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A C-BAND RF MODE LAUNCHER WITH QUADRUPOLE FIELD COMPONENTS CANCELLATION FOR HIGH BRIGHTNESS APPLICATIONS

Giuseppe Pedrocchi, Mauro Migliorati, Andrea Mostacci, Luigi Palumbo
Sapienza University of Rome, Roma, Italy
Luca Ficcadenti, INFN-Roma, Roma, Italy
Giovanni Castorina, AVO-ADAM, Meyrin, Switzerland
David Alesini, Alessandro Gallo, Anna Giribono, Bruno Spataro, Fabio Cardelli
INFN/LNF, Frascati, Italy

Abstract

The R&D of high gradient radiofrequency devices is aimed to develop innovative and compact accelerating structures based on new manufacturing techniques and materials in order to produce devices operating with the highest accelerating gradient. Recent studies have shown a large increase in the maximum sustained RF surface electric fields in copper structure operating at cryogenic temperature. These novel approaches allow significant performance improvements of RF photoinjectors. Indeed the operation at high surface fields results in considerable increase of electron brilliance. This requires high field quality in the RF photoinjector and specifically in its power coupler. In this work we present a novel power coupler for the RF photoinjector. The coupler is a compact C-band TM_{01} mode launcher with a fourfold symmetry which minimized both the dipole and the quadrupole RF field components.

INTRODUCTION

At present several efforts in the development and construction of novel accelerators are aiming at reaching the highest possible accelerating gradients to have a more compact structure. This implies a higher risk of RF breakdown in accelerating structures with present power couplers designs linked to the main cell. Furthermore the beam emittance can be heightened by the multipole components of the accelerating field. It imposes the two-fold construction objective of maintaining a multipole free accelerating field and avoiding RF breakdown phenomena. These reasons have pushed for the innovation of the nowadays power coupler structures as the solution to satisfy these requirements, supported by the many studies, also conducted by the INFN [1], that have shown the promising results, that can now be obtained with the aid of the present electromagnetic codes, a technology which has nowadays reached maturity and is fundamental for complex tasks such as this. A promising power coupler mode launcher design for reaching these purposes and operating in C-band, initially under development for a novel C-band accelerator project for SPARC and ELI-NP linac since 2013 [2-5], and part of a INFN effort to develop new C-band damped devices with higher shunt impedance and exploiting new technology based on clamping [6-9], is a four-branched geometry that allows the conversion of the rectangular TE_{10} mode coming from the klystron to the circular TM_{01} accelerating mode. Such conversion keeps the accelerating field free of multipole components and at the same time the geometry of the device is chosen to minimise the reflection of the input power. Such design is based on previous projects aimed at operating in X-band frequencies, originally developed by the INFN's laboratories in Catania, Italy, re-scaled to operate in C-band frequencies, after previous works showed the feasibility of this redesign, and modified to obtain again the minimum possible power reflection at the chosen working frequency of 5.712 GHz [10-14]. Chosen construction requirements demanded that at 5.712 GHz the S_{11} coefficient at the input power gateway be equal or below -40 dB to proceed with further project steps.

DESIGN PROPERTIES OF THE MODE LAUNCHER COUPLER

The design of this device proposes a four-branched symmetry, see Fig. 1. For the device to operate in C-band frequencies, WR187 standard dimensions have been chosen for the rectangular wave-guides that are part of its structure. This means a width of 47.5488 mm and a height set at 22.1488 mm. The radius of the cylindrical wave-guide that delivers power to the RF photoinjector has been chosen as 22 mm. The cylindrical wave-guide is positioned at the intersection of the four arms converging at the center of the device and it is lodged right behind the gun, providing the accelerating field at the cathode. The power input branch protrudes from the four-fold geometry. Inductive matching protrusions (bumps) allow the device to excite the accelerating field resonance thus minimizing reflection by matching the power delivery network to its load. This is accomplished by modifying their positions along the wave-guides as well as their width and penetration.

The shape of the whole device allows minimal increase of electrical and magnetic fields on the structure surface, avoiding the risk of RF phenomena. The design tool employed was the electromagnetic code ANSYS Electronic Desktop HFSS [15].

