# ADVANCED AUTOMATIC FREQUENCY CONTROL SYSTEM FOR A DUAL ENERGY S-BAND RF ELECTRON LINEAR ACCELERATOR

S. S. Cha[1, 2], H. D. Park[2], Y. Kim[2], B. N. Lee[2], K. B. Song[2], and B. C. Lee[1, 2]

[1]Accelerator and Beam Nano Engineering University of Science and Technology (UST), Daejeon 305-350, Republic of Korea
[2] Radiation Equipment Research Division, Korea Atomic Energy Research Institute (KAERI), Daejeon 305-353, Republic of Korea

*Abstract*

The Radiation Equipment Research Division of the Korea Atomic Energy Research Institute(KAERI) has been developing an 2856 MHz 9/6 MeV dual energy S-band RF electron linear accelerator for security inspections. The S-band dual energy electron accelerator generates X-ray by shooting electron bunches to a tungsten target. By detection the X-rays, a cargo security inspection system can distinguish between organic and inorganic materials. Matching of the resonance frequencies between the cavity and RF driver is an important factor for stable operation of accelerator. By using an Automatic Frequency Control, AFC system can obtain stable accelerator operations and stable output beam powers can be obtained. This indicates that an accurate cargo inspection is possible with the AFC. In this paper, we describe an advanced AFC system for the dual energy S-band linac.

## INTRODUCTION

KAERI has been developing an S-band RF electron linear accelerator (LINAC) for the security inspection system. The S-band LINAC consists of an e-gun, an RF accelerator structure, two focusing solenoid magnets, four steering magnets, a bending magnet, a klystron, a modulator, an RF driver, an AFC, and two chillers. The AFC system is a device the resonance frequency of the RF accelerating structure and that of the RF driver [1-3]. It is essential to match the resonance frequency of the RF driver and cavity in order to obtain the high output beam power from the accelerator structure. AFC module is mainly consists of an input terminal of the signal, 2856 MHz frequency band filtering parts, attenuation parts, phase shifter, amplitude and phase measurement parts, and a correction signal output parts. If no AFC exists, obtaining a stable beam power is difficult. Therefore, an AFC system is a required element to obtain a stable beam power. In this paper, we describe to the AFC system and its test results for the S-band electron linear accelerator.

## DESIGN

Table 1 shows the specifications of the AFC system. The automatic frequency control module system for the RF accelerator consists of many parts for measuring the magnitude of the input power and reflected power from the cavity. Figure 1 shows the overall AFC system.

Table 1: Specifications of AFC Module

| Parameter | Unit | Value |
|---|---|---|
| Forward, Reflect Frequency | MHz | 2856 ± 5 |
| AFC Analogue Output | V | -10 ~ 10 |
| RF Pulse Repetition Rate | Hz | 1 ~ 300 |
| Klystron Forward Connector, Reflect Input Connector | Ω | SMA – Female 50 |
| Input VSWR | - | < 1.4 : 1 |

1. To synchronize the resonance frequency, we used a pulse trigger input.
2. Forward and reverse signals are used to detect the size of the signal (for setting the internal attenuation values), and a coupler and pulse power detector are used for the measurement of the return loss as the magnitude of the detected signal.
3. Based on the forward power, easy to use internally control the internal attenuator and apply the same attenuation in the reverse direction (set based on the forward power magnitude).
4. The distance of the phase difference caused by the forward and reverse power from the coupler to the resonator is compensated using the phase shifter.
5. To measure each phase, the forward power and reflected power must be measured. Thus, we find out how much to compensate for the VCO resonance frequency phase.
6. Comprehensive consideration, we look for the optimal frequency (return loss maximum) using a computer for the purpose of frequency correction of the VCO and then output the DC voltage.




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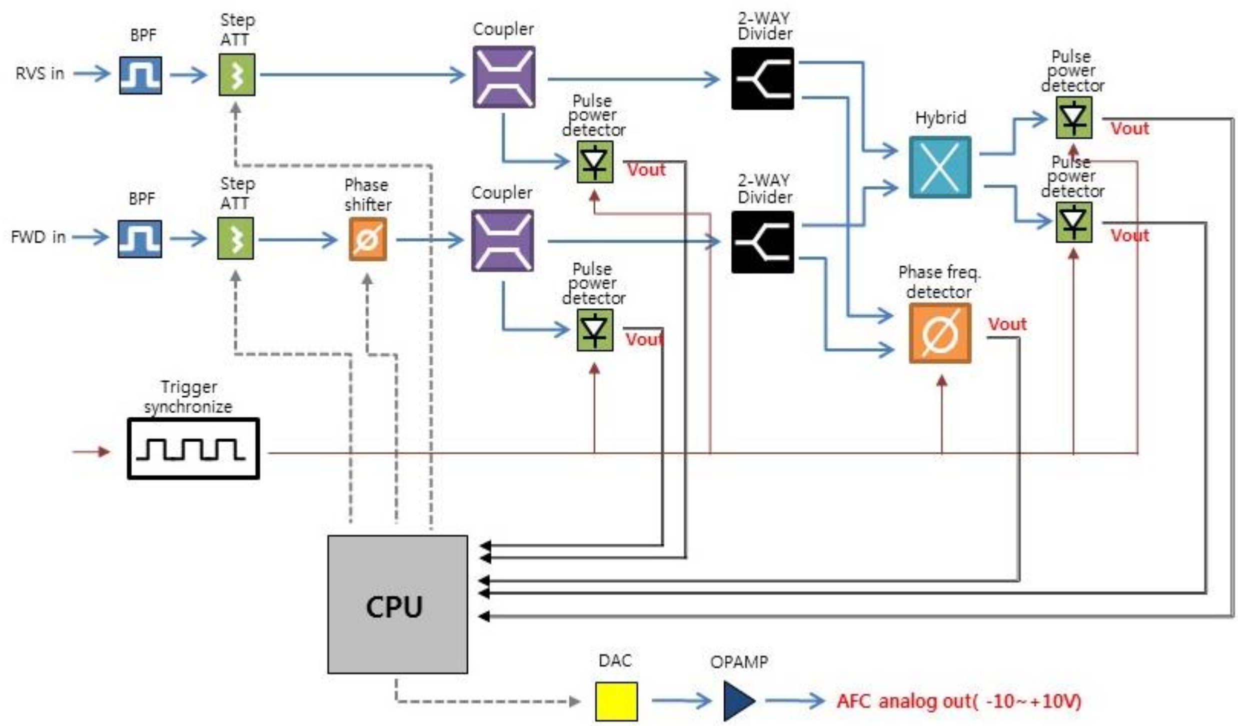


