

TABLE I
DIMENSIONS OF OPTIMIZED HAT FEED PARAMETERS [MM]

Par	Dim	Par	Dim	Par	Dim
R	9.00	l3	4.35	L1	26.01
L	145.00	W1	11.52	L2	15.99
T	1.00	W2	3.34	L3	18.48
d1	3.84	W3	1.64	L4	7.10
d2	2.16	W4	2.64	L5	8.27
d3	11.52	W5	2.74	L6	6.66
l1	5.04	W6	2.61	L7	17.59
l2	6.10	W7	4.50	L8	3.17

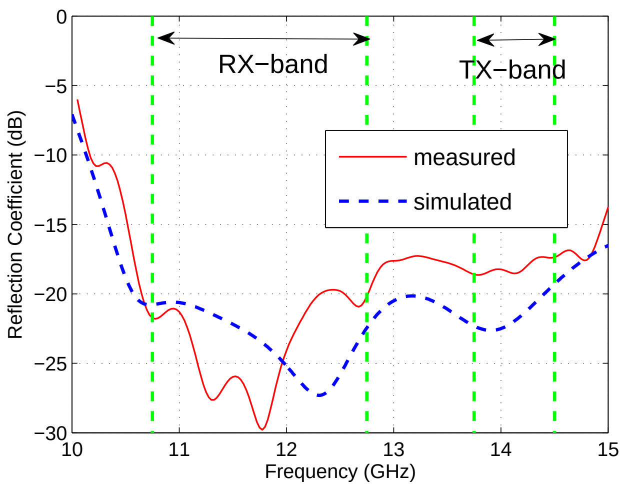

Fig. 6. Simulated and measured reflection coefficient of the optimized hat feed without reflector.

C. Co- and Cross-Polar Radiation Pattern

The co- and cross-polar radiation functions of a BOR_1 antenna can be written as [20]:

$$
\begin{aligned}
G_{co}(\theta, \varphi) &= G_{co45}(\theta) - G_{xp45}(\theta) cos(2\varphi), \\
G_{xp}(\theta, \varphi) &= G_{xp45}(\theta) sin(2\varphi).
\end{aligned} \tag{3}
$$

This states that the radiation characterization of a BOR_1 antenna is determined by only the co- and cross-polar radiation functions in the $\varphi = 45^\circ$ plane, i.e., $G_{co45}(\theta)$ and $G_{xp45}(\theta)$.

III. OPTIMIZATION OF HAT FEED

Several dimensions of the hat-fed reflector antenna are fixed before the optimization.

First, the subtended angle $2\theta_0$ of the reflector is set as $2 \times 89^\circ$, corresponding to $F/D = 0.255$, where F is the focal length and D the diameter of the reflector. This is concluded based on an initial simulation investigation of the previous hat feed in [7]. The value of F/D is varied to search for the maximum aperture efficiency, emphasizing on the Tx-band, under the condition that e_{sp} should be higher than -0.5 dB. High spillover efficiency leads to a low system noise temperature. Fig. 2 shows that the optimal value of F/D is 0.255. The criteria for determining this value is also due to the stricter requirement of the near-in sidelobes and the relatively more relaxed requirement of the far-out sidelobes and the backlobe performance for satellite ground stations [17], compared to those in terrestrial radio systems [15].

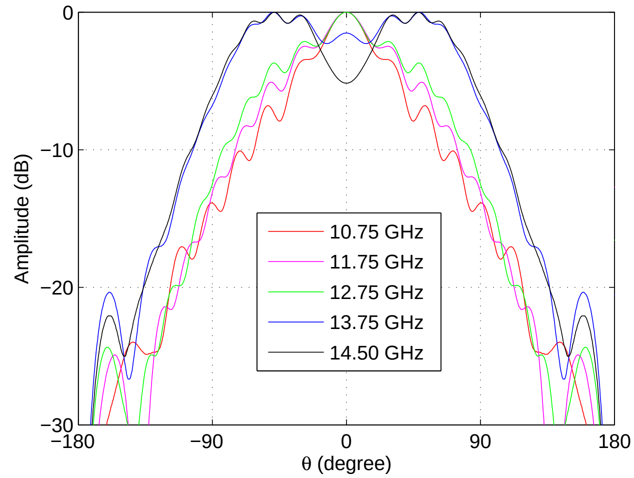

Fig. 7. Simulated co-polar radiation patterns in the $\varphi = 45^\circ$ plane of the optimized hat feed.

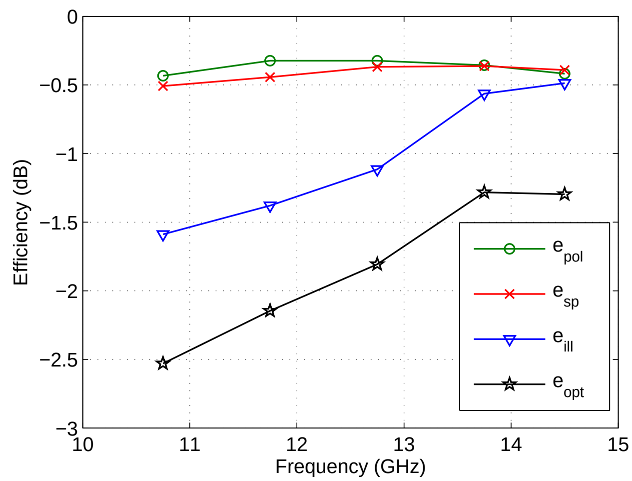

Fig. 8. Calculated efficiencies based on the simulated far-field function of the optimized hat feed with a subtended angle of $2 \times 89^\circ$.

