A DUAL FREQUENCY FEED SYSTEM FOR THE 20 M RADIO TELESCOPE AT THE ONSALA SPACE OBSERVATORY

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SUMMARY

A new dual frequency feed operating at S- and X-band is being developed for the 20 m radio telescope at the Onsala Space Observatory. Here we give a status of the ongoing project. The feed system consists of two feed reflectors, where the first one is illuminated by a dual frequency corrugated horn. The horn has been built and the measured characteristics are presented. Polarizers at both the two bands are of the septum type in quadratic waveguide making it possible to observe both right- and left-circular polarization simultaneously. The circular throat of the horn is connected directly to the X-band polarizer, whereas the horn is connected to the S-band polarizer via a coaxial wave transformer located around the X-band polarizer. The wave transformer has four branches between which there is access to the X-band polarizer outputs. The polarizers and feed reflectors have not yet been realized in practice.

INTRODUCTION

Work is underway to equip the 20 m antenna at the Onsala Space Observatory with a new set of feed systems. This presentation deals with the new dual-frequency feed at S- and X-bands. The existing feed system uses separate feed horns for the two frequency bands and a tertiary reflector for S-band which is equipped with a flat dichroic surface in the central area [*Jaldehag*, 1992; *Jaldehag et al.*, 1993]. The dichroic surface is an efficient reflector for S-band but has transmission loss at X-band. In the new feed the S- and X-bands are combined in one dual-frequency horn. The location of the existing feed for these frequencies will not be available in the future; because a new imaging array for mm-wave observations will occupy most of the space near the secondary focus of the Cassegrain antenna. Therefore, the new feed consists—in addition to the dual-frequency horn—of two feed reflectors forming a beam waveguide which deflects the beam away from the secondary focus. The feed reflectors are removable to allow alternate use of the mm-wave feed array.

Observations at S- and X-bands are made during Very-Long-Baseline Interferometry experiments for global geodesy [*Clark et al.*, 1985; *Rogers et al.*, 1993] or detailed mapping of distant radio sources [*Schilizzi*, 1995; *Hirosawa and Hirabayashi*, 1995]. Intercontinental vectors may, for example, be estimated with a reproducibility better than one centimeter and maps of radio sources can be produced with extremely high resolution (< 1 milliarcsecond at X-band). Two frequency bands are observed and recorded simultaneously in order to make corrections for the radio wave propagation delay in the dispersive ionosphere. The frequency bands are 2200–2400 MHz and 8200–8950 MHz. Since the signals received from the radio sources are extremely weak, both applications can be seen as limited by the sensitivity. Therefore, a major goal of the new feed is also to significantly improve the aperture efficiencies compared to the present system. Furthermore, since the radio astronomy application will greatly benefit from having both right and left circular polarization available simultaneously, this feature will also be implemented. In the following we will describe, the geometry of the beam waveguide system, the corrugated horn, the polarizer design, and finally the S-band wave transformer.

THE BEAM WAVEGUIDE

A basic constraint is that the area in the receiver cabin will be needed for a new imaging receiver at mm-wavelengths. A sketch of the proposed basic structure of the new S- and X-band feed in the antenna is shown in Figure 1. A complication in terms of the receiver location is the

