HIGH-POWER OPERATION OF AN L-BAND RESONANT RING

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Abstract

In the International Linear Collider (ILC), RF power is transmitted from a 10 MW klystron to 39 cavities by the Local Power Distribution System (LPDS). The compact LPDS and required RF components are designed to reduce the production costs and improve the adjustable margins of power and phase. To estimate the power capability of the RF components, an L-band resonant ring was constructed in the Super-conducting RF Test Facility (STF) at KEK to generate circular power of 5 MW with 2 ms pulse width and 5 Hz repetition rate. The resonant ring was pressurized with SF_6 gas to 0.1 MPa to prevent the arcing problems in the waveguide. The 800 kW klystron was used as the power source for high-power operation. The circular power of 4 MW with pulse width of 0.5 ms and power gain of 12.4 dB was achieved; however, arcing occurred. The 3 dB hybrid is expected to be updated with an improved design, and the whole resonant ring will be pressurized with SF_6 gas to 0.2 MPa to improve the maximum circular power.

INTRODUCTION

In the International Linear Collider (ILC), RF power is transmitted from a 10 MW klystron to 39 cavities by three Local Power Distribution Systems (LPDS) with the frequency of 1.3 GHz, the pulse width of 1.65 ms and the repetition rate of 5 Hz [1]. To reduce the production costs and improve the adjustable margins of power and phase, a compact LPDS was designed [2]. The maximum input power of the LPDS is approximately 1.3 MW. Considering the condition of total reflection, a test at four times this power (5 MW) is required to check the power capability of the RF components of the compact LPDS.

To protect the klystron from reflected power from the device under test (DUT), it is necessary to insert a circulator between the klystron and the DUT. It is difficult to produce a 5 MW circulator owing to the arcing problems; hence, the DUT cannot be directly conditioned by the 10 MW klystron. The resonant ring is frequently used for high-power tests of RF components due to its power amplification. The power gain is determined by the one-turn power loss of the ring [3]. We constructed an L-band resonant ring in the Super-conducting RF Test Facility (STF) at KEK. The power gain was estimated to be more than 10 dB. Therefore, an input power less than 500 kW to the resonant ring can be amplified to 5 MW in the ring, and this power source can be protected by the 500 kW circulator. An 800 kW klystron has already been installed in the STF and can be used as the power source for the resonant ring.

Our target for the resonant ring is to achieve circular power of 5 MW with pulse width of 2 ms. After a low-power test of the resonant ring, the power gain was demonstrated to be 14.1 dB [4]. To prevent arcing during high-power operation, the resonant ring needs to be pressurized with SF_6 gas to 0.1 MPa. Thus far, 4 MW circular power with pulse width of 0.5 ms has been achieved; however, arcing was observed.

PREPARATION FOR HIGH-POWER OPERATION

For high-power operation, the resonant ring needs be pressurized with SF_6 gas to prevent arcing. Figure 1 shows the structure of the resonant ring for high-power operation. We reconstructed the resonant ring with the fixed 11 dB hybrid and the 360° phase shifter which can be pressurized. The 500 kW circulator is used to protect the power source from the reflected power of the resonant ring. The 3-stub tuner is used to suppress the backward power in the ring. The power capability of the 3-stub tuner is more than 5 MW when filled with SF_6 gas to the pressure of 0.2 MPa. The DUT is filled with air and the rest of the resonant ring is filled with the SF_6 gas. The four RF windows are used to separate the SF_6 gas from the air. Four signals are monitored in the resonant ring: ‘Input’ is the input power of the resonant ring, ‘Input-r’ is the reflected power from the resonant ring to the power source, ‘Pf’ is the forward circular power in the ring, and ‘Pb’ is the backward power in the ring.

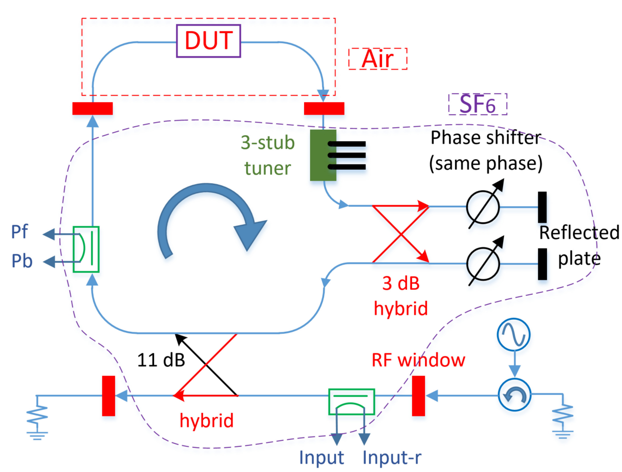

Figure 1: Structure of the resonant ring for high power operation.

