International Journal of Power Electronics and Drive Systems (IJPEDS)
Vol. 15, No. 3, September 2024, pp. 1719~1725
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v15.i3.pp1719-1725

A character driver of amplifier for the RF-generator 77.78 MHz at cyclotron DECY-13 in Yogyakarta

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Article Info

Article history:

Received Dec 20, 2023
Revised Mar 8, 2024
Accepted Mar 26, 2024

Keywords:

Cyclotron
DECY-13
Driver of amplifier
RF-generator
Smith chart

ABSTRACT

Measurement of power supply for design of experimental cyclotron in Yogyakarta (DECY-13), i.e. RF-generator 77.78 MHz, especially driver amplifier as important part, has been carried out, in order to minimize the reflected power. Starting from direct digital synthesizer (DDS) as exciter of the radio frequency (RF) wave, having power up to 20 W, the signal sent then to the driver, that has an amplifying factor of around 50. Output of driver works as input for final power of designed DECY-13, which needs about 10 kW of RF power supply for operating the cyclotron. Using network analyzer to get the best position of the RF-power-coupler, it was found the value of dee impedance equals to (50.9 - j0.3) Ω. The signal detected has the behavior as capacitively having value of around 6 nF, that showed by smith chart. An output of 0.8 W by DDS has resulted of 300W to the driver. By a pure resistance 50 Ω dummy load, the system can achieve final power of almost 10 kW.

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1. INTRODUCTION

Cyclotron is a type of charged particle accelerator, that produced by an ion source, in which the direction of motion of the particle beam inside the cyclotron chamber being circular, with first having a small radius, to an increasingly large spiral radius. The larger the radius of the path, the greater is the energy of the particle beam, until it reaches a maximum energy at the outermost path. The motion of the particle beam with a circular path takes place in the "D-space"/dee (within cyclotron chamber) caused by the acceleration of the electric field/RF voltage, then it is deflected/directed by the magnetic field B which is formatted in the hill and valley, whose direction is perpendicular to the motion of the particle beam trajectory, so as not to scatter by the wall in order to get a circular path [1], [2]. The principle of DECY-13 is a proton cyclotron that accelerates negative hydrogen ions. These negative ions are converted into positively charged hydrogen ions/protons by the stripper/carbon foil system, which are then directed through the window, towards and shooting the target material, such as H_2O to produce fluorine (radioisotope production applications).

To increase the magnitude of the particle energy, in this case the negative hydrogen ion, so that it always increases every time the radius of the circle is enlarged, then power is given from an alternating voltage in the form of an RF wave at 77.76 MHz. It generates an electric field at dee with the same frequency in accordance. An isochronous magnetic field is needed to control the motion of the particles so they do not leave the path, so that the maximum beam intensity is obtained when they arrive at the stripper [3]. The output power of the RF generator for dee consumption must be optimized. So that, with a small power, a large dee voltage can be obtained. In the DECY-13 design project, a maximum high voltage of 40 kV is planned at dee to obtain a final hydrogen ion power of 13 MeV.

In order to produce a particle beam having a desired high energy, the main requirement that must be met is the occurrence of RF wave resonance of all RF system device/components inside the cyclotron chamber. This resonance requirement is so called matching conditions in fact at 50 Ω impedance between the RF generator (DDS, driver and final amplifier) and the load [4]. This load consists of all the components involved, not only the RF equipment but also the hydrogen particle/ion beam, along with the balance with the cooling system, vacuum system and magnetic field [5]. One part of the dee is also equipped with fine tuning in the form of a variable capacitor, in order to maintain a balanced resonance condition. The requirement of λ/2 of course must also be met [6], [7].

In this experiment the characterization of driver system was carried out, because it is one of the important quantities of RF power supply at 77.76 MHz in the cyclotron DECY–13 as seen in Figure 1. The voltage products of final that appears along the dee rod, based on the equation of the electric field E generated by the RF generator/power that sent via the coupler, E= - grad V, or Ex = - dV/dx [8]. The magnitude of the RF voltage (Vpp) determines the final energy of the particle, so it is very important to measure the power delivered by the RF generator quantitatively, especially character of driver in a system generator/energy source [9].