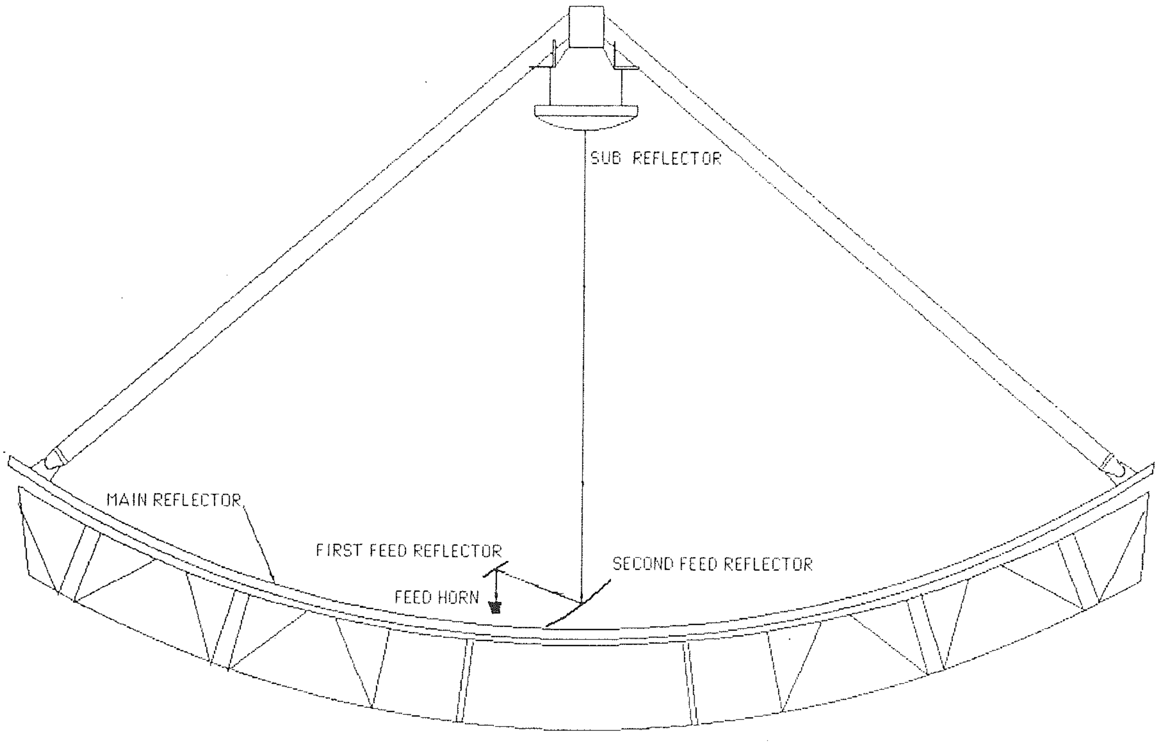

Figure 1: A sketch showing the possible feed arrangement. The two feed reflectors are removable. The mm-wave feed array is located in the antenna cabin below the second feed reflector.

torque box which prevents us from placing the receiver here, just behind the primary reflector. The two feed reflectors have been designed by using the Gaussian beam technique, and they have been analyzed and optimized by using the computer programs SUITE-3R which were developed and used to analyze the Gregorian feed of the Arecibo radio telescope [*Kildal et al.*, 1994]. Simulations using diameters of 0.7 and 1.5 m for the first and second feed reflectors, respectively, indicate that the efficiency of the feed system can be better than -3 dB and -2 dB at S- and X-bands, respectively [*Rubiños-López*, 1995; *Rubiños-López et al.*, 1996]. The process of determining the final position of the mirrors has not yet been carried out.

THE CORRUGATED HORN

A prototype horn has been designed and manufactured by using the moment method program AKBOR for bodies of revolution [*Kishk and Shafai*, 1986]. The design is based on major parts of the S/X-band horn described by *Johansson* [1994] for an offset fed reflector. A first prototype horn was found to cover a waveguide band which was slightly below the one aimed for [*Flodin*, 1995]. A second horn, which is a scaled version of the first, has now been made. Figure 2 is a photo of the manufactured unit; and the main features of the horn are shown in Figure 3. The measured beam patterns at the center frequencies of the two bands are shown in Figure 4. The cross polarization and main beam widths over the bands are shown in Figures 5 and 6, respectively.

The agreement between computations and measurements is good as S-band. The discrepancies at X-band are mainly due to limitations in computer memory which forced us to ignore the deep S-band corrugations in the numerical modelling at X-band.

