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DESIGN OF 71 MHz POWER AMPLIFIER IN A SINGLE-ENDED ARCHITECTURE FOR IRANCYC-10 CYCLOTRON*

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Abstract

In this paper, the design and simulation of a high power amplifier to provide the required power of a cyclotron accelerator (IRANCYC-10) is presented step-by-step. By combining four modules of this amplifier, a power of 2.5 kW can be achieved to start the main power amplifier. The single ended designed amplifier can generate 1 kW the operating frequency of 71 MHz continuous wave (CW). The purpose of choosing this type of design is simplicity to build without the need for a balun, low weight to build at high power, as well as cost-effectiveness. The gain and PAE of the SSPA are 21.21 and 71%, respectively. There are also ways to reduce the size of the amplifier.

INTRODUCTION

IRANCYC-10 Accelerator is a 10 MeV cyclotron accelerator for the production of radionuclides used in positron emission tomography scans. This article describes some of the components of this accelerator. The radio frequency system of this accelerator consists of three parts: low level RF, intermediate power amplifier and main power amplifier. The triode vacuum tube is used as the main power amplifier for use in the cavity and also to increase the voltage of Dee's up to 40 kV to create an electric field [1].

High power RF transistors have been proposed as an appropriate alternative to these tube with the advancement of technology. The use of solid-state power amplifiers results in better performance, higher reliability, lower maintenance costs, lower power consumption, longer life, and lower spare parts costs. So there is a strong motivation for this replacement.

Push-Pull configuration power amplifiers are widely used for high power amplification. The main advantage of using this configuration is the reduction of the Lead effect as well as easy adaptation to the input and output. However, the balance between the branches of the baluns is a big challenge, because any imbalance goes back to the transistor.

Since several modules must be used in the solid state to provide the power level of the cyclotron accelerator, the use of this type of configuration is not appropriate. Thus a single-ended configuration was recommended. The advantages of using this type of configuration include a balun-free design, suitable for mass production to create 400 kW stations, and an economical design [2].

Thanks to the selection of high power transistors and the elimination of harmonics, the output power can be provided at the level of kW with superior performance in efficiency. The most advanced transistors in this technology are LDMOS, which are used in SOLEIL [3] and ESRF [4] at 190 kW and 150 kW at 352 MHz.

Also, this configuration has been used in ESS LINAC [5] with an output power of 1250 watts in pulse mode with 71% efficiency and continuous wave with 61% efficiency to reach 400 kW power at 352 MHz frequency.

The objective of this paper is to design an SSPA module with an output power of 1 kW with maximum efficiency in the appropriate size as well as cost-effective, for use at higher powers. The operating frequency of this accelerator is 71 MHz.

METHODOLOGY

The IRANCYC-10 accelerator is an AVF cyclotron with a maximum beam energy of 10 MeV. The characteristic parameters of this cyclotron have been presented in Table 1.

Table 1: Characteristics Parameters of IRANCYC-10 Cyclotron Accelerator

Parameter	Value
Maximum Energy	10 MeV
Beam type	H^-
Central field	1.18 T
Maximum magnetic	1.85 T
Operating frequency	71 MHz
Ion source	PIG type
Maximum bean current	100 µA
Output power	15 kW

At least 11 kW of RF power is required to accelerate the negative hydrogen particles in Dee, but this power must be about 15 kW to create a beam stability factor.

A signal with a power of less than 1 watt is generated in the LLRF and feeds the preamplifier, to increase the power by 30 watts. In the middle amplifier section, by combining four 750 watt amplifier modules, 2.5 kW of power is created to power the main power amplifier. This amplifier is of 3CW20000A7 triode vacuum tube type.

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1kW Amplifier Design

BLF188XR transistor has been used for design, which is used for scientific, industrial and medical applications in the frequency range of HF up to 600 MHz. The maximum output power of this transistor is 1400 watts. This transistor has high efficiency and good thermal stability [6].

DC Analysis

A DC analysis was performed to improve the transistor bias setting by ADS software [7]. The value of V_{DS} is 50 volts and V_{GS} can be changed between 1 and 2 volts. The simulation result has been shown in Fig. 1. The drain current diagram in terms of gate voltage can also be seen.