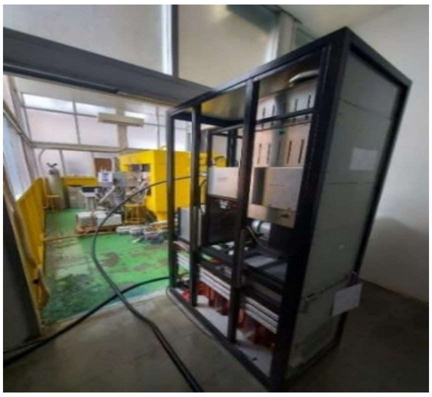

Figure 1. Cyclotron DECY 13

2. METHOD

The experiment setup is showed in Figure 2 as a block system, which mainly consist of DDS (as RF source), driver, coupler/cavity, dee (inside the chamber) as load for RF Generator, and some measurement tools [10]. An oscilloscope and a wattmeter are also needed for detecting the RF wave, i.e. the frequency and the power delivered by DDS, driver as well as final amplifier. A self–made attenuator of 20 dB and 40 dB are used to protect the oscilloscope against overvoltage. As the load, a pure–resistive 50 Ω dummy load was used aside the cyclotron dee as the main load [11].

It needs first to detect RF wave by using a network analyzer, to get an optimal condition by varying the coupler position, trough rotation to make variation angle relatively to the dee. The perfect condition is achieved by obtaining the pure 50 ohm of impedance without imaginary part [12]. Ghosh *et al*. [13] has designed RF-Amplifier by using tetrode, without driver, it works well, as integrated with all parts of RF generator. Source of the RF generator is direct digital synthesizer, as described in Figure 3

Direct digital synthesizer (DDS) is a method of producing a sine wave, by generating a time-varying signal in digital form and then performing a digital-to-analog conversion [14], [15]. The DDS in DECY–13 cyclotron consists of an IC AD9851 by analog devices. The IC works in basic frequency of the x'tal oscillator, approximately 30 MHz.

The AD9851 is an integrated component that uses advanced DDS technology, combined with high-speed, high-performance internal D/A converters and comparators, to form a digitally programmed frequency synthesis. For given a reference from an accurate clock source, the AD9851 produces then a frequency-stable analog sine wave output. The AD9851 control process is carried out by the AT-mega16 microcontroller via 8-bit parallel data. The output frequency depends on the condition of the 32 bit frequency tuning word, according to equation. The band pass filter output is fed to the RF MAV-11SM Surface Mount Monolithic Amplifier until the RF power output reaches 550 mW and amplified up to 10 Watt using amplifier at frequency output of 77.76 MHz [16].

The output is sent to the driver, having amplification of around 40× [17]. The constructed electronic circuit is shown in Figure 4. Driver amplifier has a function for driving RF power to final RF amplifier [18]. Driver power amplifier for cyclotron DECY 13 was constructed using FM BLF188XR pallet. This solid-state driver amplifier has maximal output power of 800 W as seen in Figure 5. In order to provide current according to needs, the LM317 output is strengthened with the addition of 6 current amplifier transistors TIP-3055, 48 volt/20 A.

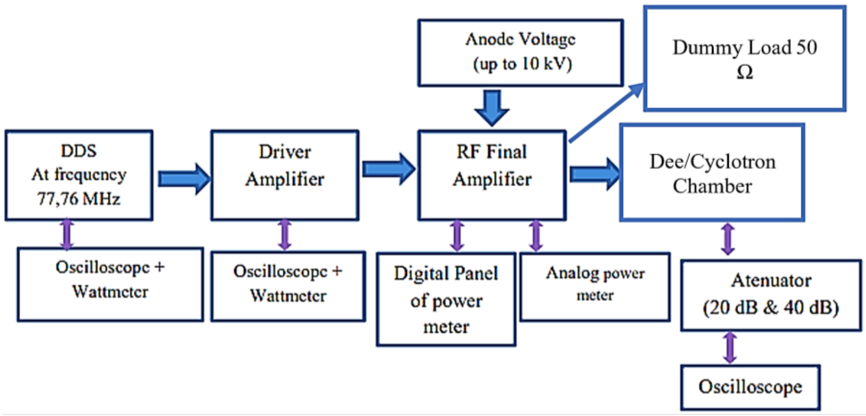

Figure 2. Block diagram of experiment for characterizing driver of cyclotron DECY 13