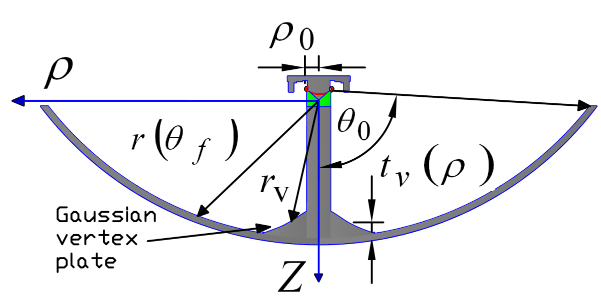

Fig. 9. Gaussian vertex plate on ring focus hat-fed reflector antenna.

Second, the hat brim diameter is chosen empirically as

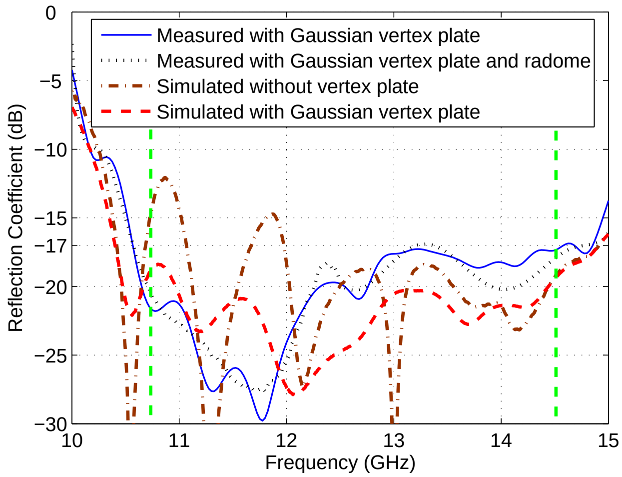

Fig. 10. Simulated and measured reflection coefficient of the hat-fed reflector antenna with and without the Gaussian vertex plate, and with the radome included.

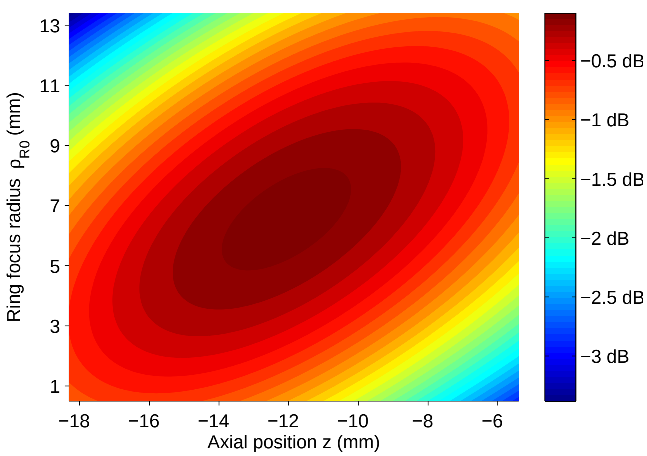

Fig. 11. Phase efficiency of the optimized hat feed with different ring radius ρ_R and phase reference location z.

58 mm, in order to avoid large blockage by the hat feeding the 53-cm diameter reflector used in this work. The reasons for choosing this size reflector are that 1) it can provide the required gain of ≥ 33 dBi over the full band; 2) it results in a compact satellite ground station; 3) we had a production tool available for this reflector.

Third, the waveguide radius R is chosen to match the waveguide output of the transceiver, i.e., $R = 9$ mm and with a wall thickness of $T = 1$ mm. The dielectric material for the head is Rexolite with the material properties of $(\epsilon_r = 2.53, \tan\delta = 0.0001)$ at 10 GHz.

Fig. 3 shows all the dimensions that will be determined by the optimization procedure. The optimization in this work is a multiple objective one with three objectives as follows: 1) low reflection coefficient; 2) high aperture efficiency and 3) satisfying the condition that the spillover efficiency must be higher than -0.5 dB in order to ensure a high G/T_{sys} value (G is the antenna gain and T_{sys} the system noise temperature), all

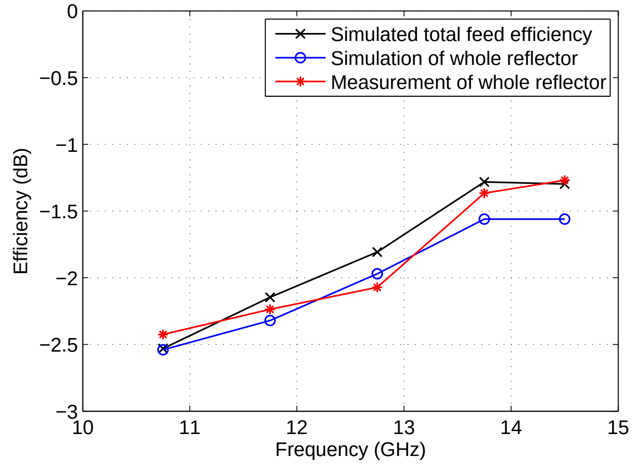

Fig. 12. Simulated and measured aperture efficiency of the hat-fed reflector antenna and simulated hat feed efficiency.

over the band of 10.75-14.50 GHz. The fitness values form a pareto front for reflection coefficient and aperture efficiency; see Fig. 4.

