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BASIC DESIGN OF THE RF POWER SYSTEM FOR IRANCYC-10 ACCELERATOR

M. Dehghan†, F. Abbasi, Department of Radiation Application, Shahid Beheshti University, Tehran, Iran
F. Ghasemi, Department of Physics and Accelerators, Nuclear Science and Technology Research Institute, Tehran, Iran
H. Azizi, Iranian Light Source Facility (ILSF) Institute for Research in Fundamental Sciences (IPM), Tehran, Iran
A. Taghibi Khotbeh-Sara, Department of Physics, Khajeh Nasir Toosi University of Technology, Tehran, Iran

Abstract

In this paper the basic design of an RF system to produce the required power of IRANCYC-10 cyclotron accelerator is reported. The designed system can generate 15 kW (CW) power at the operating frequency of 71 MHz. The authors provide a step-by-step explanation of the process of the design. It is carried out in three sections; (1) RF design features of the accelerator is investigated and power value is calculated in accordance with the requirements of the cyclotron, (2) choosing of solid state amplifiers as the RF power source is presented with its available power and structure, (3) design of RF passive instruments is reported to transfer and combine the power.

The purpose of the design is to achieve the best performance of the RF system, as well as decreasing overall size by using modular devices.

INTRODUCTION

The science, technology and research supreme council of Iran (ATF in Persian language) has programs to design and fabricate a 10 MeV cyclotron (IranCYC10) to produce a proton beam for generating radionuclides used in positron emission tomography (PET) scanning, as well as FDG. The cyclotron consists of cooling, vacuum, magnate, ion source and RF system. The electromagnetic field produced by both RF and magnet system accelerates the H^- for the appropriate energy level.

The RF system consists of three sections: resonator, LLRF (low level RF) and amplifier. The amplifier provides high power RF signals for cavity to increase the Dee voltage up to 50kV to produce an electrical field within the cyclotron.

RF DESIGN FEATURES

The IranCYC10, is an AVF (Azimuthally Varying Field) cyclotron with straight sectors and 10MeV maximum beam energy. It must provide 100µA beam current, covering the medical application. The characteristic parameters of the cyclotron are given in Table 1 [1].

† mohs.dehghan@chmail.ir

Table 1: Specification of the AVF Cyclotron [1]

Parameters	Values
Maximum energy	10 MeV
Beam species	Negative Hydrogen
Central field	1.18 T
B-field (max.)	1.85 T
Pole / Extraction radius	0.45 / 0.39 m
Operation frequency	71 MHz
Harmonic number	4th
Number of sectors	4
Resonance mode	$\lambda/2$
Pole angle	50°
Hill / Valley gap	3.48 cm
Ion source	PIG type
Dee voltage	40 kV
Dee angle	42°
Maximum beam current	100 µA
Output RF Power	15 kW
Power coupling type	capacitive

AMPLIFIER STAGE DESIGN

Progress in high-power RF transistors has proposed them as the appropriate replacements of vacuum tube amplifiers. The employment of solid state power amplifiers offer superior performance, higher reliability, lower maintenance cost, lower cost of spares and longer operating life. Thus, there is a strong motivation of migrating to solid-state active devices.

This RF system must provide up to 15kW power at 71MHz. In this design, a 1W signal produced by LLRF is transfered to a preamplifier to be amplified up to 30W. This signal goes through a main Amplifier stage, and then reaches a triode, which amplify RF signal up to 15kW. The proposed system for RF power for the cyclotron accelerator is described in Fig. 1 [2].

In order to accelerate negative hydrogen particles in the Dee, at least 11 kW RF power is required. However for beam stability factor the power must be more than this level (i.e. 15 kW).

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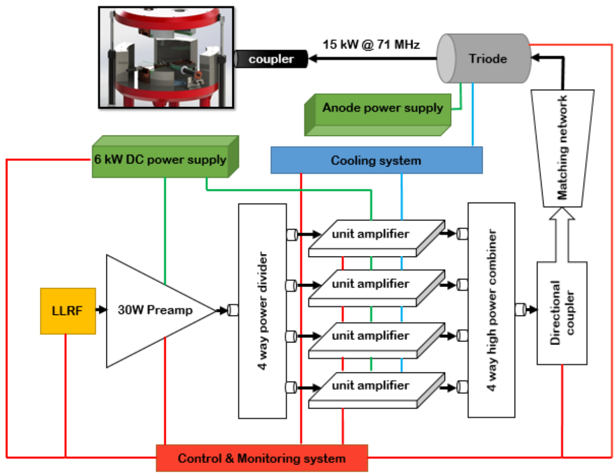

Figure 1: The proposed system for RF power [2].