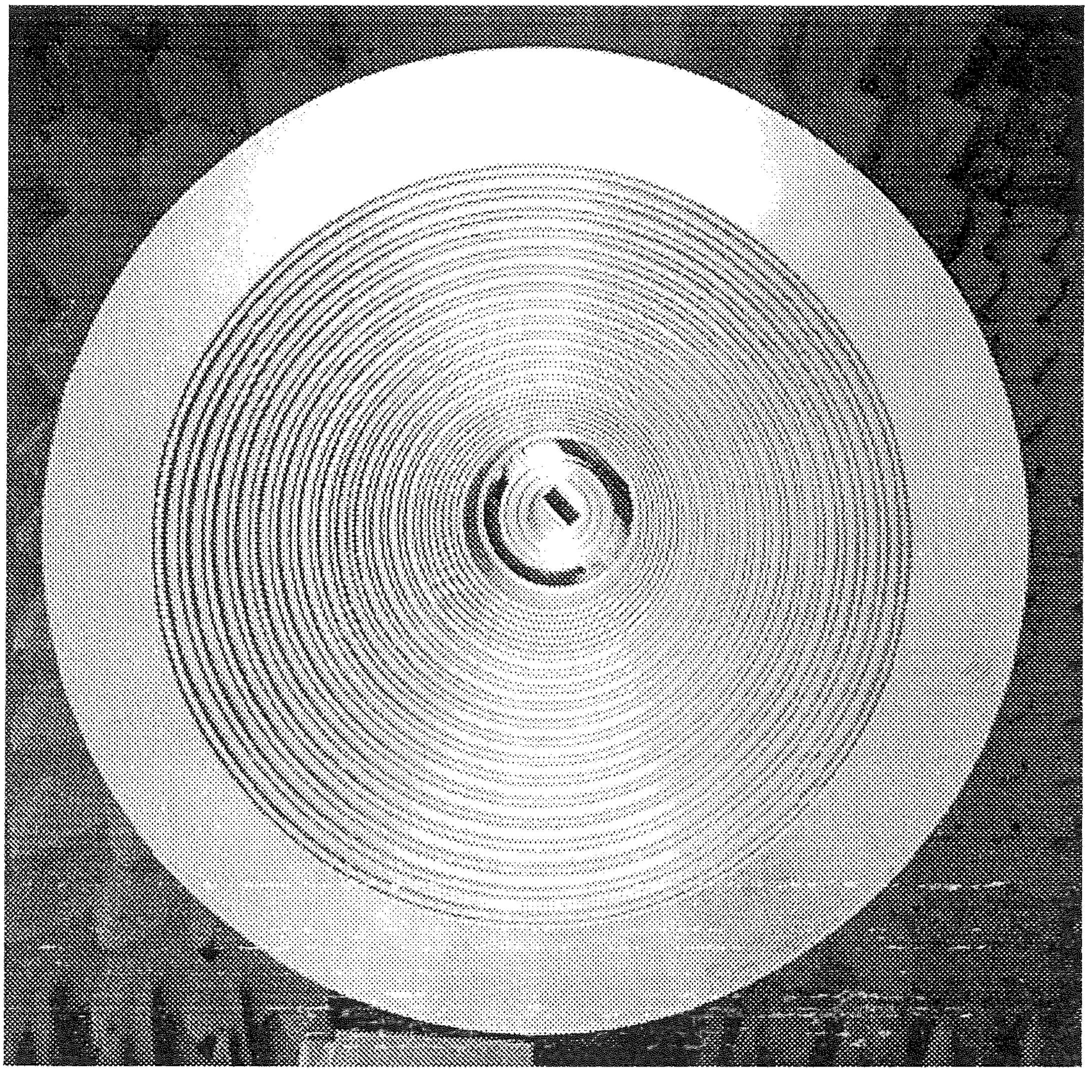

Figure 2: Front view of the prototype dual-frequency feed horn.

