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A Quasi-optical mode converter for a w-band gyrotron traveling wave amplifier

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Abstract:

A W-band corrugated horn has been designed, manufactured, and experimentally measured at the University of Strathclyde, for integration into a gyro-device as a quasi-optical launcher. This horn converts a cylindrical TE_{11} mode into a free space TEM_{00} mode in a frequency band of 84–104 GHz with a reflection better than -30 dB and a Gaussian coupling efficiency of ~98% and directivity of 26.6 dB at 95 GHz. The small beam waist makes such a horn ideal for use with a depressed collector system. The measured results are in excellent agreement with the numerical simulations.

Introduction:

Gyro-devices [1-3] are well suited to application in plasma physics, remote sensing and imaging and for electron spin resonance spectroscopy, due to the fast-wave cyclotron resonance maser instability, which is capable of producing high power coherent microwave radiation at frequencies(mm and sub-mm), that prove challenging for other sources. A W-band gyrotron traveling wave amplifier (gyro-TWA) and gyrotron backward wave oscillator (gyro-BWO) [4] based on a cusp electron beam source [5-7] and a helically corrugated interaction region (HCIR) [8] have been developed to provide a continuously tuneable source with a continuous wave (CW) power output of ~5 kW and ~10 kW respectively. The gyro-TWA was simulated to have a 3 dB frequency bandwidth of 90–100 GHz while the gyro-BWO demonstrated a tuning range of 88-102.5 GHz and has achieved an output power of 12 kW [9]

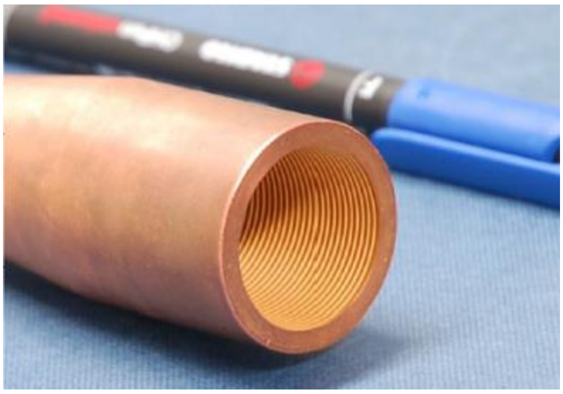

Fig. 1 W-band corrugated horn.

Corrugated output:

An energy recovery system can further increase the overall system efficiency of the gyro-devices by converting the kinetic energy of the spent electron beam into electric energy. However, energy recovery systems would cause undesired microwave reflection into the beam-wave interaction region which necessitates that the wave should be coupled out before the collector system. This decoupling of the beam and radiation may be achieved by means of a quasi-optical mode converting horn (fig. 1). This alters the fundamental operating mode within the gyro-TWA (TE_{11}) to a hybrid mode that is generally accepted to consist of 85% TE_{11} and 15% TM_{11} (by power) and is closely coupled to the fundamental free space Gaussian mode (TEM_{00}) [10]. This Gaussian radiation beam may then pass through the collector system and vacuum window [11] unperturbed while the electrons are collected at the energy recovery system that is predicted to increase overall efficiency to 40% by recovering the energy of the spent electron beam [12-14]. This type of corrugated mode converting horn was chosen over more conventional beam-wave decoupling methods due to the perceived performance advantages that it makes possible; both greater bandwidth and the capability to provide a source that is continuously tuneable over this bandwidth. From an initial the primary consideration was the reduction of the reflection, which was best achieved using a $\sin^2$ profile as described by Clarricoats and Olver [15]. From this baseline design a prototype model was constructed with corrugations linearly tapered in depth from $\lambda/2$ at the throat of the horn to $\lambda/4$ at the aperture, to produce optimum conditions for impedance matching between the horn and the gyro-TWA and minimize the reflection. The corrugation and vane length were initially set to $\lambda/10$ and $\lambda/30$. This prototype design was then numerically optimized over the operating frequency band. This was done using a mode matching technique, which allows for fast implementation and optimization of various designs and geometries and a high degree of freedom when selecting the design parameters.

Experimental Results:

This prototype horn was constructed by the electroforming of copper onto an aluminium substrate, which was constructed in-house at the University of Strathclyde. Once the aluminium had been dissolved the finalized device was then tested on a W-band Anritsu 3738A VNA. The reflection from the horn was determined by one port measurement where microwaves were radiated into free space. Fig 2 shows the measured performance of the horn compared with the simulations.

