

AUTOMATIC TUNER UNIT DESIGN, SIMULATION AND MEASUREMENT FOR AUTOMATIC OPERATION OF THE RF SYSTEM IN THE ESS-BILBAO H+ ION SOURCE*

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Abstract

The Ion Source responsible intended to generate a high current and low emittance proton beam for the ESS-Bilbao is currently under construction. The plasma in the source is generated by coupling the 2.7 GHz power input from a Klystron through a magnetic field with an intensity close to the electron cyclotron resonance (ECR) field at the input RF frequency. The electrical behaviour of the plasma strongly depends on different plasma characteristics which, at the same time, also depend on the microwave absorption. Thus, in order to maximize the RF power transferred to the plasma, a waveguide automatic tuner unit is employed to match the generator output to the electric impedance of the plasma. This device is generally adjusted manually. In this paper, the design, the electrical simulations, and measurements are presented which allow us to propose an automatic and real time control of the device. In a first approximation, with the aim of testing the proper operation of the automatic tuner unit (ATU), an in-house variable phase shifter and attenuator has been designed and manufactured to simulate the electric behavior of the plasma.

DESCRIPTION OF THE ION SOURCE H+ PROJECT (ISHP)

The proton/deuteron ECR source, where plasma formation happens due to the sequential electron impact ionization, is being designed. Table 1 gives a preliminary specification for the ion source.

Table 1: Parameters for the Proton Source [1]

Parameter	Value
Ion energy at extraction	75 KeV
Total Current	75 mA – 100 mA
Proton Fraction	≥ 90 %
Beam pulse length	1.5 ms
Duty factor	6%
RF frequency	≥ 2.45 GHz
Beam emittance at RFQ entrance	≤ 0.2π mm mrad
Reliability	98%

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In parallel with the Ion Source, the RF system shown in Fig. 1 provides the desired RF 2 KW pulses at 2.7 GHz to produce the ionization.

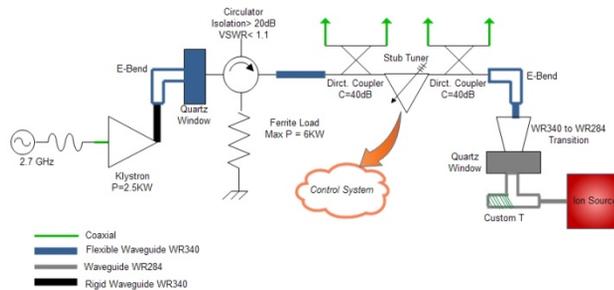


Figure 1: High power RF system.

THE ISHP CONTROL SYSTEM

Before running the whole system at full power, it is fundamental to test it in small signal mode. Small signal tests allow to check the behavior of the stub tuner and also other system parts related with the control. The system in Fig. 2 consists of four different blocks which are described below.

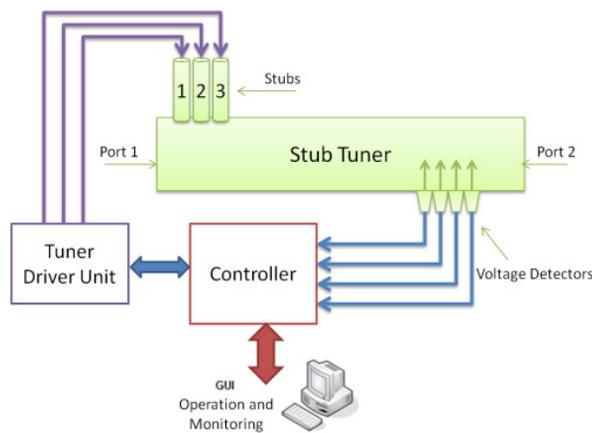


Figure 2: Control system.

Stub Tuner

The generated plasma at the ion source presents a variable electric behaviour. Therefore, the stub tuner is the responsible of matching the load to the source impedance to transfer the maximum power for ionization [2].