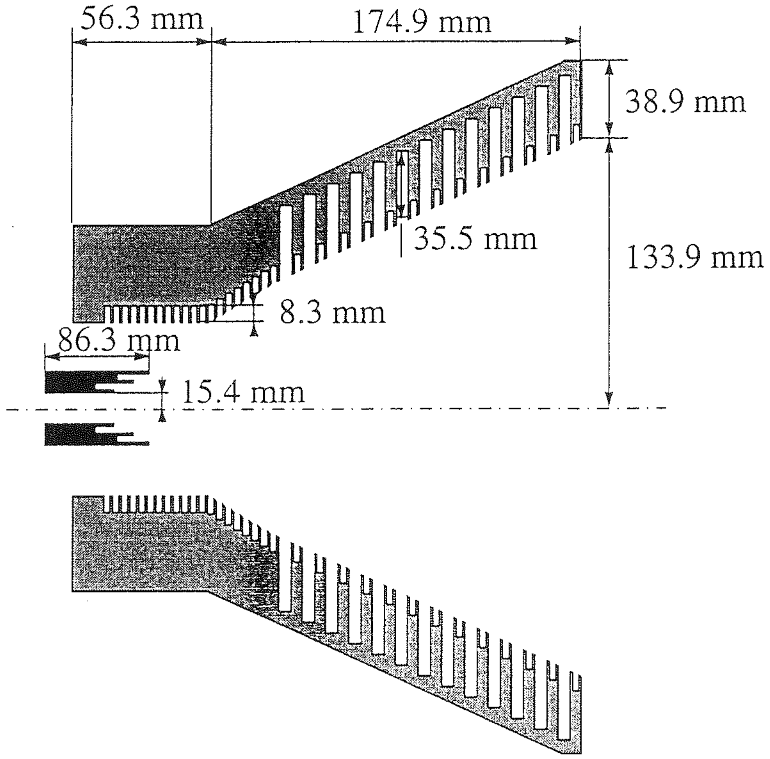

Figure 3: The cross section of the dual-frequency corrugated horn.

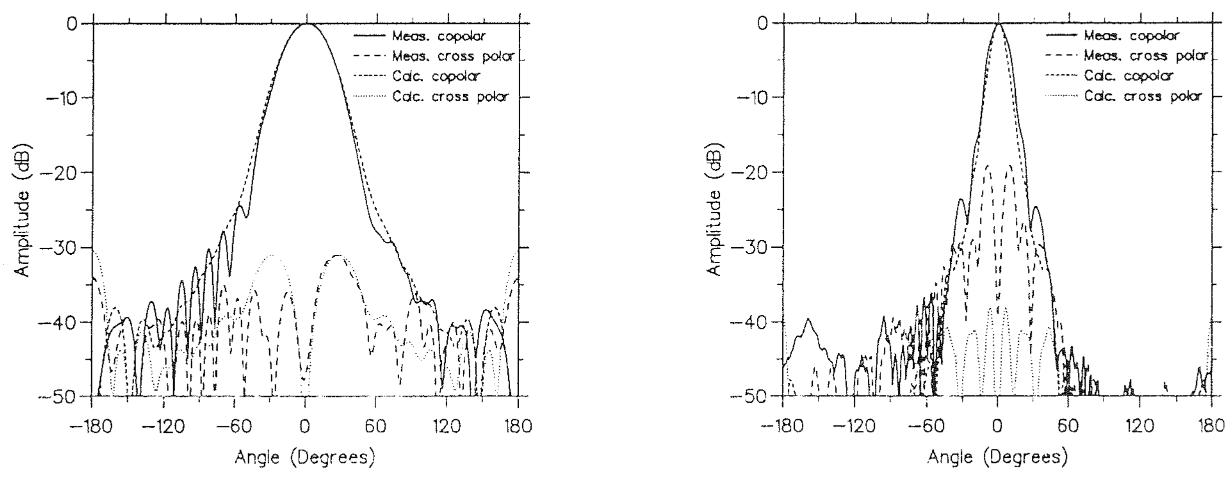

Figure 4: Measured and calculated co- and cross-polar radiation patterns of the corrugated horn at the S-band center frequency 2.3 GHz (left) and at the X-band center frequency 8.5 GHz (right).

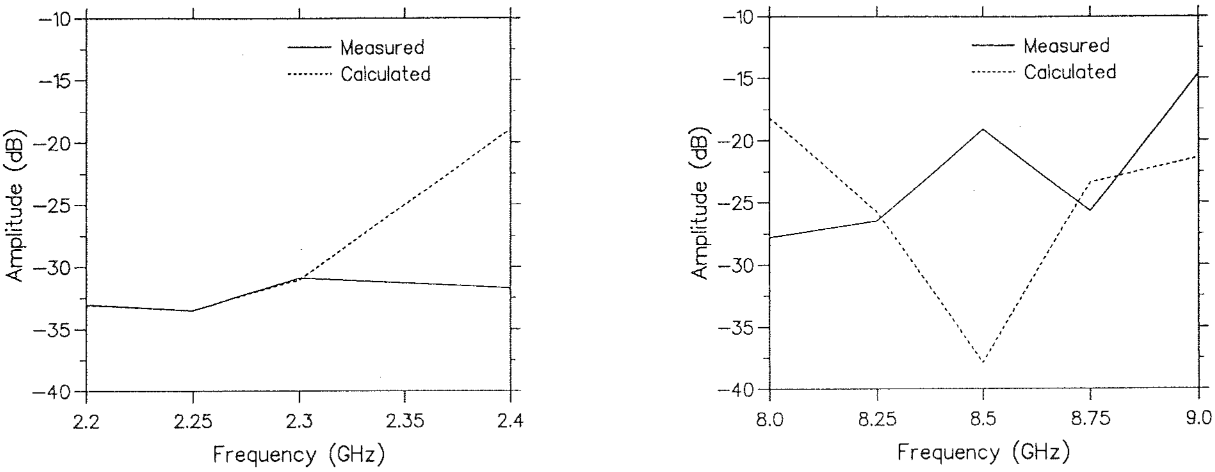

Figure 5: Computed and measured relative level of the first crosspolar sidelobe of the corrugated horn (S-band at the left and X-band at the right).

