Demonstration of TM_{01} Circular Waveguide Mode in Matched Feeds for Single Offset Reflectors

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***Abstract*—Matched-feed horns can be employed to reduce the inherent cross polarization of offset reflector antennas. For circular horns, the traditional method is to excite TE_{21} modes in the aperture. We recently proposed that TE_{01} or TM_{01} modes can be used instead, for horizontal and vertical polarization, respectively. To validate this, a matched feed using TM_{01} is designed and demonstrated for the first time. The presented horn reduces cross polarization by $17\,\mathrm{dB}$ at the design frequency and by $10\,\mathrm{dB}$ over a $2.2\,\%$ bandwidth.**

I. Introduction

Offset reflector antennas are widely used in practice since radiation blockage can be avoided. However, tilting the feed toward the offset reflector results in curved field lines in the reflector aperture, which again results in cross polarization in the far field. In a dual reflector system, this can be compensated by applying the so-called Mizuguchi condition.

A way to compensate cross polarization for single offset reflector systems is to modify the feed radiation to cancel out the otherwise curved field lines in the reflector aperture. This method was published in the 70's by Rudge and Adatia [1] and often goes under the name *matched feeds*. They achieve cross polar cancellation by exciting higher order modes in different types of waveguide-based feed horns. For circular cross-section horns, the TE_{21} mode was proposed. It was later clarified in [2] that compensation can be achieved in both polarizations with two orthogonal versions of TE_{21}.

Several circular aperture matched feeds using TE_{21} modes have been published, e.g. [3], [4], [5]. We showed in [6] that TE_{01} and TM_{01} can be used in place of the two orthogonal TE_{21} modes, but no actual design utilizing this was presented. In this paper we demonstrate a matched feed design for an offset reflector using only TM_{01} added to a Potter horn.

II. Optimal Mode Excitation

The required mode mixture in the aperture of a matched-feed horn may be found in several ways. The one used here is described in [6], and involves optimizing the mode excitation based on the reflector aperture field. It is found that one can replace the TE_{21} modes with TE_{01} and TM_{01} modes for the two polarizations, respectively. Fig. 1 shows the optimal combination of TE_{11}, TM_{11}, and TE_{01} or TM_{01}. The compensating modes must be in phase quadrature with the fundamental mode, as is also the case with traditional matched feeds — the precise relationships are detailed in [7]. Vertical polarization refers to polarization parallel to the offset plane. The TM_{11} mode is included to reduce the feeds own cross polarization, as is done in traditional Potter horns.

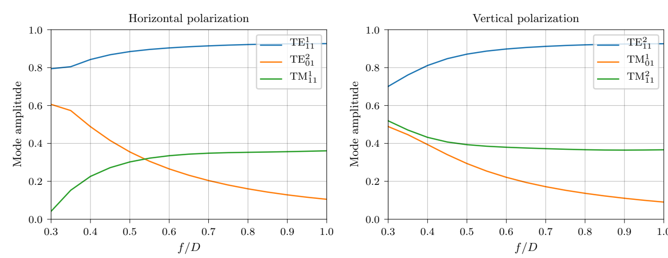
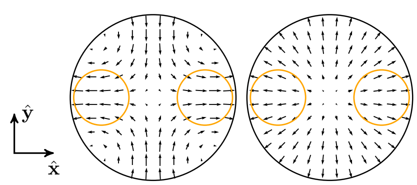


Fig. 1. Optimized mode excitation coefficients for f/D values between 0.3 and 1. TE_{21} modes have been excluded.

The suitability of TM_{01} may be understood by inspecting its modal field compared to the one of TE^1_{21} in Fig. 2. They have the same required regions of cross polarization compared to a y-polarized fundamental mode. The same argument can be made for TE_{01} and TE^2_{21}.



(a) TE^1_{21} (b) TM_{01}

Fig. 2. Transverse fields of the TE^1_{21} and the TM_{01} mode. The equivalent regions of cross polarization equivalent are highlighted.

The target reflector system is a heavily offset system with an f/D of 0.6, operating in vertical polarization. The required TM_{01} modal amplitude is read from Fig. 1 to be approximately 0.2.

III. Design

The design is carried out just like many other matched feed designs in the literature. The only differences are the mode launcher and the choice of waveguide radii. The different sections of the horn can be seen in Fig. 3. The radius a_1 is chosen such that only TE_{11} can propagate, a_2 such that TM_{01} also can, and a_3 such that TM_{11} also can.