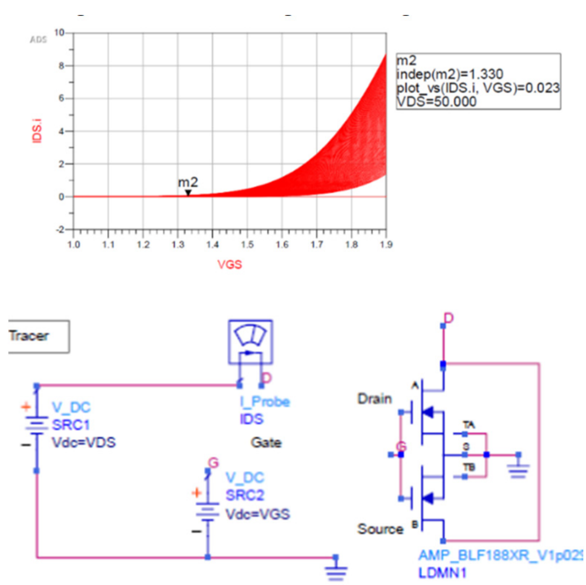

Figure 1: Schematic of DC analysis and diagram of drain current in terms of gate voltage.

Classes B and AB are usually chosen for the operating region of the transistor. Therefore, the gate voltage must reach the threshold voltage, which is between 1.25 and 2.25 according to the data sheet. The gate voltage of 1.9 volts has been selected in class B.

Stability Analysis

If the input or output impedance has a real negative part, the amplifier will oscillate. Factors K and Δ are two important factors to show the stability of the transistor [8]. Equations (1) and (2) have been used to analyse these factors

$$K = \frac{1-|S_{11}|^2-|S_{22}|^2+|\Delta|^2}{2|S_{12}S_{21}|} \geq 1 \quad (1)$$

$$|\Delta| = |S_{11}S_{22} - S_{12}S_{21}| \ll 1 \, . \quad (2)$$

If the above two conditions are met simultaneously, the system is unconditionally stable. Figure 2 provides the above conditions for the frequency of 71 MHz. Stability conditions during design can vary with the operating conditions of the transistor.

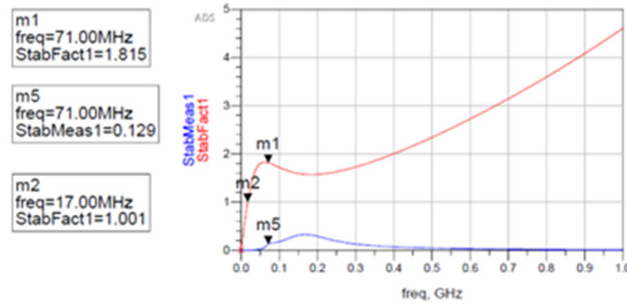

Figure 2: Stability analysis of the transistor.

Load Pull Analysis

One way to determine the large signal behaviour of a transistor is to use the output power lines in the Smith diagram as a function of the load reflectance. This method is called load-pull. The value of this simulation is changed to obtain the optimal impedance at the output of the transistor. As a result of this analysis, different impedances are obtained considering the design priority (maximum efficiency, best gain) and the appropriate value is selected. A similar analysis can be performed for the transistor input, which is called a source pull. In this simulation, the input power of 39 dBm has been considered. The simulation result has been shown in Fig. 3.

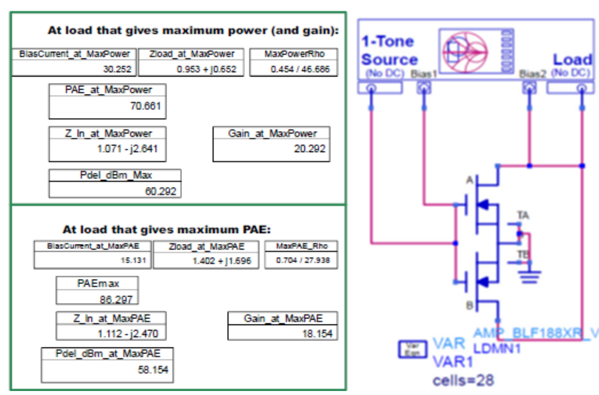

Figure 3: Load-Pull analysis of the transistor.