A GA scheme, based on the one in [7], is developed to optimize the hat feed. In the GA, one individual is presented by a chromosome consisting of 24 genes representing the dimensional parameters of the hat feed geometry.

The initial population of 500 individuals is randomly generated in order to have a good spread of genes. Then, each individual is simulated by QW-V2D and evaluated by its fitness value in Fig. 4, using our own-developed Matlab optimization program, to determine the likeliness for the individual to pass its genes to the next generation. Two individuals are selected as parents to produce two children in a crossover scheme. Mutation, a random change of a few genes, is used in this GA scheme to avoid local minima. The crossover probability is set to 80% and mutation rate to 6%.

QW-V2D utilizes a conformal FDTD method in a vector two-dimensional formulation, expressed in cylindrical coordinates. It is a very efficient method for BOR antennas.

The hat feed is modeled in QW-V2D by about 11 000 mesh cells, with a mesh size of 1 mm, which requires only 1 MB RAM. A total number of 10 000 iterations, in each simulation run, are sufficient to reach convergence and this takes approximately 10 seconds on a dual core 2 GB RAM computer. The 40-generation evolution with a population of 500 individuals takes 56 hours simulation time.

The simulation model and a hardware prototype of the final optimized hat feed are shown in Fig. 5 and the dimensions are given in Table I.

Fig. 6 shows the simulated and measured reflection coefficient of the optimized had feed alone (without being mounted in a reflector). Fig. 7 shows the simulated radiation patterns in the $\varphi = 45^\circ$ plane of the feed. The calculated efficiency based on the simulated feed radiation function is shown in Fig. 8, when the hat feed illuminates a reflector with a subtended angle of $2 \times 89^\circ$.

It can be observed that 1) the reflection coefficient of the feed is below -17 dB over the whole band; 2) the spillover efficiency of the hat feed is higher than -0.5 dB over the whole band, with a very good illumination efficiency in the Tx-band. The combination of both high spillover efficiency and high illumination efficiency is due to the very good radiation patterns in the Tx-band: almost flat beam shape between $\theta = -70^\circ$ and $\theta = 70^\circ$, and a fast drop of the radiation level outwards.

IV. Gaussian Vertex Plate

The multiple reflections between a reflector and its feed may degrade the reflection coefficient of the antenna significantly. These multiple reflections were described in [23] and analyzed further in [24] with an approach based on the moment method. In [25], a feed scattering pattern was introduced, where the scattered field from the feed when illuminated by a plane wave may have a strong effect on the performance.

The effect of multiple reflections can be minimized by introducing a vertex plate of either flat shape or preferably Gaussian form. The contribution from the reflector to the reflection coefficient was initially studied in [26]. The Gaussian vertex plate for a hat-fed reflector antenna with the derived mathematics was presented in [27]. The Gaussian vertex plate can make the reflected field from the reflector a null at the focus of the reflector where its feed is located, which minimizes the degrading effect of the multiple reflections and reduces the diffractions from the brim of the hat. In addition to this, the Gaussian vertex plate reduces far-out sidelobes. The shape of the Gaussian vertex plate, referring to Fig. 9, can be defined by [27]

$$t = t_0 e^{-(\rho/\rho_0)^2}, \tag{4}$$

with

$$t_0 = 0.15\lambda, \qquad \rho_0 = 0.5\sqrt{F\lambda},$$

where λ is the wavelength, and F the focal length. The wavelength $\lambda = 23.76$ mm, corresponding to the center frequency of 12.625 GHz, is used in the work.

Fig. 10 shows the simulated and measured reflection coefficient of the optimized hat feed mounted in the reflector antenna (see Sect. V) with and without the Gaussian vertex plate designed by using (4). It can be clearly seen from the simulated data that the multiple reflections between the feed and the reflector cause a periodical fluctuation in the reflection coefficient when there is no vertex plate employed. This fluctuation is significant below 13.25 GHz where the radiation field from the feed along the waveguide is strong (see the radiation at $\theta = 0^\circ$, in Fig. 7), and has been alleviated by using the Gaussian vertex plate. Above 13.25 GHz, due to that the feed radiation pattern (Fig. 7) has a dip along the waveguide, the multiple reflections between the feed and the reflector are already at a low level and therefore the vertex plate has less effect. Over the whole band of 10.75–14.50 GHz, the measured reflection coefficient is below -17 dB, corresponding to a bandwidth of 30%.