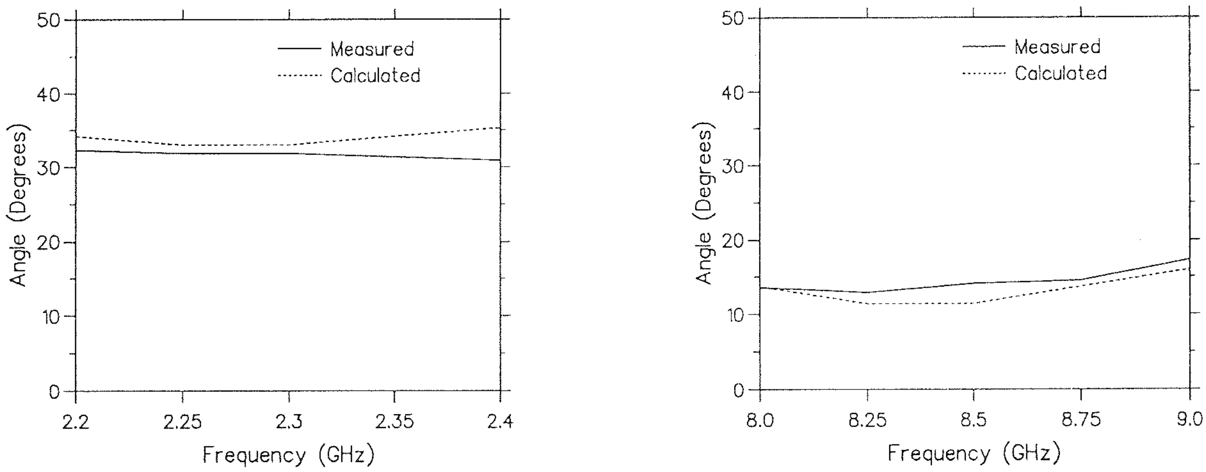

Figure 6: Computed and measured full-width half-power beam widths of the radiation patterns of the corrugated horn (S-band at the left and X-band at the right).

THE POLARIZERS

Two septum polarizers [*Bornemann and Labay*, 1995], both in a circular/quadratic waveguide geometry are in the process of being designed by using Hewlett Packard's HFSS (High Frequency Structure Simulator) based on the Finite Element Method. A drawing of the X-band polarizer and the corresponding simulated results are shown in Figures 7 and 8. It consists of a quadratic waveguide (port 3) with a stepped metal septum in the center which separates the quadratic cross subsection into two rectangular waveguides (ports 1 and 2). When the polarizer is excited at port 3 with a left (right) hand circular signal, it appears in the basic TE_{10} mode at the rectangular waveguide port 1 (2). When the manufacture and validation of this unit is completed we anticipate to make a scaled version for S-band.

