TRIUMF CYCLOTRON BOOSTER FREQUENCY TUNING SYSTEM

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Abstract

For the auto frequency tuning of TRIUMF cyclotron booster, a new control module based on the VXI Bus has been designed, tested, and put into commission. This new auto tuning control module, which replaced the old analogue control box, has more features, including the implementation of PIC16C71 microprocessor to generate Pulse Width Modulation (PWM) pulse, the utilization of digital RF phase detector, and the most important aspect of computer control capability. Thus, the resonant frequency of the cyclotron booster RF cavity is tuned automatically by this control module, and the reflected RF power is kept at the minimum level in the operation.

INTRODUCTION

For an accelerator RF cavity, the auto frequency tuning system keeps the cavity at resonant frequency to achieve the desired RF voltage with minimum RF power input. If the RF cavity is out of tune, RF power is partially or totally reflected and the reverse power may damage the RF power amplifier or the transmission line, especially in cases of high power operation.

Thus, the auto frequency tuning system is essential for the RF resonant structure. The TRIUMF RF Booster operates at 92MHz with a nominal voltage of 150kV[1]. In order to realize the auto frequency tuning, two capacitor tuners called Master Tuner and Slave Tuner, are implemented in the TRIUMF cyclotron booster cavity to cover the resonant frequency excursion.

This design uses the microprocessor PIC16C71 to generate a PWM waveform to drive the DC motor of the cyclotron booster tuner. Such a design has good flexibility to adjust the PWM pulse width by using programming software. Furthermore, a digital type of RF phase detector is implemented in the new tuner control module and covers a wider phase error range. These new features make this control module more flexible and reliable.

PRINCIPAL CIRCUITS AND FUNCTIONS

Figure 1 shows the block diagram of the new booster tuner control module. It mainly consists of two logarithmic amplifiers, a RF phase detector, a PIC16C71 microprocessor, a RF amplitude detector, and a driver amplifier.

PIC16C71 Microprocessor

The PIC16C71 is a low-cost high-performance 8-bit micro-controller. It has 36 bytes of RAM and 13 I/O pins. Also, a 4-channel high-speed 8-bit A/D converter is provided within the chip. The 8-bit resolution is ideally suited for applications requiring low-cost analogue interface (e.g. tuner control, thermostat control, etc).

In the booster tuner control PCB, two PIC16C71 microprocessors are used to control the master tuner and the slave tuner separately. For the master tuner PIC16C71 controller, RB0 and RB1 of port B are set up as the PWM pulse output channels. Port A 4-channel A/D converter is set up like the following: RA0 is the RF phase input; RA1 is the RF amplitude input; RA2 is the master tuner position input; and RA3 is the standard ADC reference voltage input. As to the slave tuner PIC16C71 controller, Port B RB0 and RB1 are similarly set up as PWM pulse output channels. Port A RA0 is the master tuner position ADC and RA1 is the slave tuner position ADC.

For timing insensitive applications such as the RF cavity frequency tuning controller, the "RC" oscillator for the microprocessor is good enough to let the controller running. The RC oscillator frequency is mainly a function of the supply voltage, the external resistor (Rext), the external capacitor (Cext) values, and the operating temperature. For Rext values below 2.2kΩ, the oscillator operation may become unstable, or stop completely. For very high Rext values (e.g.1MΩ), the oscillator becomes sensitive to noise, humidity, and leakage. Thus, Rext values should be chosen between 3.3kΩ and 100kΩ. As to Cext, the oscillation frequency can vary dramatically due to residual capacitance with no or small external capacitance. Therefore, it is recommended to choose Cext values above 20pF for noise and stability reasons.

In this design, 3.3kΩ is selected as Rext value and 22pF is selected for Cext. The oscillation frequency is about 6MHz, including residual capacitance on the PCB board.

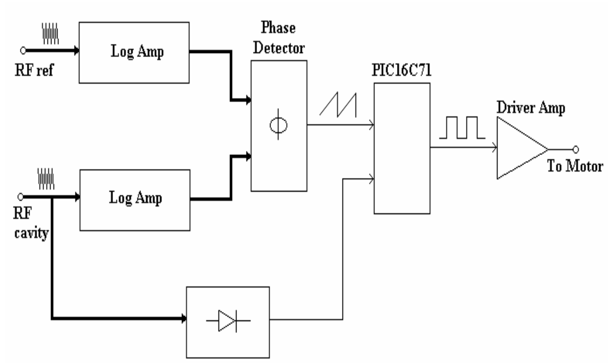

Figure 1: Block diagram of booster tuner control module.

RF Phase Detector

In the old booster tuner control unit, a SRA-1 mixer was used to detect the RF phase error. For the new tuner control module, a different type of phase detector is utilized. This phase detector uses two F100304 chips, which is a low power quintuplet AND/NAND gate chip.

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This digital phase detector generates saw-tooth-waveform phase error output by applying two different RF signals into its inputs. This kind of phase detector is easier to get auto frequency tuning locked and more stable because of its wider phase coverage. The actual phase detector circuit is illustrated in Fig.2. The detected phase error is the output of TL082 and ranges between –2.5V and +2.5V.