V. Reflector with Ring-shaped Focus

It is known that the hat feed has a ring-shaped phase center [22], which means that the optimal reflector with nearly 100% phase efficiency has a ring-shaped focus, defined by

$$\rho = 2F\tan(\theta_f/2) + \rho_{R0}\,, \quad z = F - F\tan^2(\theta_f/2)\,, \tag{5}$$

where ρ_{R0} is the radius of the reflector's focus ring, F the focal length and θ_f the polar angle of the feed, as defined in Fig. 9.

The radius of the focus ring can be determined analytically [22] or numerically. Fig. 11 shows the phase efficiency of the optimized hat feed with different ring radius ρ_R and phase reference location z. From this, we can obtain numerically that the optimal focal radius $\rho_{R0} = 6.8$ mm and the phase center $z_{pc} = -12$ mm, with the origin of the coordinate system located at the peak of the cone of the hat. We see that the phase efficiency of the ring focus is approaching 0 dB.

The reflector, with a diameter of 53 cm, is constructed from a 516.4 mm diameter paraboloid extended at the center by a 6.8 mm radius circle.

The aperture efficiencies, obtained by three different methods, are shown in Fig. 12. The first method, with the legend of *simulated total feed efficiency* in the figure, is the calculation of all sub-efficiencies based on the simulated feed radiation function as defined by (1). The second and the third methods, with the legends of *simulation of whole reflector* and *measurement of whole reflector*, are first calculating the directivity of the whole hat-fed reflector antenna based on the simulated and the measured radiation patterns, respectively, and then obtaining the ratio of this directivity to the maximum theoretical directivity of the 53-cm-diameter reflector. The agreement between them is very good.

Fig. 13 shows the simulated and measured co- and cross-polar radiation patterns of the antenna in the $\varphi = 45^\circ$ plane, where the sidelobe envelopes of the requirements defined by the ETSI EN 301 [17] and M-x standards [18] are included. It can be observed that the co- and cross-polar sidelobes are below the M-x standard envelope. The cross-polar requirement, according to the M-x nomenclature, is 20 dB discrimination in the 1 dB contour of the main beam, as shown in Fig. 14 and by the black dashed lines in the detailed figures embedded in Fig. 13. For frequencies above 13.75 GHz, the measured far-out sidelobe levels are quite flat and significantly higher than the simulated values, which, we believe, is due to the insufficient dynamic range in the anechoic chamber we used.

VI. Low-cost Monolayer Radome

The hat-fed reflector antenna developed in this work is for satcom applications, potentially used on yachts, cruise liners and trucks etc. Therefore, development of a low-loss radome to protect the antenna from harsh outdoor environments is essential.

The radome to house the reflector antenna is made as a hemisphere on a cylinder in order to enable the antenna to rotate around its axis point located behind the reflector. Fig. 15 shows the outer dimensions of the radome and the modeling of the radome with the hat-fed reflector antenna in QW-V2D.