Figure 2 shows the 360° phase shifter which can be pressurized. The phase shifter consists of a 3 dB hybrid and two reflection phase shifters with the same phase shift [5].

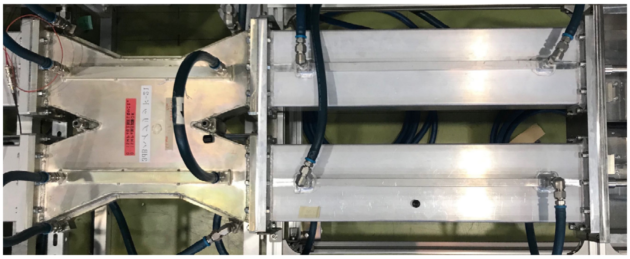

Figure 2: 360° phase shifter (pressurized).

The whole resonant ring was pressurized with the SF_6 gas to 0.1 MPa. A solid state amplifier with a maximum output power of 500 W was used as the power. The measured transmission ratio and coupling ratio of the hybrid are -0.41 dB and -11.16 dB by power, respectively. The measured one-turn power loss of the ring was -0.11 dB. Based on these three parameters, the maximum simulated power gain should be 13.6 dB [4]. Table 1 presents the measured result of a low-power test from the power meter. The input power was 302 W and the circular power is 7.56 kW. The power gain was 14.0 dB. One possible reason for the difference between the simulated and measured power gain is the error in the measured parameters. The backward power was too low to be measured by the power meter.

Figure 3 shows the waveform of the low-power test. The pulse width was 2 ms. The amplitude of the waveform can be used to adjust the phase shifter and 3-stub tuner to an optimal condition. The one-turn delay of the ring was measured as 26 ns. If the input signal is assumed to be a perfect rectangular wave, then the simulated rise time (10% to 90%) of Pf will be 0.93 µs. The measured rise time (10% to 90%) of Input and Pf were 0.62 µs and 1.1 µs, respectively. One possible reason of the difference between the simulated and measured rise time of Pf is the nonzero rise time of the input.

Table 1: Measured Result of the Low-power Test from the Power Meter

	Power
Input	302 W
Pf	7.56 kW
Gain	14.0 dB

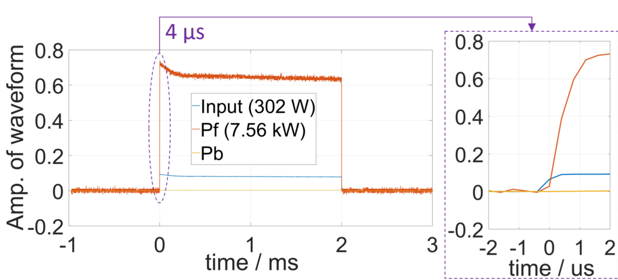

Figure 3: Waveform of the low-power test.

HIGH-POWER OPERATION OF THE RESONANT RING

As noted, the target for the resonant ring is 5 MW circular power with pulse width of 2 ms and repetition rate of 5 Hz. To protect the resonant ring from arcing problems, it was pressurized with SF_6 gas. The 3 dB hybrid in the 360° phase shifter can only be pressurized to 0.15 MPa, otherwise leakage of SF_6 gas will occur. The other components of the resonant ring can be pressurized to more than 0.2 MPa. Therefore, the resonant ring was pressurized with SF_6 gas to 0.1 MPa. During initial high-power operation, the pulse width was 0.5 ms. The 800 kW klystron was used as the power source for high-power operation of the resonant ring. As the power gain of the resonant ring is more than 10 dB, less than 500 kW of output power from the klystron is sufficient to generate 5 MW of circular power. The 500 kW circulator can be used to protect the klystron.

Table 2 presents the measured result of the high-power operation as measured by the power meter. The pulse width was 0.5 ms. With an input power of 234 kW from the klystron, the resonant ring can generate the circular power of 4.01 MW, with the power gain is 12.4 dB. The backward power was again too small to be measured by the power meter. Arcing occurred when the circular power was increased to 4 MW.

Table 2: Measured Result of High-power Operation from the Power Meter

	Power
Input	234 kW
Pf	4.01 MW
Gain	12.4 dB

Figure 4 shows the waveform during the 4 MW operation. The rise time (10% to 90%) of the input and circular power were 0.32 µs and 1.0 µs, respectively.

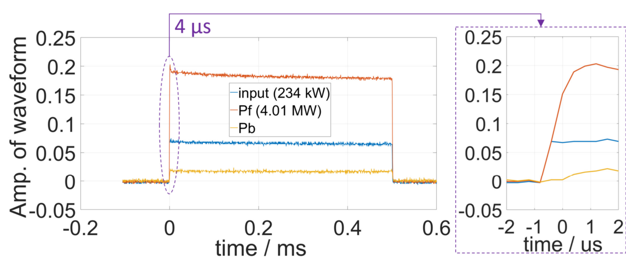

Figure 4: Waveform of 4 MW operation.