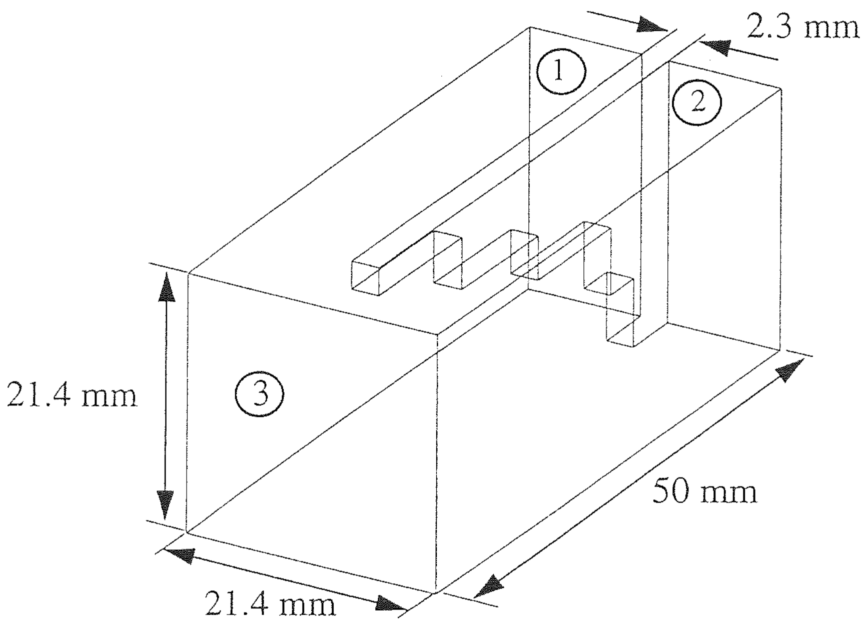

Figure 7: A drawing showing the principle design of the septum type polarizer at X-band.

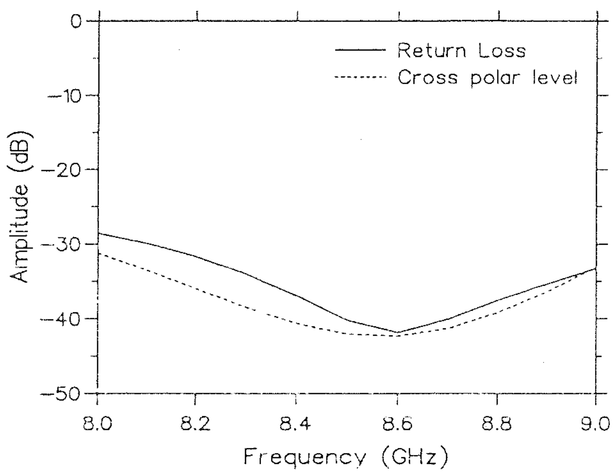

Figure 8: The return loss and cross polarization for the X-band polarizer simulated with HFSS.

THE COAXIAL WAVE TRANSFORMER

This component makes it possible to have access to the X-band ports (RCP and LCP) that are inside the coaxial S-band waveguide, before transforming the S-band coaxial waveguide into the S-band septum polarizer in circular/quadratic waveguide. In the final circular waveguide we will locate a septum polarizer for S-band. A sketch of the complete circular-coaxial-radial-foursplitcoaxial-radial-coaxial-circular transformer is shown in Figures 9. Figure 10 shows the return loss over the S-band frequencies of this entire unit and a 3-D model is found in Figure 11.

Before adopting this present design a lot of effort was spent trying to implement a septum type dual polarizer within the coaxial S-band waveguide around the X-band septum polarizer. However, we concluded that the results obtained were not acceptable and finally decided to aim for the slightly more complicated design which works satisfactory according to the HFSS simulations.