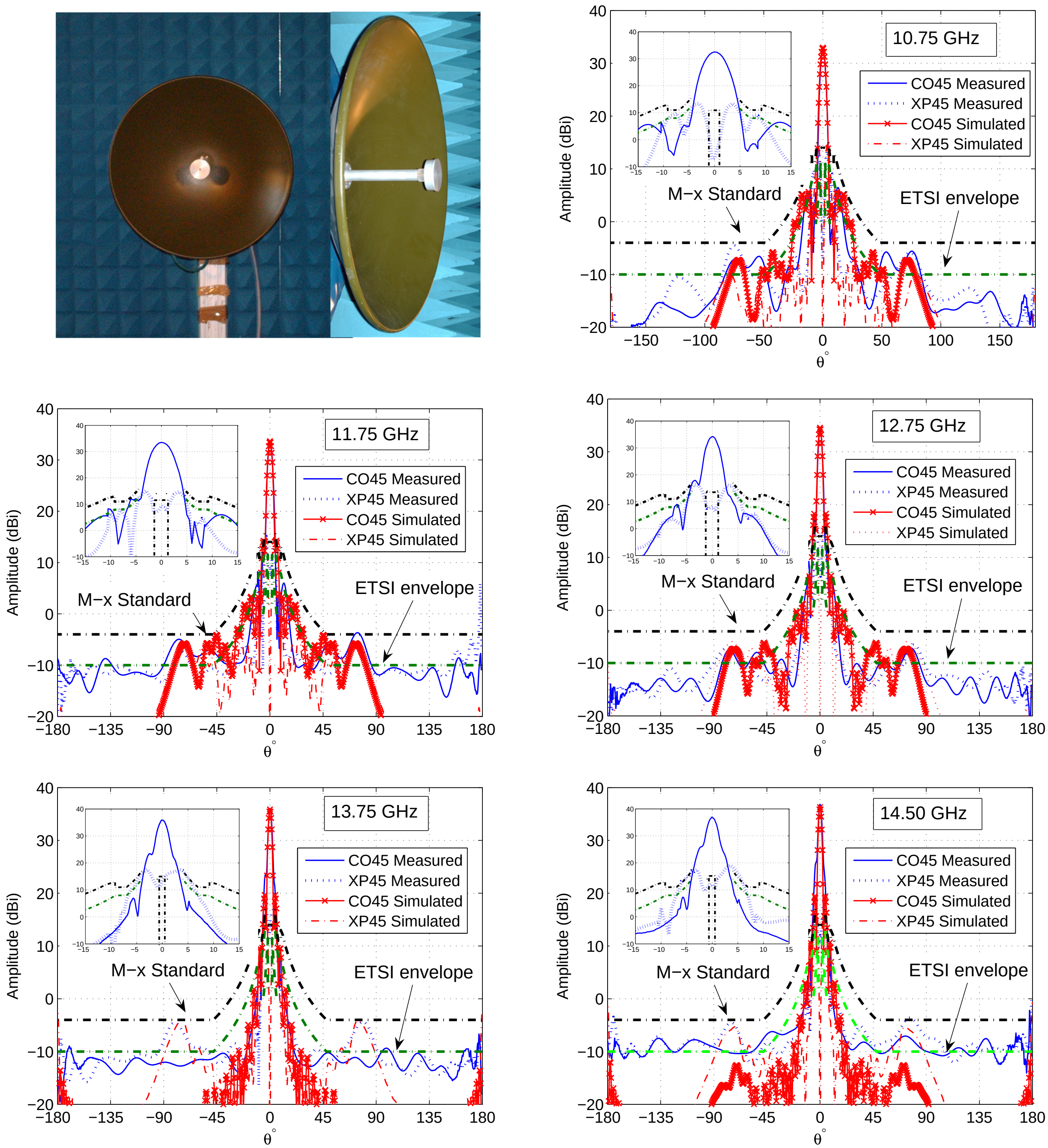

Fig. 13. Measurement setup, and the simulated and measured co- and cross-polar radiation patterns in the $\varphi = 45^\circ$ plane. The measured near-in patterns are detailed by the embedded figures.

Two types of radome configurations have been investigated in this project: 1) the monolayer homogenous and 2) the triple-layer sandwich.

Fig. 16 shows the simulated reflection coefficients of the hat-fed reflector antenna with the monolayer homogenous and the triple-layer sandwich radomes of different thickness. The material for the monolayer is polycarbonate ($\epsilon_r = 2.9, \tan\delta = 0.005$). The sandwich is built using 1 mm thick skins of a mixture of e-glass ($\epsilon_r = 6.06, \tan\delta = 0.004$) and epoxy ($\epsilon_r = 4.4, \tan\delta = 0.016$), and a core layer of polyurethane foam ($\epsilon_r = 1.05, \tan\delta = 0.0005$). It is observed that the 8-mm-thick monolayer (thick red dashed curve) and 18-mm-thick core layer sandwich (thick red dashed curve) have a minimum effect on the reflection coefficient by comparing to that without radome. Considering the lower manufacturing cost and simplicity, the 8-mm-thick monolayer radome is

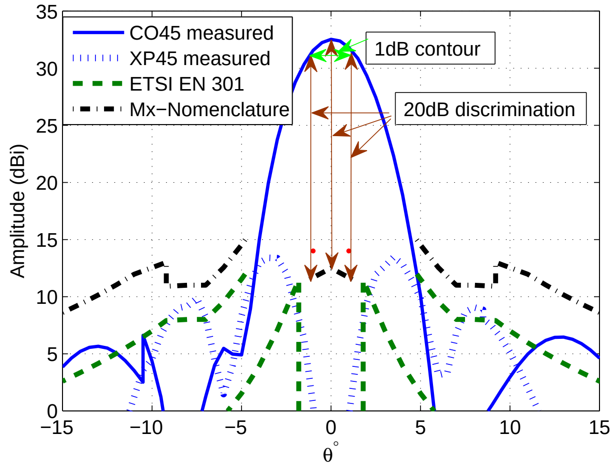

Fig. 14. Co- and cross-polar sidelobe requirement including the 20 dB cross-polar discrimination requirement within a 1 dB contour of the main beam.

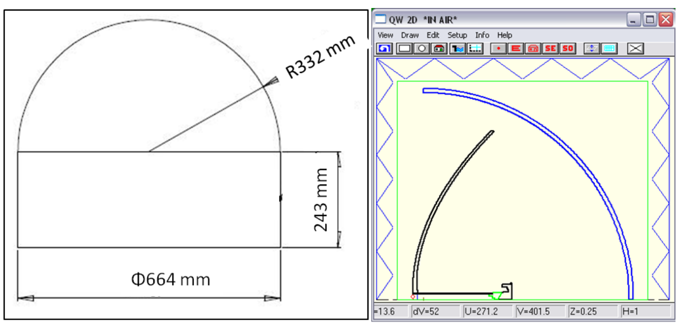

Fig. 15. Outer dimensions of the radome and the QuickWave-V2D modeling of the monolayer radome enclosing the hat-fed reflector antenna.