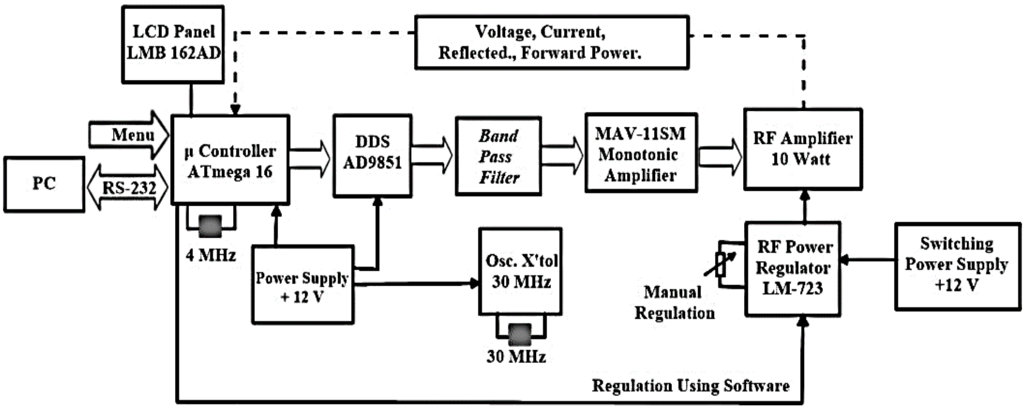

Figure 3. Block diagram DDS of cyclotron DECY 13

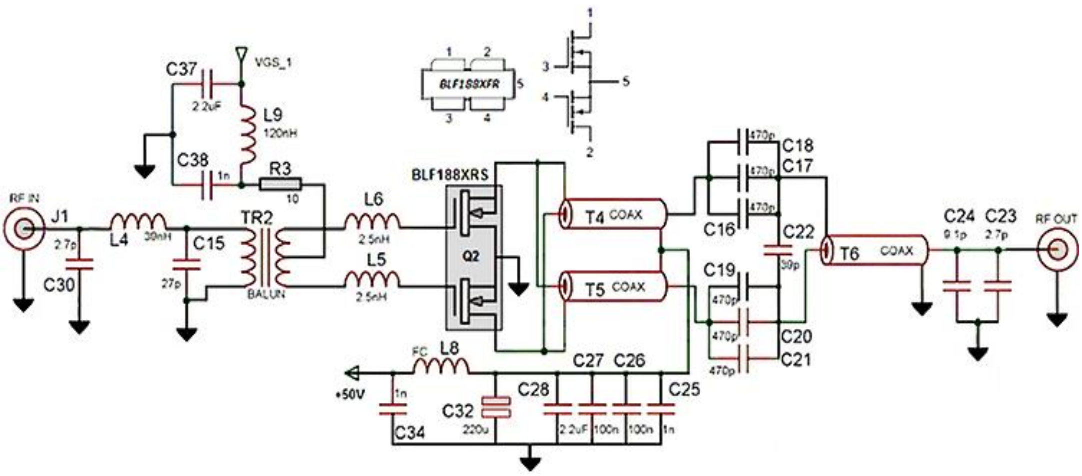

Figure 4. Schematic of solid-state diver amplifier (800 watt) cyclotron DECY 13

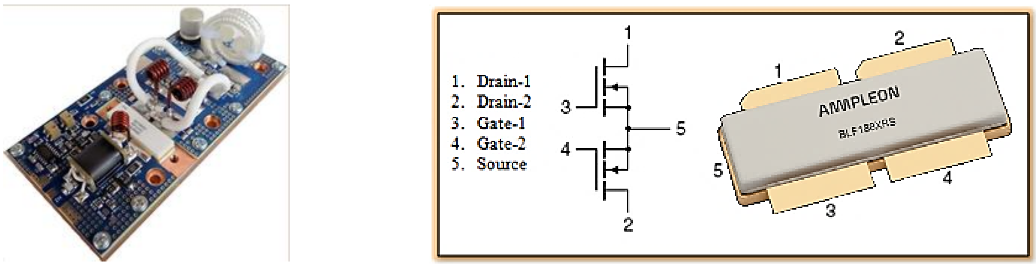

Figure 5. FM BLF188XR pallet

3. RESULTS AND DISCUSSION

Figure 6 shows the best result of detected RF wave using network analyzer (NA), that was connected to coupler as important part for power transfer, conductively. A power of some mW of NA is released in the cyclotron chamber via RF cavity, and so captured by system dee, and re-emitted by dee, detected by NA in form of smith chart [19]. The impedance value of 51.5 ohm and 0.9 ohm is achieved, for real and imaginary part, respectively. The using of fine tuner, that mainly contents of capacitor, is included, in order to minimize the imaginary part [20], [21]. A frequency of 77.764 MHz is also detected, in accordance with that emitted by driver. The magnitude of S11 (indicated the reflected power by NA), is shown in Figure 7.

Figure 6. Smith chart showed by NA

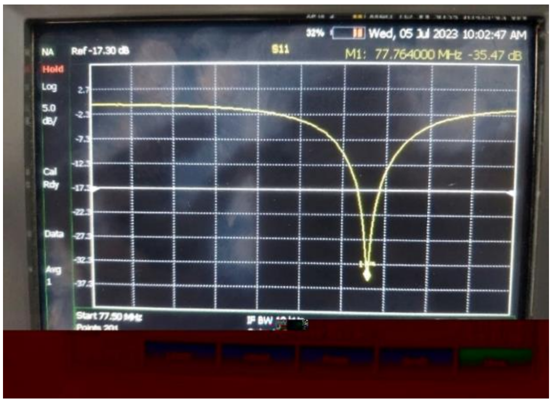

Figure 7. Smith chart shows the magnitude of reflected power

In ideal case, the value of S11 is -60 dB, with R= 50 ohm, and without imaginary part, indicates a pure resistive load [22]. But Figure 7 shows a deviation, means that the conditions for resonance to occur have not been met, because we have -35.47 dB at the frequency of 77.764 MHz. As a result, there is still reflected power that detected by measured tool, if power is sent to from DDS and driver to cavity, maximal 2%, as showed by Figure 8. This reflected value is still accepted for the followed experiment in general.

Compared to Tena-Ramos *et al.* [23], in which the frequency area/work frequency slightly difference, the result is different, may be caused by the type of pallet that used for the manufacturing electronic circuit. DECY-13 cyclotron will work at an energy of 13 MeV on frequency of 77.76 MHz. For this purpose, an RF wave with a power of 10 kW is needed which will be used for the ion acceleration process in the cyclotron system. An RF-power amplifier used by DECY-13 has a gain of 10, so the RF wave input required by the power amplifier must have a minimum of 1 kW. For this purpose, an RF-Driver has been designed which will be able to supply the RF wave with a power of 300 Watts from its RF-wave generator [24], having the character showed by Figure 8. Solid state technology is used in the RF-driver component, because this component has been widely used in the industrial world and has the characteristics of good power, gain, efficiency, linearity, low noise and reliability [25], [26]. The laterally diffused metal oxide semiconductor (LDMOS) transistor type is used in the RF-driver DECY-13 design, namely LDMOS type BLF578. The RF-driver will receive RF-power from an RF-wave generator device whose value can be set from 0 to 20 Watts, as showed by Figure 9, using dee as load.