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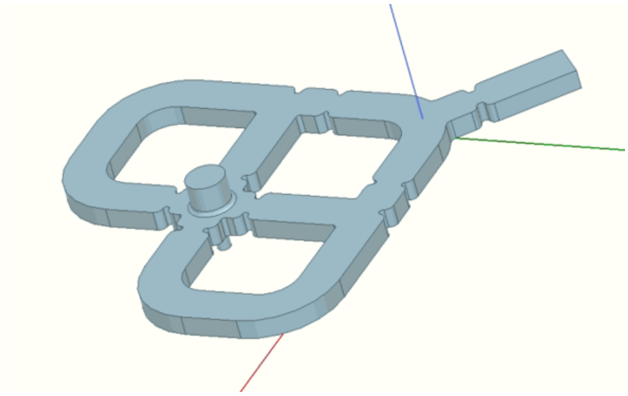

Figure 1: 3D CAD of the C-band Mode Launcher Coupler.

ELECTROMAGNETIC DESIGN PROCESS OF THE DEVICE

The device can be decomposed in sub components in order to develop its design. The protruding branch marked in yellow stands as a power splitter dividing the input power in half and channeling the field into the four other branches, see Fig. 2. Right next come two crossed power splitters marked in red which further divide the power until four waves each 25% of the original input wave converge at the center of the structure. Altogether these elements along the curved wave guides marked in purple compose the power feeding network. The central module in green is the Mode Launcher which operates the conversion of the accelerating field mode.

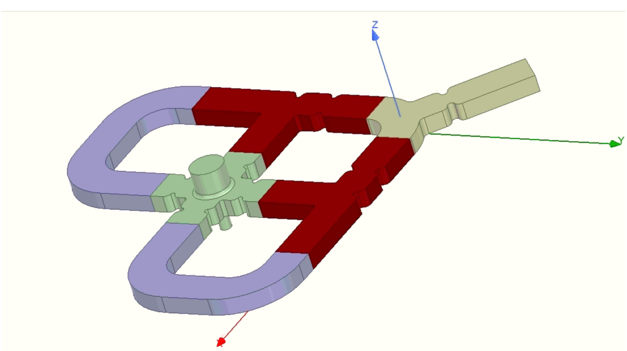

Figure 2: The power coupler with its components in evidence. In yellow is marked the input splitter, in red the crossed splitters, which all together with the purple extensions form the power delivery network, and at the centre in green the mode launcher.

Each module has to undergo the process of tuning in order to find the minimum input power reflection point at the working frequency of 5.712 GHz. At first, the tuning of the two red crossed power splitter has been accomplished, then the one of the yellow input splitter. Subsequently they have been united with the two curved wave guides in purple to form the power delivery network. Next the Mode Launcher in green has been tuned, exploiting its symmetric geometry to simulate exactly one octave of the structure. Lastly all the pieces were brought together to form the entire design. To perform the tuning the geometry and the position of the inductive matching protrusions has been modified until the S_{11} coefficient of the chosen power input of 1 W was equal or below -40 dB for every piece analyzed as well as the entire coupler. Great attention was placed on how these modifications were made since the device is extremely sensible even to small variations of tenths or cents of millimeters. Initially the modifications of the geometry and position of the bumps were extensive. Once a low reflection configuration was reached analysis focused on improving the initial results. Small modifications subsequently took place until the minimal reflection point was found. The results of the analysis for each device can be found in Table 1, below.

Table 1: S_{11} Coefficient at 5.712 GHz Found in Each Structure at the End of the Simulations

Structure Type	**S_{11} at f=5.712 GHz**
Crossed splitters	−51.2 dB
Input splitter	−47.1 dB
Power delivery network	−56.3 dB
Mode Launcher	−54.7 dB
Power coupler	−42.2 dB

Phase analysis of the electric field waves along the converging four branches of the power delivery network has also been accomplished in order to ensure the length of each arm was just the right one to avoid destructive field interference. The field phase at the four inner doors of the power delivery network at the end of the design process was found to be at 2.19 rad. At the completion of each design step also the electric field along the entire structure was plotted assuring the right functioning of the device and that the excited modes where the right ones, see Fig. 3. Boundary conditions have also been set, often simulating the structures as copper or PEC when such setup was sufficient for obtaining valid results. The power coupler assembled was simulated as a copper structure.

