High Gaussicity feedhorns for sub- / millimeter wave applications

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***Abstract*—In feedhorn design, the power coupling to the fundamental free-space LG_{00} mode, or Gaussicity, is a good proxy for high performance, particularly the sidelobe and cross-polar levels and the near-field behavior. Gaussicity can be maximized by ensuring that the first few horn modes reach the aperture with the appropriate phase and amplitude relationship. We present two feedhorn designs for which the Gaussicity was maximized in order to achieve high performance. The first is a 94 GHz corrugated horn with a tanh-linear profile, manufactured by electroforming, which achieves a Gaussicity of 99.92% at band center and sidelobes at the -60 dB level. The second is a 340 GHz smooth-walled spline horn which achieves a Gaussicity of >99.2% over a 10% bandwidth, sidelobes below -30 dB and excellent near-field behavior. This design has been successfully fabricated in E-plane split block suitable for low volume manufacture, for example for imaging arrays.**

I. INTRODUCTION

FEEDHORN antennas are mode converters that transform waveguide modes from the input waveguide, via modes supported by the particular horn structure, into directive free-space modes. Often it is desirable they do this with high efficiency, low sidelobe levels and low levels of cross-polarization. Such antennas are frequently used in quasi-optical instruments, as feeds in large telescopes, communications or radar systems, or as part of imaging arrays.

It is common to characterize high performance feedhorns by their Gaussicity, or power coupling to the fundamental free-space LG_{00} mode. Gaussicity is an excellent proxy for the commonly sought-after measures of performance in feedhorns such as sidelobe and cross-polar levels and near-field beam quality [1]. High Gaussicity can be achieved by ensuring the first few fundamental modes supported in the horn are in the correct phase and amplitude relationship at the aperture [2].

We present two feedhorn designs whose profiles have been optimized to maximize the Gaussicity and thus achieve target performance metrics.

II. CORRUGATED TANH-LINEAR PROFILE DESIGN

The first horn design is a 94 GHz corrugated horn with a tanh-linear profile [3], fabricated in gold-plated copper by electroforming. The horn is designed to excite the first three hybrid corrugated waveguide modes, HE_{11}, HE_{12} and HE_{13}, such that they arrive in the correct amplitude and phase relationship at the horn aperture. We used the CORRUG mode matching software integrated with an optimization routine in MATLAB to achieve a design with a 20 dBi directivity which maximized Gaussicity, and hence minimized the sidelobe and cross-polar levels, in as short a horn as possible, operating over a 20% bandwidth centered at 94 GHz. The horn has a 2.39 mm diameter circular input waveguide.

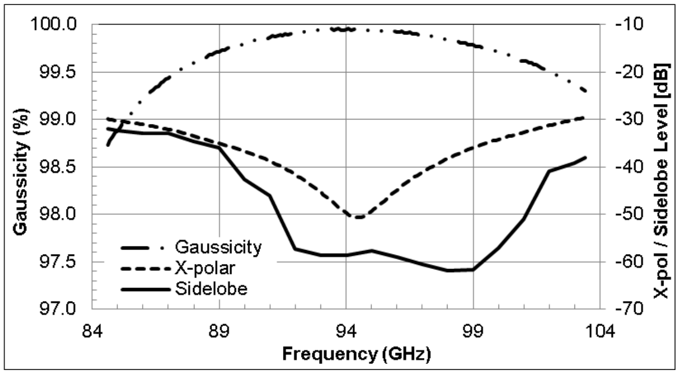

Fig. 1. Simulated Gaussicity, cross-polar and sidelobe levels for corrugated tanh-linear profile horn.

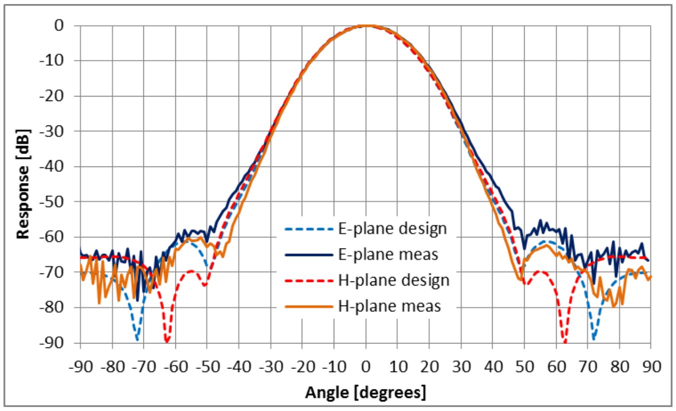

Fig. 2. Measured and simulated far-field antenna patterns at 94 GHz for corrugated tanh-linear profile horn.

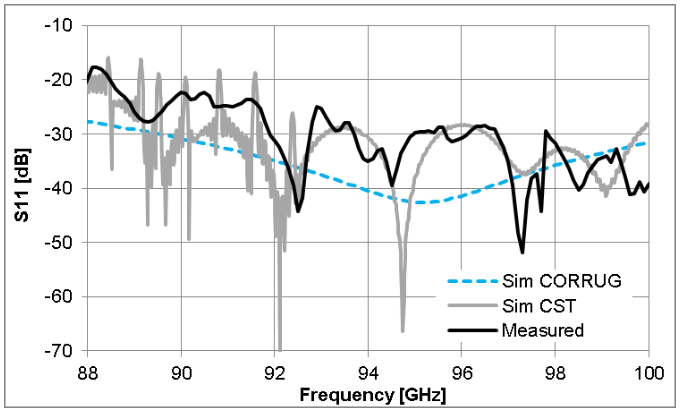

Fig. 3. Measured and simulated input return loss S11 for corrugated tanh-linear profile horn.