Unfortunately, if the output of driver is sent to final amplifier, it shows a high reflected power, above 50%. On the other hand, if a dummy is used as load, instead of dee, the reflected power almost zero, means that the all power of emitted RF is fully consumed by dummy load, as in Figure 10, almost 10 kW, i.e pure resistance of 50 Ω without imaginary part is achieved. The RF source is also in matching condition with all parts in the cyclotron chamber.

The output power of driver as function of DDS is considered very good without reflection if the dummy of 50 Ω is used as load for RF generator as shown in Figure 11. The pure resistance of load without imaginary part is also in matching condition with DDS as well as with the driver one. It shows that the DECY–13 is ready to operate.

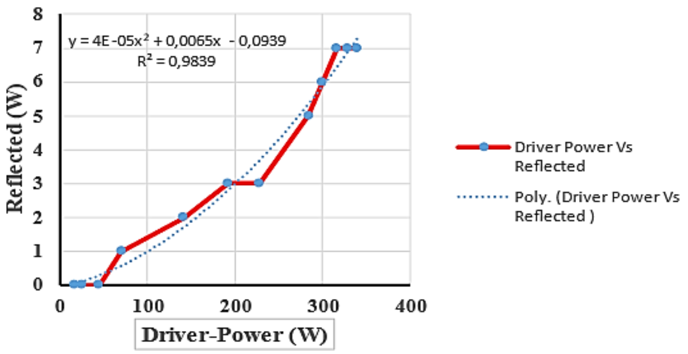

Figure 8. The dependency of reflected power from the driver output

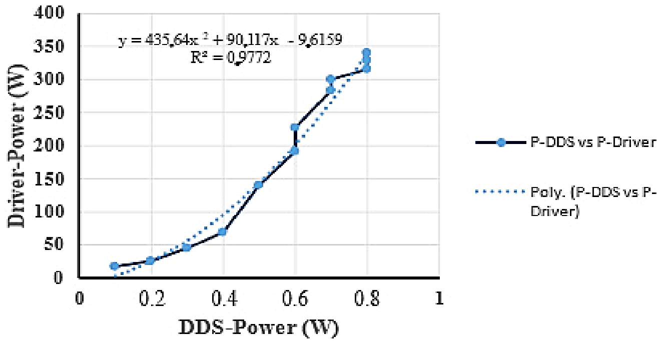

Figure 9. The driver output as function of DDS, using dee as load

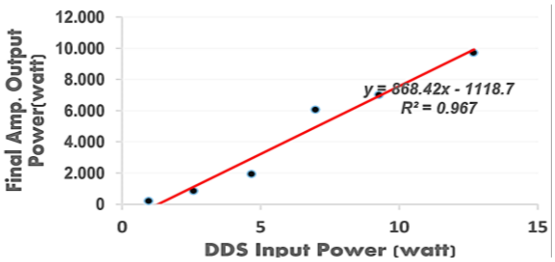

Figure 10. The dependency of final power from DDS, using dummy as load for RF generator

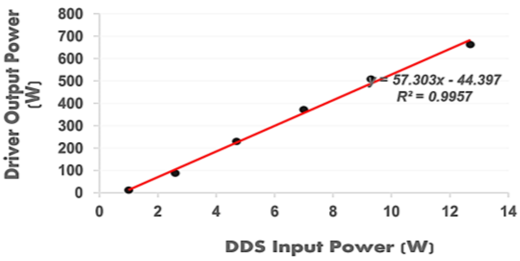

Figure 11. Driver output as function of DDS

4. CONCLUSION

As an important part of RF generator, a solid-state driver amplifier has low value of reflected power, maximum 2%. Measurement of real part and imaginary part using network analyzer shows a smith chart of 51.5 Ω and -j 0.9 Ω, having attenuation of -35.47 dB. Using dummy as load for testing measurement shows an output power of almost 10 kW without reflection.

ACKNOWLEDGEMENTS

This paper was fully supported by the Research and Innovation for Onward Indonesia (RIIM) and Nuclear Technology Innovation Products (HITN) research grant, held by the National Research and Innovation Agency and Ministry of Finance, Republic of Indonesia.

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