To change dynamically the characteristics of the transmission chain, an ATU has been placed between the

generator and the load as shown in Fig. 3. It consists of three transverse rods which can be introduced in the waveguide. The effect that it produces has been studied and modeled previously by other researchers [3]. In our system, the rods are placed along the longitudinal direction instead of the transversal one.

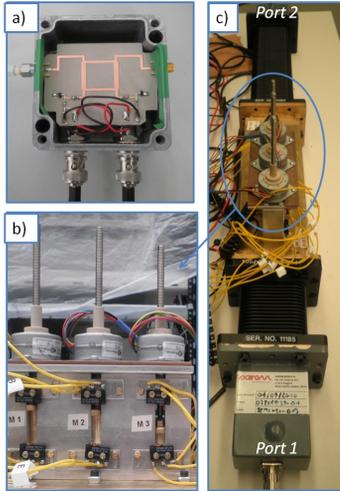


Figure 3: a) In house designed phase shifter. b) View of the three stubs with their motors and limit switches. c) Experimental set-up with transitions, waveguides, and the stub tuner.

Tuner Driver Unit

This unit, as shown in Fig. 4, consists of three stepper motor drivers each of them with a corresponding in house developed Front-End Electronics (FEE) as well as the required supply voltages (+24V,+12V,+5V). Each motor moves the tuning post to the required position using TTL pulses and the corresponding direction signal. In addition, they control the six limit switches, two for each stub, to protect the tuner in case motors try to move more than the specified physical limit.

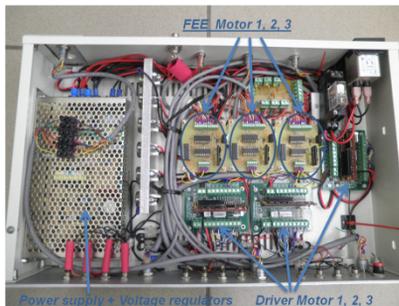


Figure 4: Tuner driver unit.

Controller

The Controller is a cRIO-9024 Unit from National Instruments. It runs LabVIEW Real Time for control and analysis, and it has an embedded FPGA (Field Programmable Gate Array) Virtex V unit which could implement the more time critical processes.

Its 800 MHz processor allows to implement a reliable control algorithm on it, using the real-time, the FPGA and the I/O extensions. To do this, we have connected two I/O modules, the NI 9205 for analog inputs and the NI 9403 for digital I/O

The main functions of the Controller are the following: to control the I/O modules using the FPGA, to read the signals from the limit switches and from the voltage detectors and, to generate the pulses for the motors. In addition, the FPGA makes some fast calculation to ensure the correct behavior of the whole control algorithm. The real time is responsible for the synchronization with the FPGA and with the host computer.

The automatic matching algorithm, currently implemented in MATLAB, will be integrated in this platform and it is explained in more details in the following section.

Operation and Monitoring

A LabVIEW monitoring program has been implemented in the host computer. It interacts with the controller providing automatic or manual modes of operation. With the programs, the motors can be moved in a controlled way and it is possible to read the scattering parameters connecting the Network Analyzer (N.A.) to the host.

The manual mode allows to move the stubs freely. It means that the user can choose the direction and the number of pulses that is going to be applied to the selected motor. There is a unique measurement and movement of the selected stub.

With the automatic mode, the selected motor sweeps across the movement range until it reaches any limit while all the scattering parameters are saved in each step. When finished, there is a collection of measurements and positions of the selected stub. The results are shown in Fig. 5.

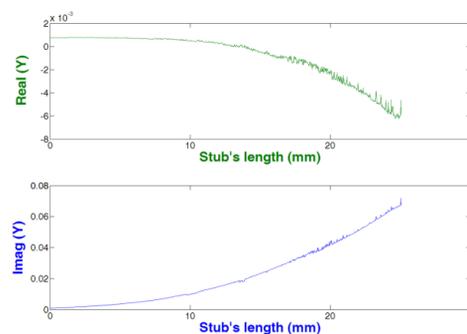


Figure 5: Stub Characterization, admittances vs. length.