Swept frequency simulation results obtained from CORRUG are given in Fig. 1 which show that the horn achieves 99.92% Gaussicity at band center and >99.6% over 88 to 101 GHz. Cross-polar and peak sidelobe levels are better than -30 dB over the full 20% bandwidth. Cross-polar reaches -50 dB at 94 GHz and the peak sidelobe level reaches approximately -60 dB from 92 to 100 GHz. These very high levels of performance are achieved in a horn which is just 15.6λ long.

The measured and simulated far-field patterns at 94 GHz are shown in Fig. 2. An external 25 mm long tapered transition was used to convert from WR-10 rectangular waveguide to the circular waveguide input. The results display excellent agreement between measurement and simulation and confirm the extremely low sidelobe level of -60 dB is achieved at 94 GHz, believed to be one of the lowest ever reported at this frequency, and hence confirm the high Gaussicity achieved with this design.

The return loss of the horn was measured (including the external transition) using an Anritsu ME7838A VectorStar vector network analyzer. The results are compared with CORRUG and CST Microwave Studio simulations in Fig. 3 and show general agreement of the frequency trend. Note the CORRUG model does not include the rectangular-to-circular transition. The CST simulations show better agreement with the measured data, although some simulation artefacts are observed below 93 GHz which are thought to be due to imperfect meshing within the corrugations.

III. SMOOTH-WALLED SPLINE PROFILE DESIGN

The second horn design is a 340 GHz smooth-walled horn with spline profile [4], fabricated in E-plane split-block aluminum by direct machining. This fabrication method was chosen to lower the cost of manufacture, suitable for producing low volume quantities for imaging arrays. In this design the TE and TM modes were optimized using a genetic algorithm to maximize Gaussicity to achieve both good near-field behavior and wideband performance. The key target performance metrics were that it should have a symmetric -10 dB beamwidth of 9.8° ± 5% over a 30 GHz bandwidth centered at 340 GHz and as high a Gaussicity as possible (>98%). The horn has a WM-650 (650 x 325 µm) rectangular waveguide input with integral transition to circular waveguide, a 6.75 mm diameter aperture and is 36 mm long.

The spline profile part of the horn was simulated in CORRUG and the full structure including the rectangular-to-circular transition was then verified in CST. Swept frequency simulations obtained with CORRUG are shown in Fig. 4. The predicted -10 dB beamwidth is very close to requirements and the Gaussicity exceeds 99.2% over the full 30 GHz bandwidth, exceeding that reported for similar designs [5].

The far-field patterns were measured in the E- and H-planes at low-, mid- and high-band frequencies and results for two sample horns at 340 GHz are shown in Fig. 5 alongside CST simulations. The agreement between measurement and simulation is excellent down to below -40 dB. The mainlobe shows some low level asymmetry below -15 dB, probably due to the smooth-walled nature of the horn, and the sidelobe level is below -30 dB. The repeatability between the two units measured is excellent which verifies the split-block direct machining approach is appropriate for manufacturing such horns in quantities suitable for imaging arrays.

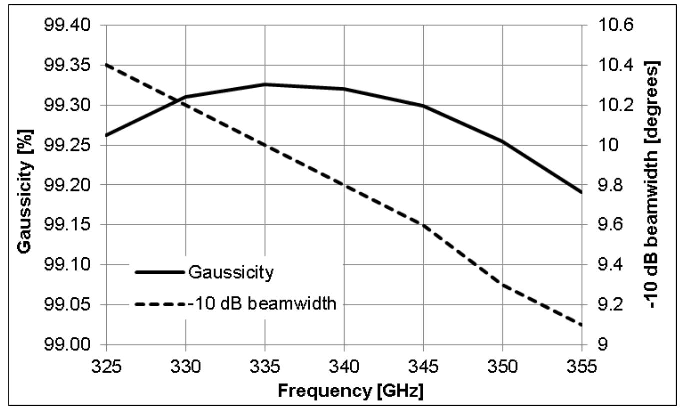

Fig. 4. Simulated Gaussicity and -10 dB beamwidth for smooth-walled spline profile horn.

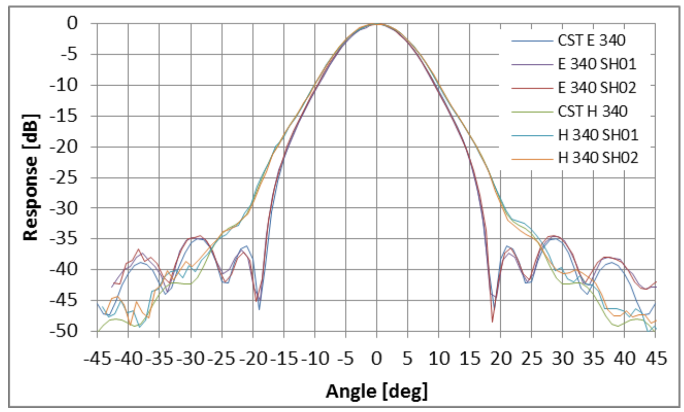

Fig. 5. E- and H-plane far-field antenna patterns at 340 GHz for smooth-walled spline profile horn: CST simulations and measurements for two sample horns.

IV. CONCLUSIONS

We have reported two feedhorn designs which use modal optimization to maximize performance. Gaussicity is used as an optimization target and is an excellent proxy for near-field beam quality and low sidelobe and cross-polar levels. The corrugated tanh-linear design achieves 99.92% Gaussicity and -60 dB sidelobes at 94 GHz. The smooth-walled spline design achieves >99.2% Gaussicity over a 30 GHz bandwidth at 340 GHz; for many applications such levels of performance would be sufficient and the directly machined construction offers significant benefits over electroforming.

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