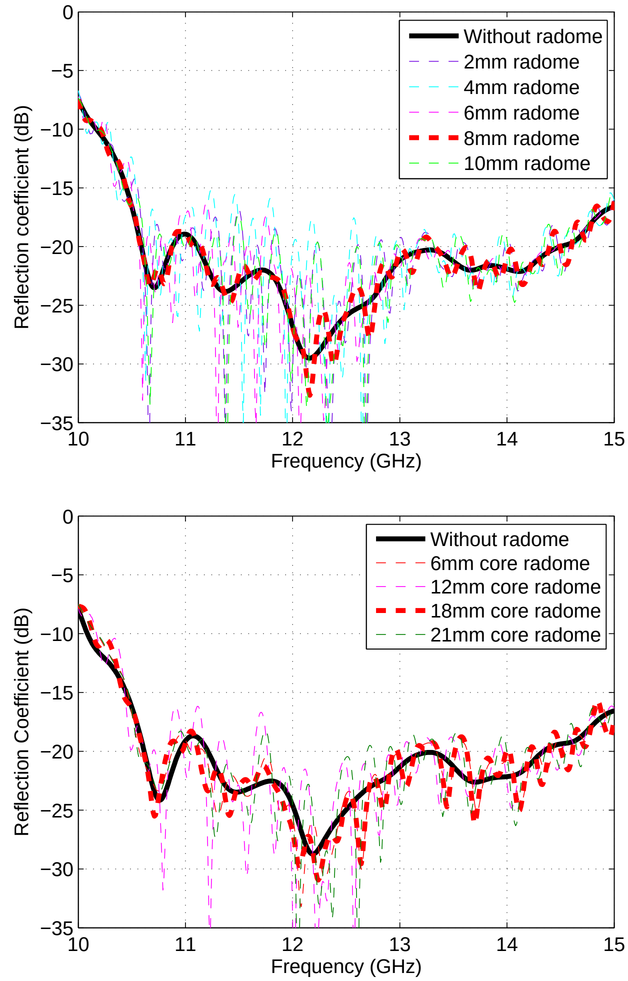

Fig. 16. Simulated reflection coefficient of the hat-fed reflector antenna with the monolayer homogenous (top) and the triple-layer sandwich (bottom) radomes of different thickness.

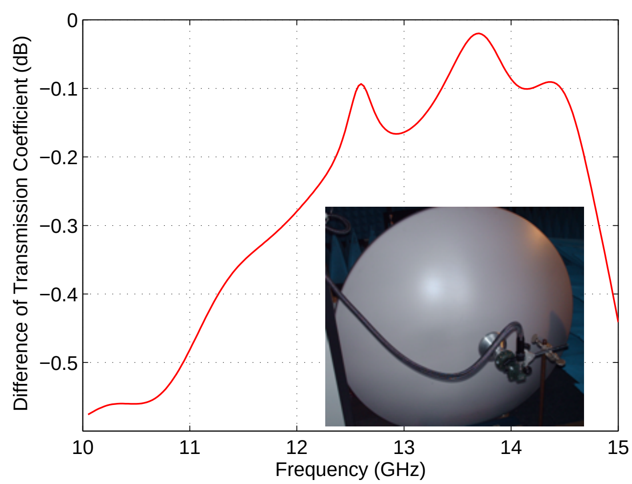

Fig. 17. Measured difference of the transmission coefficients of two horns separated by 7.14 mm with and without the monolayer homogenous polycarbonate radome of 7.14 mm thickness placed in between.

chosen. The thickness of the final manufactured radome by the vacuum forming technique was measured to 7.14 mm, which can be improved in future production.

The final measured reflection coefficient of the antenna with the monolayer radome is presented by the black dotted curve in Fig. 10, showing levels below -17 dB over 10.75–14.50 GHz and confirming the minimum effect of the radome.

The ohmic loss of the radome was investigated by the following measurement. Two circular horns (55 mm long, 95 mm in diameter and fed by a 18 mm diameter circular waveguide) are separated by a distance of 7.14 mm. The transmission coefficient S_{21} was measured when there was nothing in between the horns, and when there was the radome in between. Fig. 17 shows the difference between the two measured transmission coefficients. It can be seen that in the Tx-band, the difference is only about 0.1 dB, indicating that the ohmic loss of the radome is less than 0.1 dB. In the Rx-band, due to the reflection of the radome, there may be a radiation leakage, so the difference is slightly bigger. However, we believe that the ohmic loss in the Rx-band is similar to that in the Tx-band.

Fig. 18 shows the measured radiation patterns in the $\varphi = 45°$ plane with and without the radome. The effect of the radome on the main lobe is hardly seen, and there are only