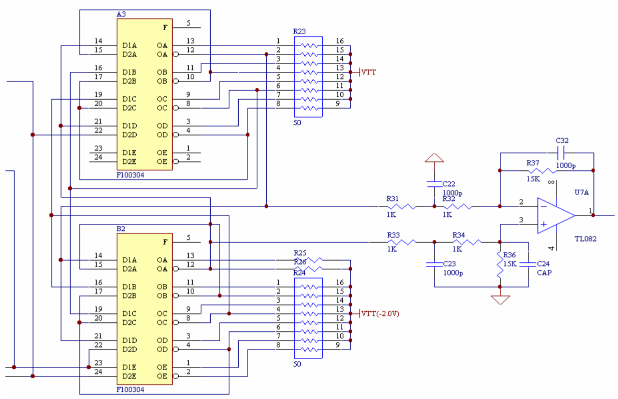

Figure 2: Phase detector circuit.

Logarithmic Limiting Amplifier

For a normal RF phase detector, the phase error signal is not only related to input signals phase difference, but also related to input signals amplitude level. In order to get an accurate phase error, the amplitude of input signals to the phase detector must be set to a fixed value. Therefore, limiting-logarithmic amplifiers are necessary at the RF input for every phase detector to achieve an accurate phase control. [2]

In this booster tuner control module, Log amplifier AD8306 is implemented. It has super high dynamic range and amplitude gain. Its operation frequency range is from 5 MHz to 400 MHz and its dynamic range is 100 dB, from –91dBV to +9dBV. The designed schematic circuit of the limiting-logarithmic amplifier is shown in Fig.3.

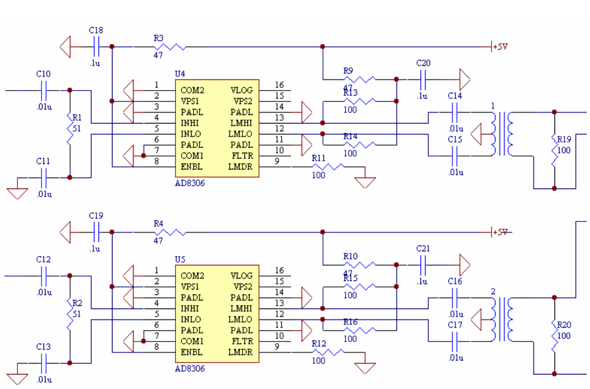

Figure 3: Logarithmic amplifiers circuit.

Amplitude Detector

The amplitude detector is used to monitor the booster cavity's RF voltage level. Only when the booster amplitude reaches a certain level is the booster auto-tuning control set to close-loop. During the power-up procedure, the cavity is firstly powered by RF pulse to pass through the multipactoring. So during start-up, the auto frequency tuning control is not operational. Only when the pulsed RF signal is switched to CW RF signal can the auto-frequency-tuning module work properly. After that, it is possible to set the tuner to close-loop when the appropriate RF amplitude level has been reached.

Driver Amplifier

The driver amplifiers are incorporated into the tuner control board to drive the DC motors of booster tuners. Each driver amplifier consists of a pair of power transistors, MJE340 and MJE350. MJE340 is a NPN silicon transistor and MJE350 is a PNP silicon transistor. Both transistors are useful for high-voltage general-purpose applications. The driver amplifier for the master tuner DC motor is indicated in Fig.4.

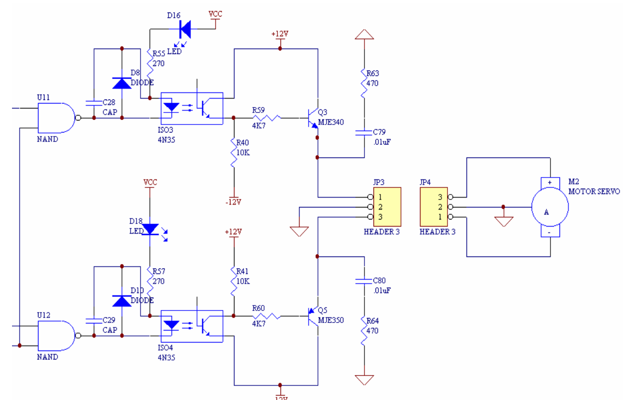

Figure 4: Driver amplifier for tuner DC motor.

SOFTWARE

For PIC16C71, a set of special instructions is used for programming. All instructions are recognized by the MPASM assembler or by the Integrated Development Environment MPLAB IDE. The program for the booster tuner control module is written in this assembly language. [3]

CONCLUSION

This auto frequency control module has already been put into commissioning. It has been installed in a VXI crate and can communicate with the local control computer to realize the booster tuner control properly. High power tests have been done for the booster cavity power level up to 40kW. The auto tuning system keeps the tuners moving and tracks the resonant frequency well.

REFERENCES

[1] K. Fong, M. Laverty, "RF Control for TRIUMF Booster Cavity", Proceedings of the Third European Particle Accelerator Conference, Berlin, March 1992, pp. 1176 - 1178.

[2] Q. Zheng, "High Performance Limiting-Logarithmic Amplifier", TRIUMF Design Note TRI-DN-02-25, Dec. 2002.

[3] Microchip Technology Inc, Microchip PIC16/17 Microcontroller Data Book, 1996/1997.