Design of Single Ended Amplifier

Several solid-state modules must be used to provide the power level of the cyclotron accelerator, so a single-ended configuration has been suggested.

Figures 4 and 5 show the final power amplifier design for the IRANCYC-10 accelerator. One of the most important design steps of this amplifier is the design of impedance matching circuits, which increases the signal-to-noise ratio as well as maximizing power output and low loss. Due to the use of this configuration and the operating frequency of the accelerator, the size of the matching circuit increased. For this reason, two approaches were proposed. First: the use of the FR4 substrate with a dielectric constant of 4.5 and also adding compact elements such as inductors and capacitors. Second: the use of a transformer, which greatly reduces the size of the module. ADS software has been used for design and simulation.

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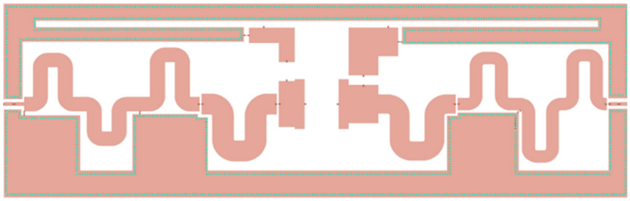

Figure 4: PCB design of the 1 kW power amplifier.

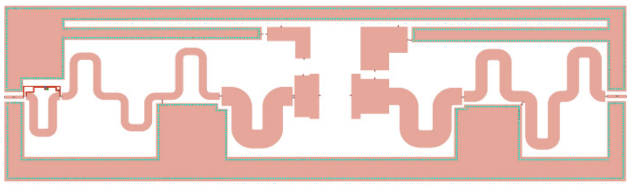

Figure 5: PCB design of 1 kW power amplifier with input transformer.

RESULT

In the design presented in Figs. 4 and 5, 1 kW output power was measured with 76% efficiency and 21.21 gain. Figures 6 and 7 show the values of this simulation.

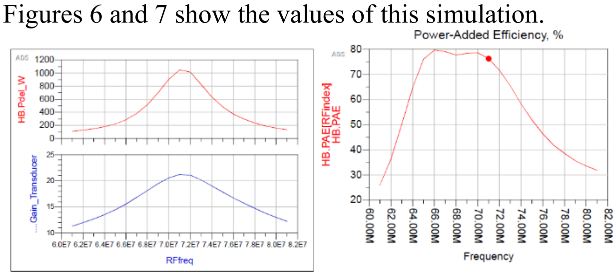

Figure 6: Final results of 1 kW power amplifier design.

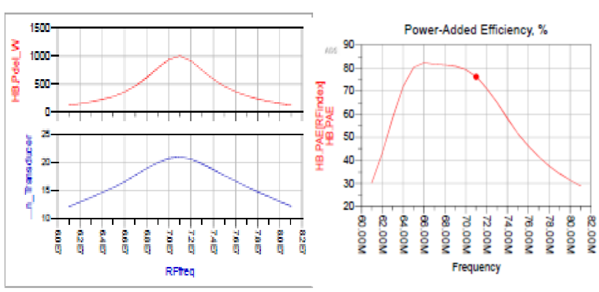

Figure 7: Final results of 1 kW power amplifier design with input transformer.

CONCLUSION

Some of the simulations and results of the cyclotron accelerator radio frequency generator have been presented in this paper. The RF power system of this accelerator has been provided by implementing the latest technology and high power consumption strategy. Also, a solution to reduce the module size has been provided with maximum power and minimum loss. The maximum output power is 1 kW and the efficiency is 71% and the gain has been estimated at 21.21. The size of this module is 30 x 15 cm.

Also, it is possible to assemble 15 modules of this amplifier using a combiner, and use it as a main power amplifier of 15 kW and replace the triode lamp.

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