The Preamplifier Design

The design of this low power amplifier was carried out using a BLF175 transistor. The goal of the design was to achieve the maximum gain and output power at the frequency of 71MHz. The Fig. 2 and Fig. 3 illustrate the fabricated 30W preamplifier and measurement of its output power, respectively.

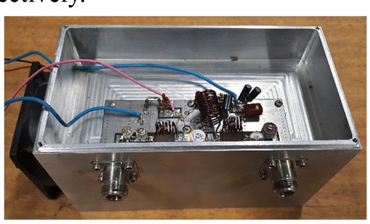

Figure 2: The fabricated 30W pre-amplifier @ 71MHz.

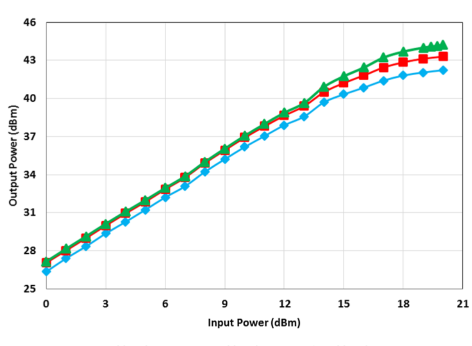

Figure 3: Measurement of the preamplifier's output power.

The Unit Amplifier Design

The BLF178XR transistor is an LDMOS power transistor offers maximum power of 1200 W in continuous wave mode [3]. DC and stability simulation was performed by the Keysight ADS software [4] to improve the transistor bias regulation (Fig.4 and Fig. 5). The input power is changed from 30dBm to 39dBm to achieve the desired output power of 700W. The simulation result is shown in Fig. 6. The final amplifier is shown in Fig. 7.

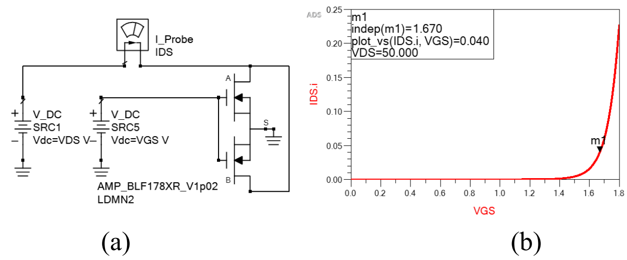

Figure 4: a) DC simulation of the transistor in ADS; b) IDS as function of VGS for BLF 178XR.

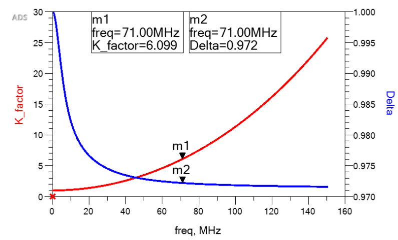

Figure 5: Stability analysis in ADS for BLF178 XR.

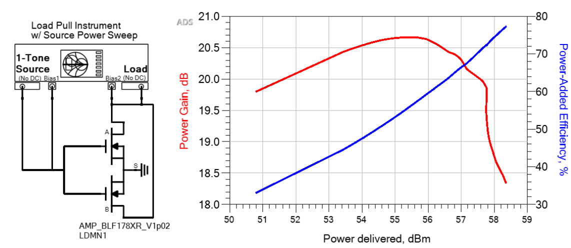

Figure 6: Simulation of output performance in load pull.

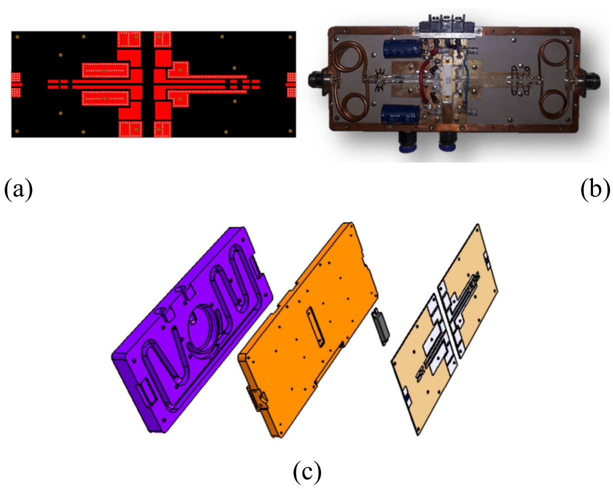

Figure 7: a) PCB of the unit amplifier; b) the unit amplifier constructed at 71 MHz. c) the efficient water-cooled heat sink is used for cooling the amplifier.