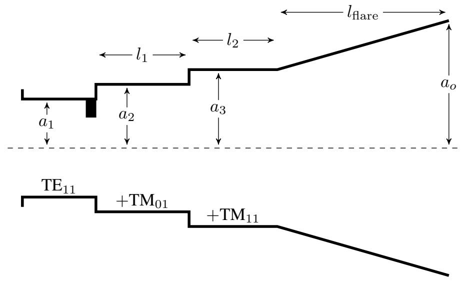


Fig. 3. Topology of the TM_{01} matched feed. The pin type mode launcher is indicated in the step between a_1 and a_2.

A mode launcher converting power from the incident TE_{11} mode to the TM_{01} may be designed by the techniques given in [8]. One solution is to place radial pins in the top or bottom half of the waveguide (not both, as they would cancel out). Higher order modes will be generated as well, but the following piece of waveguide will suppress them because it only supports TE_{11} and TM_{01} modes.

The design procedure is as follows:

1) Fix a_1 and a_2 and adjust pin lengths (l_{pin}) of the mode launcher until the TM_{01} mode amplitude is ≈ 0.2.
2) Optimize Potter horn part of the feed for low cross polarization and appropriate edge taper. Variables are a_3, l_2, l_{flare}, and a_o.
3) Assemble mode launcher and Potter horn. Adjust l_1 until TM_{01} is 90° ahead of TE_{11} in the aperture.
4) Optimize reflector far field for low cross polarization with l_1 and pin length as variables.

The last step fine tunes the design, as the intermediate goals are somewhat approximate. The different sections of the horn are analyzed using 3D MoM, mode matching, and BoR-MoM, and combined using generalized scattering matrices. The reflector field is evaluated with PO/PTD. The dimensions of a feed design carried out at $5\,\text{GHz}$ are listed in Table I. The design is rendered in Fig. 4.

TABLE I
FINAL DIMENSIONS OF THE DESIGN.

	[mm]		[mm]
a_1	21.0	l_1	79.9
a_2	25.0	l_2	75.2
a_3	36.7	l_{flare}	147.5
a_o	56.0	l_{pin}	10.2

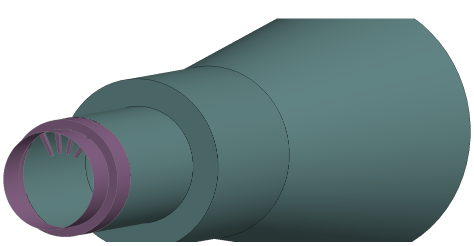
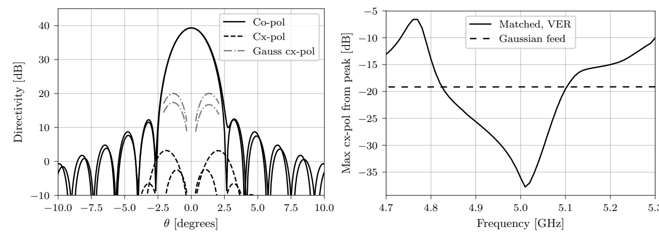


Fig. 4. Feed viewed from the back. The TM_{01} mode launcher part is highlighted showing the four radial pins.

IV. RESULTS

The radiation pattern of the full reflector system at the design frequency is shown in Fig. 5a. The cross polarization is drastically reduced compared to a reference purely co-polarized feed. Fig. 5b shows this reduction as a function of frequency. The fractional frequency band within which the feed reduces cross polarization by $10\,\text{dB}$ or more is $2.2\,\%$.

To make sure that we have not inadvertently made a regular TE_{21} matched feed, the modal spectrum in the horn aperture is examined. The amount of TE_{21} mode is below $-50\,\text{dB}$ in the band of interest, and therefore has very negligible effect.



(a) (b)

Fig. 5. Cross-polar performance of the TM_{01} matched feed. (a): Reflector radiation pattern in asymmetry and diagonal planes. Cross polarization of a Gaussian beam feed is indicated in grey. (b): Cross polarization relative to peak directivity as a function of frequency.

V. CONCLUSION

A matched feed using the circular TM_{01} instead of the TE_{21} mode has been designed for the first time. The feed is designed for a single frequency for demonstration purposes, but achieves $10\,\text{dB}$ cross polar reduction over a $2.2\,\%$ fractional bandwidth. In single polarized applications, the TM_{01} mode has potential for wider bandwidth than the TE_{21} mode, since it is closer in cutoff to the fundamental mode.

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