The breakdown voltage increased with increasing SF_6 pressure [6]. The circular power may be increased if the resonant ring is pressurized to 0.2 MPa. A new 3 dB hybrid that can be pressurized up to 0.2 MPa will be designed and manufactured. High-power operation of the resonant ring will then be continued.

TEST PLAN FOR RF COMPONENTS USING THE RESONANT RING

There are two types of RF components used for the compact LPDS of the ILC: two-ports and four-ports devices. The two-ports devices consist of the variable phase shifter, the fixed phase shifter, the H-corner and the straight waveguide. The four-ports device is the variable hybrid.

As Figure 1 shows, the DUT will be inserted between the two RF windows in the resonant ring and filled with air. The resonant ring can be adjusted to maximum power gain using the 360° phase shifter and 3-stub tuner after the DUT is inserted.

Figure 5 shows the resonant ring test model for the variable hybrid. The symbols k_1 and k_2 denote the transmission ratio and coupling ratio of the variable hybrid by voltage, respectively. Two variable hybrids are set to the same coupling ratio and constructed as a pair. The phase difference between the two chains of the variable hybrids should be 180°. With this construction, all the power will be transmitted to the upstream output of the pair of variable hybrids, and the power transmitted to the downstream output will be cancelled.

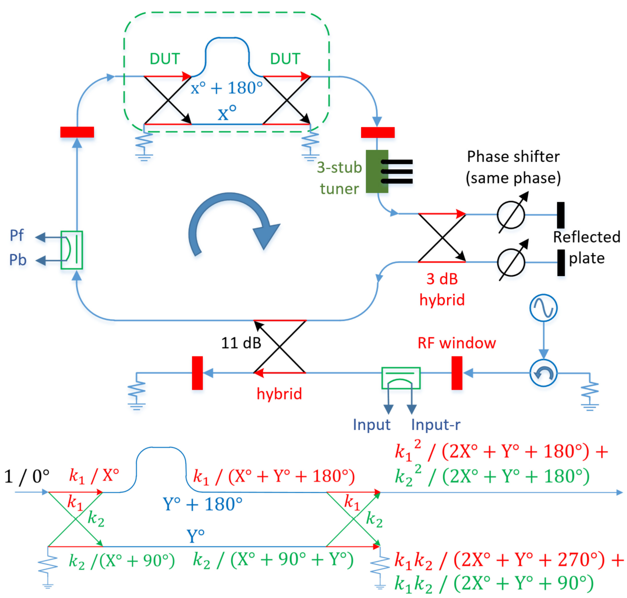

Figure 5: Test model for the variable hybrid using a resonant ring.

CONCLUSION

A test plan for RF components using a resonant ring was determined. An L-band resonant ring was constructed in the STF and pressurized with SF_6 gas to 0.1 MPa. The RF frequency was 1.3 GHz and the repetition rate was 5 Hz. The circular power of 4 MW with the pulse width of 0.5 ms was achieved with the power gain of 12.4 dB; however arcing occurred under this power. A new 3 dB hybrid will be designed and manufactured to increase the pressure of SF_6 gas in the entirety of the resonant ring from 0.1 MPa to 0.2 MPa. It is expected that this will allow circular power and pulse width to be increased to 5 MW and 2 ms, respectively.

REFERENCES

[1] ILC, `http://www.linearcollider.org/ILC/?pid=1000895`

[2] B.T. DU *et al.*, "Design of a Compact Power Distribution System for the ILC", *Proc. 10th International Particle Accelerator Conf. (IPAC'19)*, Melbourne, Australia, May. 2019, pp. 436-438.

[3] H. Golde *et al.*, "Theory and measurement of Q in resonant ring circuits", *IRE Transactions on Microwave Theory and Techniques*, vol. 8, pp. 560-564, 1960. doi: 10.1109/TMTT.1960.1124786.

[4] B.T. Du *et al.*, "L-Band Resonant Ring for Testing RF Windows for ILC", in *Proc. 29th Linear Accelerator Conf. (LINAC'18)*, Beijing, China, Sep. 2018, pp.679-681. doi: 10.18429/JACoW-LINAC2018-THPO003

[5] R.K. Cooper and R.G. Carter, "High-power RF Transmission", *Proc. RF Engineering for Particle Accelerators*, Oxford, England, 1991, pp. 245-268.

[6] H. Itoh *et al.*, "Measurement of the effective ionisation coefficient and the static breakdown voltage in SF_6 and nitrogen mixtures", *J. Phys. D: Appl. Phys.*, vol. 12, pp. 2167-2172, Feb. 1979.