AUTOMATIC MATCHING ALGORITHM

The flow diagram of the matching algorithm is shown in Fig. 6 and its goal is to achieve the impedance matching of the variable load to the power generator, the klystron.

The starting point for the algorithm is to know how much signal is reflected with the initial configuration. To do this four probes are mounted at equal distances of $\lambda_g/8$,

connected to voltage detectors which measure the voltage amplitudes present in the waveguide. With these values we calculate the incident and the reflected wave voltages, as well as the reflection coefficient, its amplitude and phase, at a specific waveguide point, and the corresponding Voltage Standing Wave Ratio (VSWR) [4], [5].

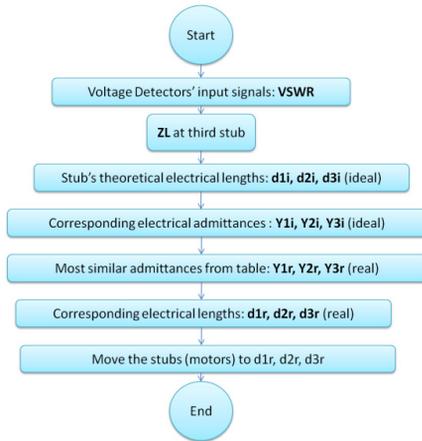


Figure 6: Flow diagram.

Then we translate the reflection coefficient along the waveguide to the generator until we reach the position of the third stub and calculate the corresponding impedance at this point.

Knowing the impedance to be matched, and the specific characteristics of our stub tuner (the maximum length of the stubs, 25mm, and the separation between them, $3\lambda_g/8$) we calculate the theoretical electrical lengths of each stub and their corresponding admittances using the method in [6], which guarantees a perfect matching.

After that, we access to the memory where we have loaded the table with the data of Fig. 5, and find out the lengths that correspond to the most similar admittances.

TRIPLE STUB MATCHING CASE STUDY

As stated before, the system has to be able to match different load impedances. Obviously, as the stubs stroke is limited to a specific length, 25mm, there is a limitation in the impedances that can be matched. However, in our case, the stroke can be increased mechanically.

To test the response of the tuner to different loads, we have designed a variable phase shifter shown in Fig. 3. Varying the supply voltage input impedance is changed. In order to simulate Plasma's behavior the phase shifter could be connected to an arbitrary function generator which supplies an arbitrary voltage, and thus, it is possible to obtain a changing reflection coefficient which imitates plasma's behavior.

The case study presented in the paper consists of a load of $(41.8276 + 61.0321*j)$ Ohms generated with the phase shifter connected to the port two. With this load, leaving the stubs up, the measured reflection coefficient amplitude at the input port one is -5 dB (m6 in Fig. 7). After applying the matching algorithm the reflection coefficient decreases to around -10 dB (m7 and m8 in Fig.

7).The measured reflection coefficient values after matching are different from the ADS simulations due to the influences of one stub in the other, and the non ideal behavior.

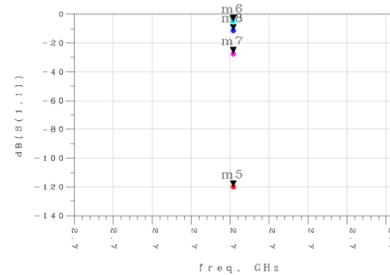


Figure 7: Case Study: m6 (Initial Refl. Coef), m5(with ideal lengths), m8(with calculated lengths), m7(with corresponding Refl. Coef).

This is an initial example real case without taking into account possible coupling effects between stubs. Now the described system is deployed and more tests are being performed.

SUMMARY AND CONCLUSIONS

An automatic tuning unit has been presented in this work. A special effort has been made to focus on ATU modeling and characterization. The full system has been described and the stub characterization results have been shown. Moreover, the behavior of the tuner has been explained by using a specific case study. In the near future extensive measurements will be carried out using the final deployment with the real source.

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