

AUTOMATIC TUNER UNIT OPERATION FOR THE MICROWAVE SYSTEM OF THE ESS-BILBAO H⁺ ION SOURCE *

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Abstract

The operation of the waveguide Automatic Tuner Unit (ATU) for optimizing both the impedance matching and the RF power coupling in the ESS-Bilbao H⁺ Ion Source (ISHP) is presented. Since the plasma chamber can be considered as a time varying load impedance for the pulsed RF 2.7 GHz high power generator, several approaches have been studied for accurately measuring the load impedance. In the later case, a set of power detectors connected to electric field probes, IQ demodulators and gain/phase detectors connected to dual directional couplers have been integrated. An experimental comparison of these approaches is presented, showing their accuracy, limitations and error correction methods. Finally, the control system developed for the automatic operation of the triple capacitive post tuner is described, as well as illustrative results.

DESCRIPTION OF THE H⁺ ION SOURCE (ISHP)

The ISHP is responsible for generating a high current and a low emittance proton beam in the ESS-Bilbao accelerator. The Electron Cyclotron Resonance (ECR) Ion source, where plasma formation happens inside the chamber due to the sequential electron impact ionization, has been designed, including a High Power RF System. The plasma in the source is generated by coupling RF power at 2.7 GHz from a Klystron. The initial steps of the development of the automatic matching algorithm for the ISHP were presented in [1]. Firstly, the algorithm was tested in low power mode (maximum transmitted power 25 dBm) by using a phase shifter at the end, to simulate the random impedance of the plasma. After that, the high power deployment was assembled, thus making possible to increase the power. Finally, the phase shifter was replaced by the plasma chamber, in order to test the operation of the Automatic Tuner Unit (ATU) in real conditions.

THE ATU CONTROL SYSTEM

In order to maximize the power transfer from the Klystron to the load located at the end of the chain, a proper

* Work supported by the Basque Government and Spanish Ministry of Science and Innovation

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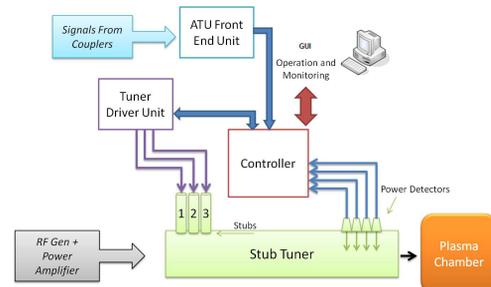


Figure 1: The ATU Control System block schematic.

impedance matching is required. Fig. 1 shows a block diagram of the control system developed to this end. The reflection coefficient is measured at several points distributed along the waveguide as shown in fig. 2. Once the reflection coefficient is obtained, the optimum configuration for the ATU is calculated. The three capacitive posts of the ATU are moved to the desired position thus changing the load impedance seen from the amplifier. The impedance matching allows us to have an efficient power transmission during plasma formation. Later on, different methods used to measure the reflection coefficient will be explained.

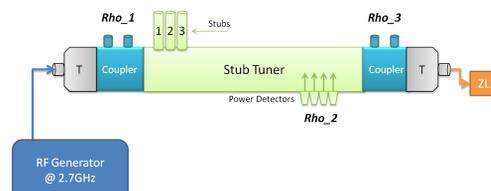


Figure 2: Low power RF system squematic.

Automatic Matching Algorithm

Fig. 3 depicts the flow diagram of the automatic matching algorithm. The goal is to optimize the impedance matching and therefore the RF power coupling in the ISHP. The control system implements the automatic operation of the triple capacitive post tuner. The starting point for the algorithm is to compute the initial load reflection coefficient, following one of the methods described below. Once the reflection coefficient is calculated, the optimum configuration of the triple stub tuner is obtained. Firstly, the algorithm calculates the theoretical post positions and their corresponding susceptances [2]. Then, it finds the real positions that better fits the ideal susceptances and finally it

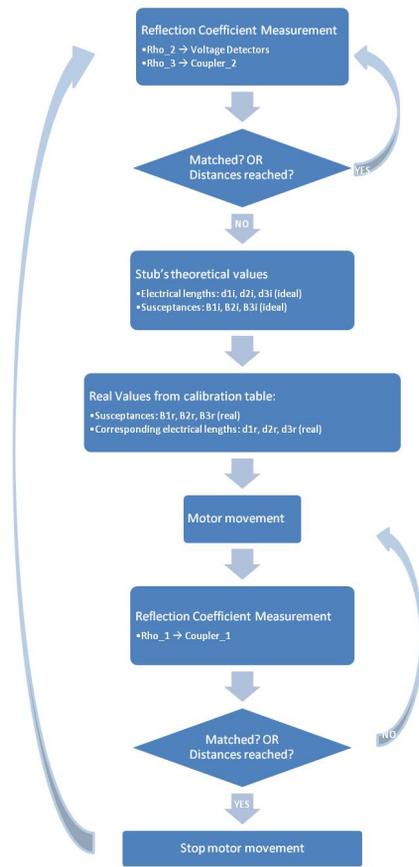


Figure 3: Automatic Matching Algorithm flow diagram.