The gain and efficiency are obtained 19.06 dBm and 77.41%, respectively, which show a good agreement with simulation results.

To determine the rate of heat transfer through the amplifiers, thermal performance of the amplifiers had been evaluated using a FLIR C2 thermal camera (Fig. 8).

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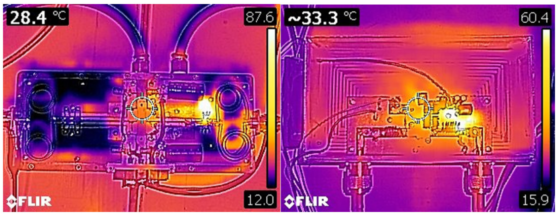

(a) (b)

Figure 8: IR images of a) the unit amplifier and b) the pre-amplifier in long-term operation.

DESIGN OF RF PASSIVE EQUIPMENTS

The Low Power Divider

The output of 30 W power amplifier must be equally divided into four equal parts to drive 2.5kW IPA stage. There are three suitable divider types based on ports matching and desired isolation: T junction, Wilkinson [5] and Gysel power divider [6].

The problem of the T junction divider is the lack of matching on output ports and also the poor isolation between the input ports. However, the problem of mismatching can be solved by using resistive dividers [7], but the isolation cannot be easily realized. Also the Gysel divider is so large for VHF frequency range.

In Fig. 9, the designed Wilkinson circuit is shown. A calibrated vector network analyzer (VNA) is used to measure scattering parameters of the divider (Fig. 10).

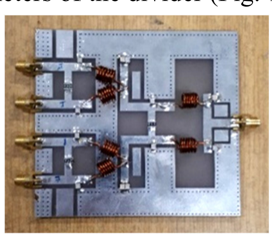

Figure 9: The constructed low power divider.

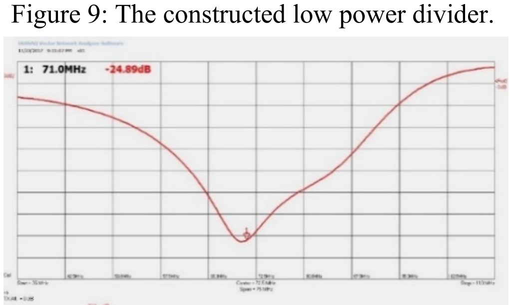

Figure 10: Measurement of S11 of the divider with the VNA.

The High Power Combiner

The Wilkinson combiner has been selected for de-signing and fabrication in this section. Figure 11 shows the designed combiner in HFSS [8]. The results of the combiner simulation in HFSS are shown in Fig. 12. At the operating frequency, the return loss and the isolation are about -45 dB and -27 dB, respectively. The phase difference between the input ports is also less than 0.03 degree.

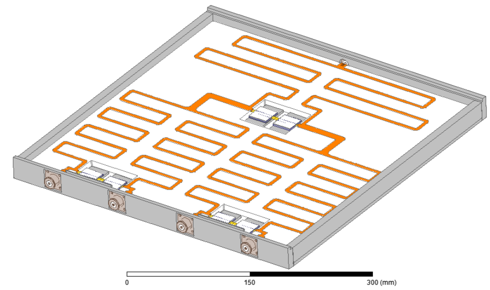

Figure 11: Inner view of the designed Wilkinson 1: 4 thick stripline corporate combiner.

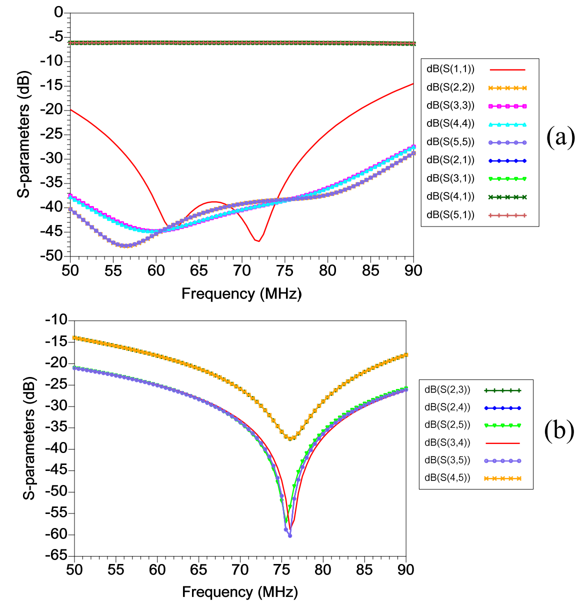

Figure 12: (a) The return loss, (b) Isolation and values obtained from the combiner simulation in HFSS.

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