Figure 1: Automatic frequency control module for electron accelerator operation.

Figure 2 shows the simulation data obtained using the PSPICE tool. The green line is the reflected power, and the red is the AFC output control voltage. The simulation confirms that the AFC voltage control produces the same frequency and same phase in the resonance frequency of the VCO and cavity. According to the simulation results, we found that the magnitude of the reflected power is at minimum when the resonance frequency of the resonator and the resonance frequency of the VCO are the same. We fabricated the AFC module to apply to the S-band RF electron linear accelerator and accomplished AFC testing with the dummy cavity. For feedback testing with the AFC module, we made a 2856 MHz dummy cavity, as shown in Figure 3, and test the resonance frequency synchronization between the VCO and cavity. Using a dummy cavity for the RF testing of the AFC, we saved space as well as time. Figure 4 shows the resonance frequency of the dummy cavity. The resonance frequency of the dummy cavity is 2855.58 MHz, which is 420 kHz less than the designed resonance frequency of the cavity, which is 2856 MHz. The minimum loss occurred while it was resonating. Figure 5 (a) illustrates the AFC. There is an attenuator, return loss, DAC, and phase offset on the front panel. When the switch is turned on, the device finds the resonance frequency automatically. Figure 5 (b) shows a picture of the manufactured AFC module. It receives forward power and reflected power from the cavity and sends out a control voltage of ±10 V.

Figure 2: AFC system simulation result (PSPICE).

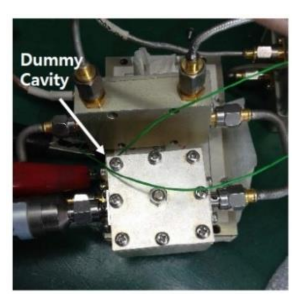


Figure 3: Dummy cavity for RF test of AFC module.

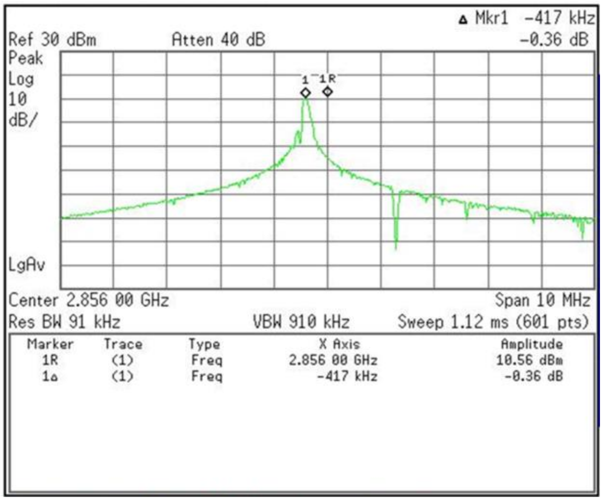


Figure 4: Resonance frequency of dummy cavity for RF test (2855.58 MHz).

(a) Automatic frequency control (module)

(b) Automatic frequency control module (inside)

Figure 5 (a), (b): Automatic frequency control module for S-band RF electron LINAC.

Figure 6 (a) shows that the resonance frequency is 2852.43 MHz when the AFC analogue output is +9.77 V. At this point, the maximum return loss is -7.49 dB, which shows that there is a great loss. Figure 6 (b) also shows that the resonance frequency is 2859.52 MHz when the AFC analogue output is -9.94 V. At this point, the maximum return loss is -5.76 dB. Therefore, it is proven that there is a great loss.

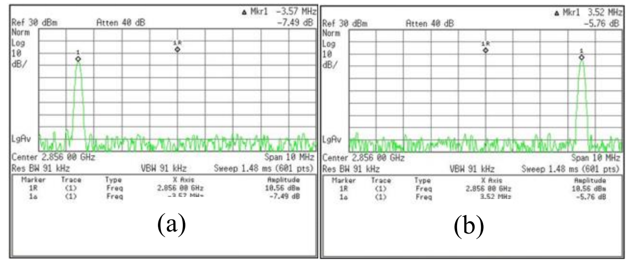


Figure 6: Return loss of center frequency (a) (2852.43 MHz), (b) (2859.52 MHz).

## TEST RESULTS AND CONCLUSION

An automatic frequency control system for the s-band electron linear accelerator was developed, and basic performance tests were conducted using a dummy cavity. We conducted a full scan of the AFC analogue output voltage for ± 10 V (2856 ± 5 MHz). As a result of analyzing the data from the spectrum analyzer, +9.77 V and -9.94 V were the maximum reflected power. As we expected during the simulation, the AFC control module test result shows that the reflected power from the cavity was measured to be the lowest at a frequency of around 2856 MHz. This means that the RF power will be fully and stably delivered from the local oscillator to the cavity.

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