moves the motors. To be able to execute this step, it is necessary to have a calibration look-up table previously loaded. This table has the relation between the rod's penetration length and the corresponding susceptance measured with a network analyzer. If while moving the rods towards the optimized position, the reflection coefficient reaches an acceptable value, the motors will be stop, otherwise they will continue until the ordered position.

Methods for Measuring the Reflection Coefficient

As mentioned before, in order to calculate the load impedance of the plasma chamber, the reflection coefficient is measured through different methods. It is important to point out that in order to obtain a successful result with the automatic matching algorithm, it is essential to accurately calculate the reflection coefficient.

Reflection Coefficient Measurement using a Dual Directional Coupler, IQ Demodulator Technique

In this first case, the incident and reflected signals are determined by using a dual directional coupler mounted on the RF chain. The electronics needed for developing this solution has been implemented in the ATU Front End Unit shown in fig. 4. This unit receives two pairs of samples, forward and reflected, from the couplers located at both ends of the ATU. This configuration allows us to calculate the reflection

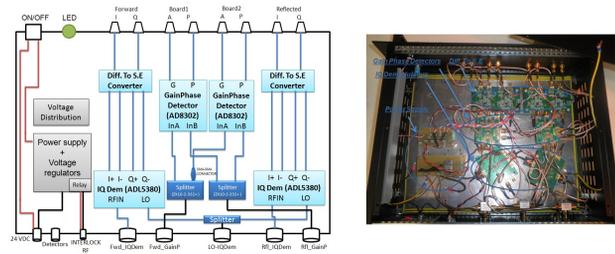


Figure 4: ATU Front End Unit schematic and implementation.

coefficient in the controller.

The two In phase and Quadrature (IQ) demodulator boards, ADL5380 from Analog Devices, convert to baseband the incident signals (L_{inc}, Q_{inc}) and the reflected signals (L_{refl}, Q_{refl}). The controller is responsible for calculating the reflection coefficient using the four baseband values obtained from the demodulator boards.

Reflection Coefficient Measurement using a Dual Directional Coupler, Gain/Phase Detector Technique

An alternative solution to the previous technique, based also on a dual directional coupler and implemented in fig. 4, is to use the gain/phase detector method. Two identical boards are needed in order to disambiguate the calculated phase [3]. Each gain/phase detector takes out an amplitude and phase value of the reflection coefficient. The signals coming from the coupler are splitted in order to introduce each pair of incident and reflected signals in each gain/phase detector. Besides, a known shift (80 degrees in this case) is introduced in one of the signals.

Reflection Coefficient Measurement using Electric Field Probes, Power Detector Technique

A set of four power detectors, ZX47-40+ from Mini-Circuits, directly connected to the electric field probes spaced λ/8 allows one to measure the voltage standing wave pattern, thus avoiding the need for bulky directional couplers [4]. The calculations can be performed by only using three of them at the same time. Once the Voltage Standing Wave Ratio (VSWR) and phase are calculated, the reflection coefficient is directly obtained.

COMPARISON AMONG THE IMPLEMENTED METHODS

In order to minimize the systematic errors in the measurements, a 1-port calibration (error correction procedure) has been performed, by using 3 known standards (short, offset short and load) to determine the three error terms of the model [5]. After the calibration of the three measurement methods, multiple tests have been done using a vector network analyzer and the previously explained techniques: power detectors and the ATU Front End Unit by means of the IQ demodulators and the gain/phase detectors.

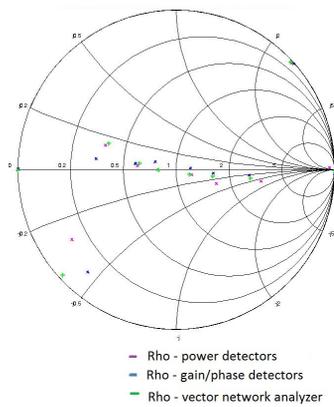


Figure 5: Comparison of Γ measurement methods in Low Power Tests.