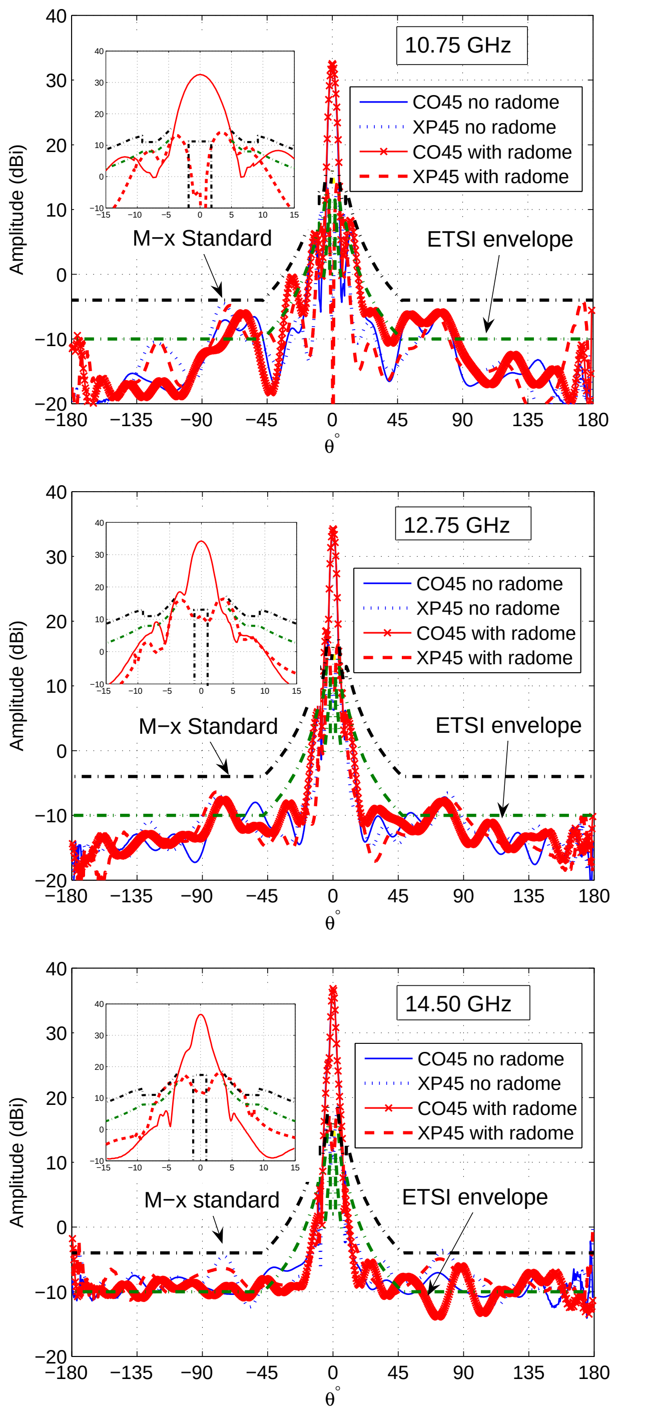

Fig. 18. Measured co- and cross-polar radiation patterns in the $\varphi = 45°$ plane with and without the monolayer radome.

minor effects on the sidelobes.

VII. Conclusion

We present a hat-fed reflector antenna of 53 mm diameter with a low-loss, low-cost monolayer homogenous radome as satellite ground station for communication in the Ku-band (10.75–14.50 GHz). The hat feed has been successfully optimized using the Genetic Algorithm and the QuickWave-V2D electromagnetic solver and the aperture efficiency is higher than -2.5 dB (55%) over the full band due to the good illumination- and spillover efficiencies, which also maximizes G/T_{sys}. The Gaussian vertex plate has been employed for improving the reflection coefficient. The phase efficiency is nearly ideal by using a parabolic reflector with a ring focus. A monolayer polycarbonate radome has been designed and manufactured, which is low-loss, sufficiently rigid and easy to produce using a vacuum forming process at a low cost. The radiation patterns of the antenna fulfill the co- and cross-polar sidelobe requirements defined by the M-x standard for ultra small satellite ground stations. The design can be extended to a larger reflector to satisfy the stricter ETSI EN 301 standard. The self supported hat feed is patent protected [28].

References

[1] C. C. Cutler, “Parabolic antenna design for microwaves,” *Proc. IRE*, vol. 35, no. 11, pp. 1284–1294, Nov. 1947.

[2] P.-S. Kildal, “The hat feed: a dual-mode rear-radiating waveguide antenna having low cross polarization,” *IEEE Trans. Antennas Propagat.*, vol. 35, no. 9, pp. 1010–1016, Sept. 1987.

[3] A. Moldsvor, M. Raberger, and P.-S. Kildal, “An efficient rectangular hat feed for linear polarization and low sidelobes,” vol. 1. Digest of 1993 IEEE AP-S International Symposium, 28 June - 2 July 1993, pp. 270–273.

[4] J. Hansen, A. Kishk, P.-S. Kildal, and O. Dahlsjo, “High performance reflector hat antenna with very low sidelobes for radio-link applications.” Proc. 1995 IEEE AP-S International Symposium, Newport beach, June 1995, pp. 893–896.

[5] J. Yang and P.-S. Kildal, “FDTD design of a Chinese hat feed for shallow mm-wave reflector antennas.” Atlanta, Georgia: Proc. 1998 IEEE AP-S International Symposium, 21-26 June 1998, pp. 2046–2049.

[6] M. Yousefnia, A. Pirhadi, and M. Hakkak, “Analysis and design of parabolic hat feed antenna.” Proc. 2005 IEEE AP-S International Symposium, 3-8 July 2005, pp. 650–653.

[7] M. Denstedt, T. Ostling, J. Yang, and P.-S. Kildal, “Tripling bandwidth of hat feed by genetic algorithm optimization.” 2007 IEEE AP-S International Symposium, Hawai, 10-15 June 2007.