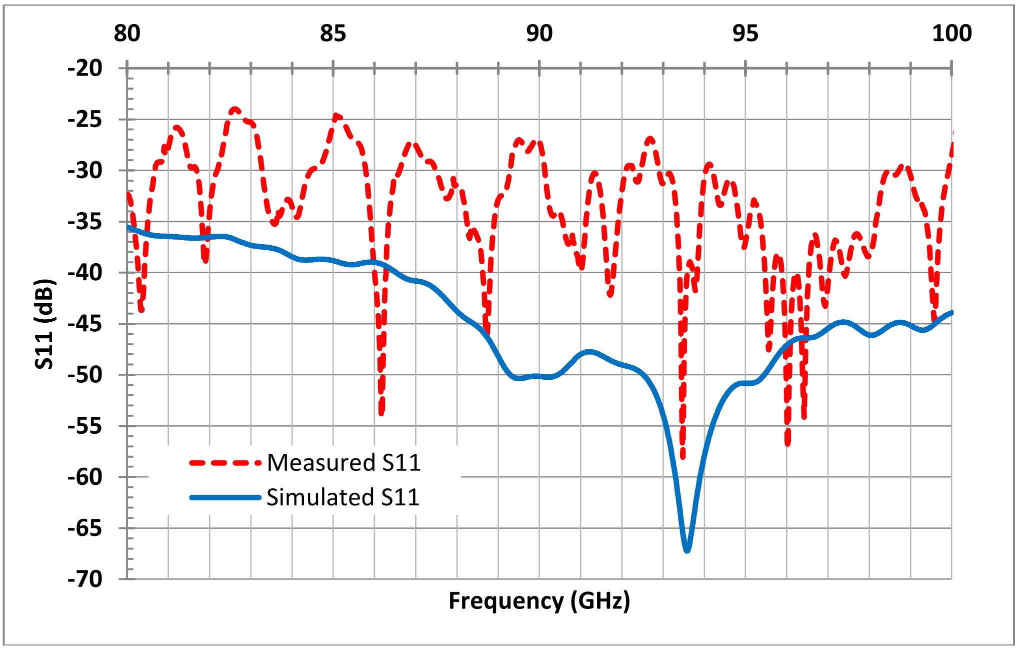

Fig. 2 Simulated and measured S_{11} performance of horn.

Fig. 3 shows the measured far-field pattern at 95 GHz compared with numerical simulation. The -30 dB edge is within a half angle of 15.2 degrees and the pattern shows more than 99% of the output power is within 30 degrees. The simulated results showed a Gaussian couple efficiency of ~98% and measured results show a reflection of better than -30 dB, as shown in Fig. 2, over 88-102 GHz, and directivity of 26.6 GHz at 95 GHz.

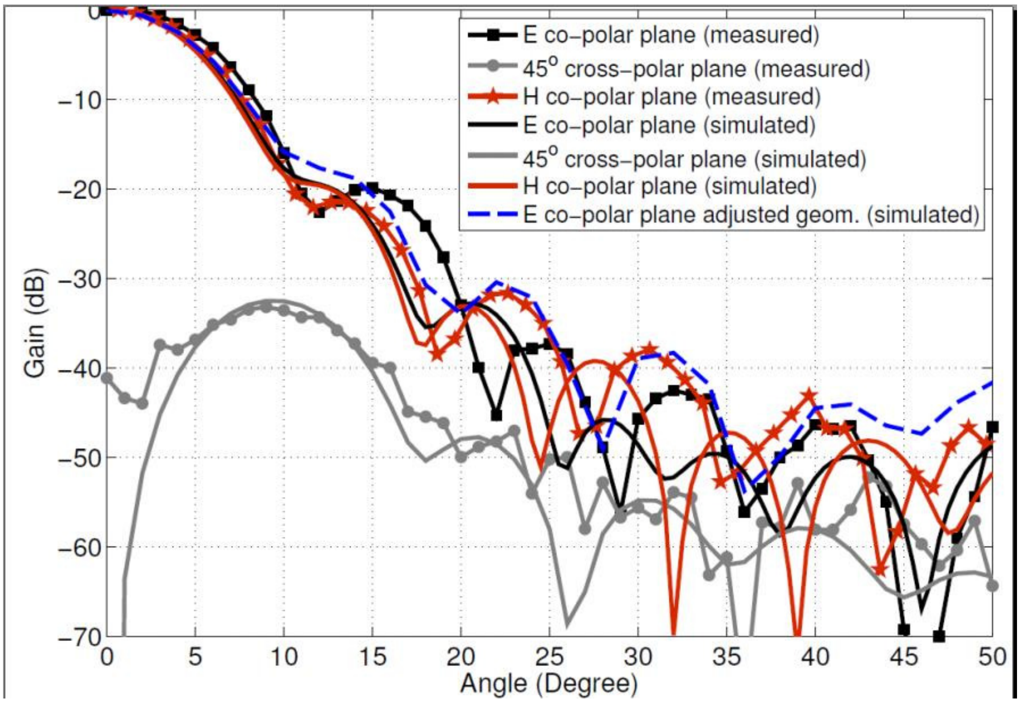

Fig. 3 Far-field performance of the corrugated horn.

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