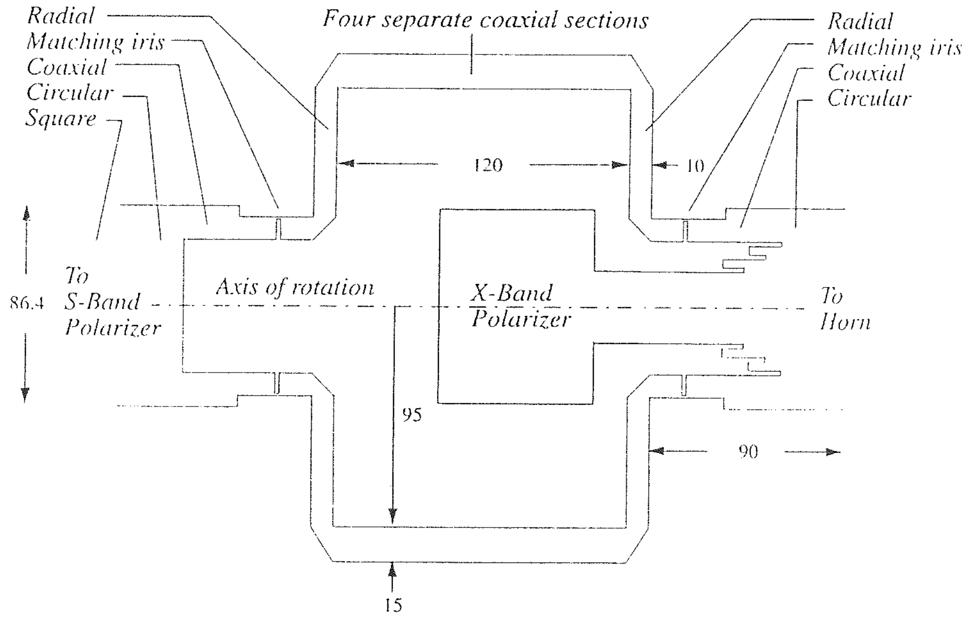

Figure 9: Cross section of the S-band wave transformer. The received wave propagates from the circular horn via the transformer to the S-band polarizer in square waveguide.

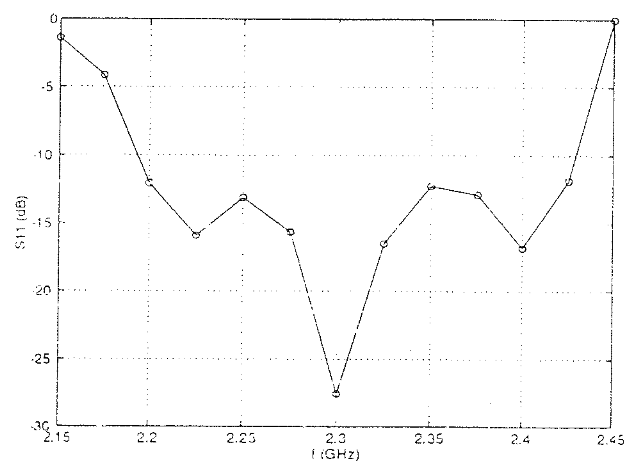

Figure 10: The return loss of the S-band coaxial wave transformer simulated using the HFSS.

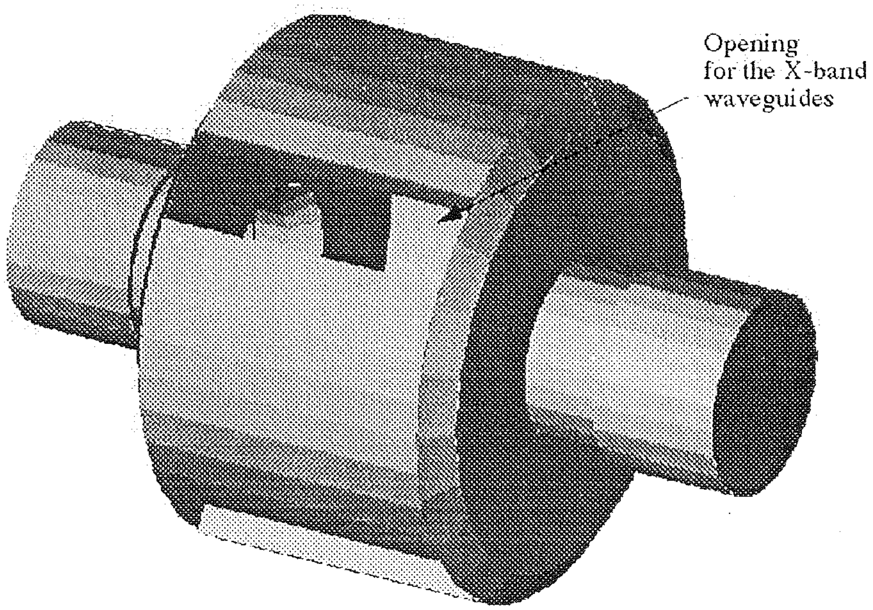

Figure 11: This gray-scale picture shows the wave transformer with one of the openings, between the four coaxial sector S-band waveguides, where the X-band waveguides will pass through.

CONCLUSIONS

The work with the new S- and X-band feed system has now gone into a production phase. All components have been characterized with reasonable results using different types of software simulations. The dual-frequency corrugated horn has been manufactured and the performance is satisfactory.

We are confident that the new system will be an improvement compared to the existing one, providing dual polarization and significantly higher aperture efficiencies at both S- and X-bands.

Acknowledgements

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References

Bornemann, J. and V. A. Labay, Ridge waveguide polarizer with finite and stepped-thickness septum, *IEEE Trans. Antennas and Propagat.*, **AP-43**, 1782–1787, 1995.