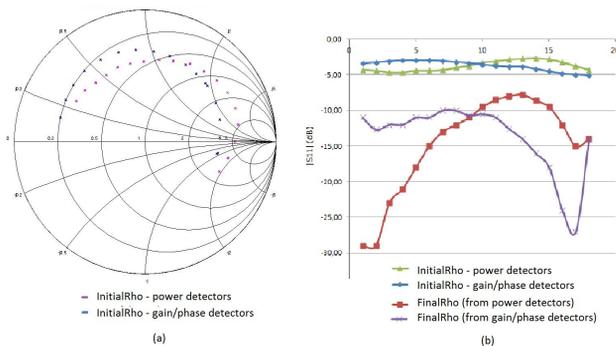


Figure 6: Different Γ measurements in Low Power Tests.

Low Power Tests

The low power tests have been carried out by using the configuration in fig. 2, a transmitted power of 25dBm and a set of loads (shorting plates, terminations, attenuators, phase shifters). Fig. 5 depicts that the reflection coefficients obtained with the proposed methods show a good agreement with those obtained by the vector network analyzer. The IQ demodulators technique is not included due to the dynamic range limitation of the IQ demodulator board.

The measured reflection coefficients, before and after applying the automatic matching algorithm are shown in fig. 6. These results have been obtained with the same input power and a commercial phase shifter which allows us to cover all the Smith Chart. Fig. 6-a displays the initial measured impedances with 10° phase steps of the shifter. Fig. 6-b shows the magnitude of the reflection coefficients, before and after applying the matching algorithm.

As a conclusion, either power detectors or gain/phase detectors can be used to calculate the load impedance of the plasma. Taking this result as a starting point the automatic matching algorithm is applied and the resulting reflection coefficient seen by the Klystron is measured.

High Power Tests

The next step has been to test the ATU under high-power operation. First, the same 1-port calibration procedure has

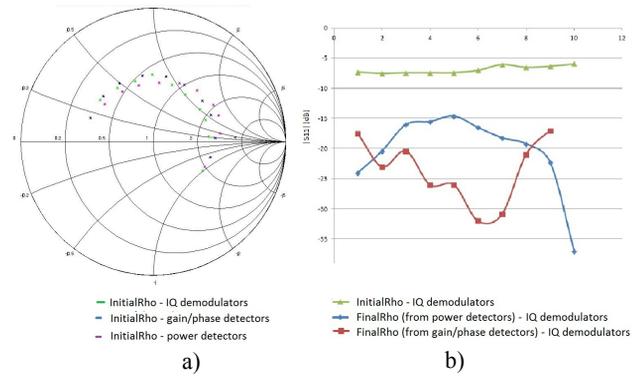


Figure 7: Different Γ measurements in High Power Tests.

been repeated for 50 Watt. At this power level, the three measurement methods show good agreement as shown in fig. 7-a. This behavior repeats when increasing the input power up to 500 Watt. Finally, it is important to point out that the automatic matching algorithm works in the same way as in low power operation, thus minimizing the reflected power (see fig. 7-b).

CONCLUSIONS AND FUTURE WORK

In this work, three techniques to measure the reflection coefficient of the ECR Ion Source plasma chamber have been presented. The three measurement methods show good agreement in both low and high power operations. Moreover, it has been shown that the automatic matching algorithm minimizes the reflected power from the load. The study performed also demonstrates that the calibration procedure applied to each measurement method has a direct influence on the obtained final results. As future work, the behavior of the automatic tuner unit with these three measurement methods but using the real plasma chamber will be analyzed.

REFERENCES

- [1] L. Muguira et al., "Automatic Tuner Unit Design, Simulation and Measurement for Automatic Operation of the RF System in the ESS-Bilbao H+ Ion Source," IPAC2011, San Sebastian, Spain, September 2011, VTHPS023, p. 3469, <http://www.JACoW.org>
- [2] J. O. Sophocles, *Electromagnetic Waves and Antennas*, (Piscataway: Rutgers University, 2004), <http://eceweb1.rutgers.edu/orfanidi/ewa/>
- [3] S. Wetterlin, "Use of Phase Shift to Resolve sign Ambiguity and Improve Accuracy in the AD8302 Phase Detector," <http://www.wetterlin.org/sam/>
- [4] Y. Ishida and M. Taniguchi, "Automatic impedance adjusting apparatus for microwave load and automatic impedance adjusting method therefor," Daihen Corporation, U.S. Patent 5079507, January 1992.
- [5] J. Fleury and O. Bernard, "Designing and characterizing TRL fixture Calibration standards for device modeling," October 2001, Applied Microwave and Wireless, vol. 13, no. 10, p. 26, oct-2001.