[8] A. Pirhadi, M. Hakka, and M. Yousefnia, “Analysis and design of a novel hat feed with narrow beamwidth for the fresnel zone plate antenna,” *International Journal of RF and Microwave Computer-Aided Engineering*, vol. 19, no. 3, pp. 416–422, Dec. 2008.

[9] L. Slama, R. Galuscak, and P. Hazdra, “Design of a prime-focus feed with backward radiation.” COMITE 2008 - 14th Conference on Microwave Techniques, Prague, 23-24 April 2008.

[10] R. Olsson, P.-S. Kildal, and S. Weinreb, “The Eleven antenna: a compact low-profile decade bandwidth dual polarized feed for reflector antennas,” *IEEE Trans. on Antennas Propagat.*, vol. 54, no. 2, pp. 368–375, 2005.

[11] J. Yang, X. Chen, N. Wadefalk, and P.-S. Kildal, “Design and realization of a linearly polarized eleven feed for 1-10 GHz,” *IEEE Antennas Wireless Propagat. Lett.*, vol. 8, pp. 64–68, 2009.

[12] J. Yang, M. Pantaleev, P.-S. Kildal, B. Klein, Y. Karadikar, L. Helldner, N. Wade-falk, and C. Beaudoin, “Cryogenic 2-13 GHz Eleven feed for reflector antennas in future wideband radio telescopes,” *IEEE Trans. Antennas Propagat.*, vol. 59, no. 6, pp. 1918–1934, June 2011.

[13] W. Wei, J. Yang, T. Ostling, and T. Schafer, “A new hat feed for reflector antennas realized without dielectrics for reducing manufacturing cost and improving reflection coefficient,” *IET Microwaves Antennas Propagat.*, vol. 5, no. 7, pp. 837–843, July 2011.

[14] J. Yang, W. Wei, T. Ostling, and T. Schafer, “A new metal-rod-supported hat antenna for potentially combining with the Eleven antenna as a dual-band feed for reflectors.” 5th Eur. Conference on Antennas Propagat. (EuCAP2011), Rome, 11-15 April 2011.

[15] ETSI, “Fixed Radio Systems Characteristics and requirements; Final draft ETSI EN 302 217-4-2 V1.5.1 (2009-09).” Available: http://www.etsi.org/WebSite/homepage.aspx.

[16] E. Geterud, J. Yang, and T. Ostling, “Wide band hat-fed reflector antenna for satellite communications.” 5th Eur. Conference on Antennas Propagat. (EuCAP2011), Rome, 11-15 April 2011.

[17] ETSI, “Satellite Earth Stations and Systems (SES) Harmonized EN for Very Small Aperture Terminal (VSAT).” ETSI EN 301 428 V1.3.1 (2006-02).

[18] Eutelsat, "Conditions of operations of earth stations not fully complying with standard M. Nomenclature of standard M-x." Nomenclature of standard M-x. Addendum to EESS 502. Issue 1, Rev.1, Oct. 2008.
[19] QuickWave-V2D; http://www.qwed.eu/qw_v2d.html.
[20] P.-S. Kildal and Z. Sipus, "Classification of rotationally symmetric antennas as types BOR_0 and BOR_1," *IEEE Antennas Propaga. Mag.*, Dec. 1995.
[21] J. Yang, S. Pivnenko, and P.-S. Kildal, "Comparison of two decade-bandwidth feeds for reflector antennas: the Eleven antenna and quadridge horn." 4th European Conference on Antennas and Propagation, (EuCAP 2010), Barcelona, April 2010.
[22] J. Yang and P.-S. Kildal, "Calculation of ring-shaped phase centers of feeds for ring-focus paraboloids," *IEEE Trans on Antennas and Propagat.*, vol. 48, no. 4, pp. 524–528, April 2000.
[23] P.-S. Kildal, "A small dipole-fed resonant reflector antenna with high efficiency, low cross polarizaton and low sidelobes," *IEEE Trans on Antennas and Propagat.*, vol. 33, no. 12, pp. 1386–1391, Dec. 1985.
[24] P.-S. Kildal, S. A. Skyttemyr, and A. A. Kishk, "G/t maximization of a paraboidal reflector fed by a dipole-disk antenna with ring by using the multple-reflection approach and the moment method," *IEEE Trans on Antennas and Propagat.*, vol. 47, no. 7, pp. 1130–1139, July 1997.
[25] A. Moldsvor and P.-S. Kildal, "Systematic approach to control feed scattering and multiple reflections in symmetrical primary-fed reflector antennas," *IEE Proceedings Part H*, vol. 139, no. 1, pp. 65–71, 1992.
[26] S. Silver, *Microwave antenna theory and design*. McGraw-Hill, New York, 1949.
[27] J. Yang and P.-S. Kildal, "Gaussian vertex plate improves reflection coefficient and far-out sidelobes in prime-focus reflector antennas," *Microwave and optical tech. letters*, vol. 21, no. 2, pp. 125–129, 20 April 1999.
[28] P.-S. Kildal, "Improved reflector antenna with self supported feed," *US patent*, no. 6 137 449, Oct. 2000.

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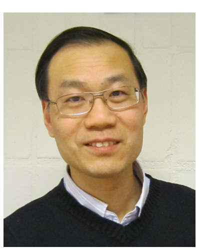

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