Clark, T.A., B.E. Corey, J.L. Davis, G. Elgered, T.A. Herring, H.F. Hinteregger, C.A. Knight, J.I. Levine, G. Lundqvist, C. Ma, E.F. Nesman, R.B. Phillips, A.E.E Rogers, B.O. Rönnäng, J.W. Ryan, B.R. Schupler, D.B. Shaffer, I.I. Shapiro, N.R. Vandenberg, J.C. Webber, and A.F. Whitney, Precision Geodesy Using the Mark-III Very-Long-Baseline Interferometer System, *IEEE Trans. Geoscience and Remote Sensing*, **GE-23**, 438–449, 1985.

Flodin, J., Design of an S/X Band Corrugated Horn Feeding the Onsala Radio Telescope via a Reflector System, *Master Thesis*, Department of Microwave Technology, Chalmers University of Technology, 1995.

Flodin, J., P.-S. Kildal, and A. Kishk, Moment Method Design of a Large S/X Band Corrugated Horn, *Proc. IEEE Int. Symp. on Antennas and Propagation*, Baltimore, MD, July 21-26, 1996.

Hirosawa, H., and H. Hirabayashi, VLBI Space Observatory Programme (VSOP) Satellite, *IEEE AES Systems Magazine*, **10**, No. 6, p. 17, 1995.

Jaldehag, R.T.K., Studies of Reflector Antenna Systems for Geodetic Very-Long-Baseline Interferometry, *Tech. Rept. No. 120L*, School of Electrical and Computer Engineering, Chalmers University of Technology, 1992.

Jaldehag, R.T.K., P.-S. Kildal, and B.O. Rönnäng, Dual Band Reflector Feed Systems for Classical Cassegrain Radio Telescopes, *IEEE Trans. Antennas Propagat.*, **AP-41**, 325-332, 1993.

Johansson, M., Low Noise VLBI Antenna Feed, *Proc. Antenn 94*, 327-336, Eskilstuna, Sweden, 1994.

Kildal, P.-S., L.A. Baker, and T. Hagfors, The Arecibo Upgrade: Electrical Design and Expected Performance of the Dual-Reflector Feed System, *Proc. IEEE*, **82**, 714-724, 1994.

Kishk, A.A, and L. Shafai, Different Formulations for Numerical Solution at Single or Multibodies of Revolution with Mixed Boundary Conditions, *IEEE Trans. Antennas Propagat.*, **AP-34**, 666-673, 1986.

Pettersson, L., Design of the S-Band Part of the S/X-Band Feed System for the Onsala Telescope, *Master Thesis*, Department of Microwave Technology, Chalmers University of Technology, 1997.

Rogers, A.E.E., R.J. Capallo, B.E. Corey, H.F. Hinteregger, A.E. Niell, R.B. Phillips, D.L. Smythe, A.R. Whitney, T.A. Herring, J.M. Bosworth, T.A. Clark, C. Ma, J.W. Ryan, J.L. Davis, I.I. Shapiro, G. Elgered, K. Jaldehag, J.M. Johansson, B.O. Rönnäng, W.E. Carter, J.R. Ray, D.S. Robertson, T.M. Eubanks, K.A. Kingham, R.C. Walker, W.E. Himwich, C.E. Kuehn, D.S. MacMillan, R.I. Potash, D.B. Shaffer, N.R. Vandenberg, J.C. Webber, R.L. Allshouse, B.R. Schupler, and D. Gordon, Improvements in the Accuracy of Geodetic VLBI," *Contributions of Space Geodesy to Geodynamics: Technology*, eds. D.E. Smith, and D.L. Turcotte, AGU Geodynamics Series, **25**, pp. 47-63, 1993.

Rubiños-López, J.Ó., Study of S/X-band reflector feeds for the Onsala radio telescope, *Report No 19*, Department of Microwave Technology, Chalmers University of Technology, 1995.

Rubiños-López, J.Ó., P.-S. Kildal, J. Flodin, and G. Elgered, S/X-Band Beam Waveguide for the Onsala Radio Telescope, *Proc. IEEE International Symposium on Antennas and Propagation*, Baltimore, MD, July 21-26, 1996.

Schilizzi, R.T., Current Developments in VLBI Astronomy on the Ground and in Space, *The Radio Science Bulletin*, No. 274, p. 14, 1995.