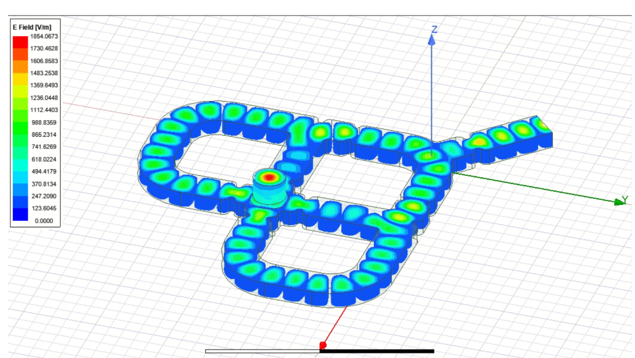

Figure 3: Electric field configuration in the device at the end of the design process.

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FURTHER RESULTS

The final S_{11} coefficient obtained for the whole device simulated as copper at the end of the electromagnetic design process at the working frequency of 5.712 GHz has been of -42.42 dB, just below the project target of -40 dB, as shown in Fig. 4, and as a result the transmission coefficient at the same frequency from the rectangular input to the cylindrical output S_{21} was close to 0 dB. With the structure simulated as PEC the S_{11} coefficient obtained was -43 dB. Dipole and Quadrupole components cancellation has also been verified by plotting the H field components along three non-model circumferences with radius of 5, 10 and 15 mm positioned right below the cylindrical power output, see Fig. 5, as expected with this geometry.

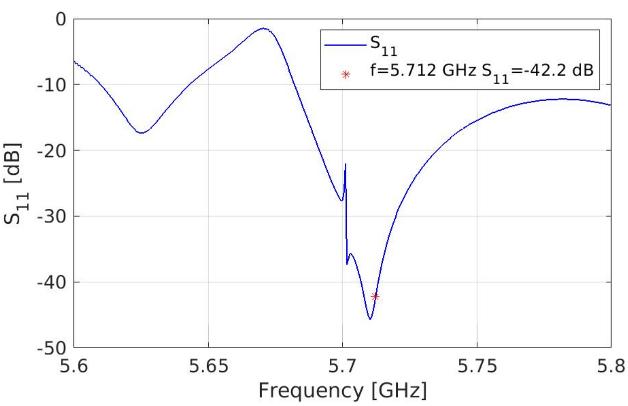

Figure 4: S_{11} plot obtained at the end of the design process with the structure simulated as copper.

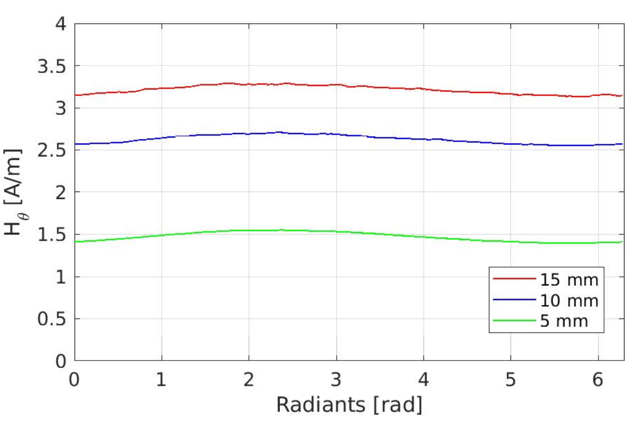

Figure 5: H_θ in the cylindrical pipe characteristics when plotted on three circles of radius 15 mm, 10 mm and 5mm. Its sinusoidal shape confirms the dipole and quadrupole field components cancellation. The input power was of 1 W.

The results obtained were so with an input power of only 1 W, just to ensure the right behavior of the device without analyzing yet the nominal working conditions of the device. Studies have to be carried forward in order to further analyse the electric and thermal behavior of the structure when fed with the accelerating machine which will house the device nominal power of tens of MW. The current device design obtained is still too cumbersome for the industrial oven at INFN's disposal and is in process to be scaled down.

CONCLUSION

The redesigning process of the original X-band power coupler to obtain a C-band preliminary design was successful. The novel structure seems promising in making possible to attain high gradient performances for an accelerating machine which will be equipped with the device. Further work is being made to provide the device with the support to house it in the machine and the vacuum pumps to allow it to operate in internal void conditions. Reshaping of the cylindrical output is also in progress to ensure the best pathway for the emitted beam. Further analysis will be also be carried out to determine the thermal and electric behavior of the structure, and calculate the peak surface current at nominal working conditions. The development of the optimised mode launcher is particularly relevant for the ongoing research activity of C-band high gradient structure for novel accelerators. This prototype is a work in progress at the LNF-INFN. Further results of this work will be the subject of dedicated papers.

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