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*Development of 1.2 Mega-Watt P-band Travelling Wave Resonant Ring**

Fanyu Wang[1,2], Zusheng Zhou†[1,2], Ouzheng Xiao[1], Yiao Wang[1,2], Yu Liu[1,2], Wenbing Gao[1,2], Han Xiao[1,2], Fei Li[1], Nan Gan[1], Noman Habib[1,2], Munawar Iqbal[1], Abid Aleem[1]

[1]Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China

[2]University of Chinese Academy of Sciences, Beijing 100049, China

中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

High power microwave devices, such as ceramic windows and couplers, are critical components in accelerators, where safety and reliability are paramount. To ensure their safe operation, these devices must undergo rigorous high-power testing. The Traveling Wave Resonant Ring (TWRR) is an economical and efficient device used for such testing. The Institute of High Energy Physics (IHEP) is currently designing a TWRR at the P-band frequency to support the development of klystrons in CEPC[1]. The TWRR's main components include a directional coupler, observation window, 3-stub tunner, load, and cooling system. This TWRR is capable of testing at 1.2MW(1.5 times the rated power of an 800-kW klystron), significantly reducing the risk of the window being penetrated during operation.

INTRODUCTION

A resonant ring, also known as a traveling wave resonator(TWRR), is a loop of waveguide which can amplify apparent power through the coupling of waves at its input. Figure 1 shows a basic resonant ring circuit.

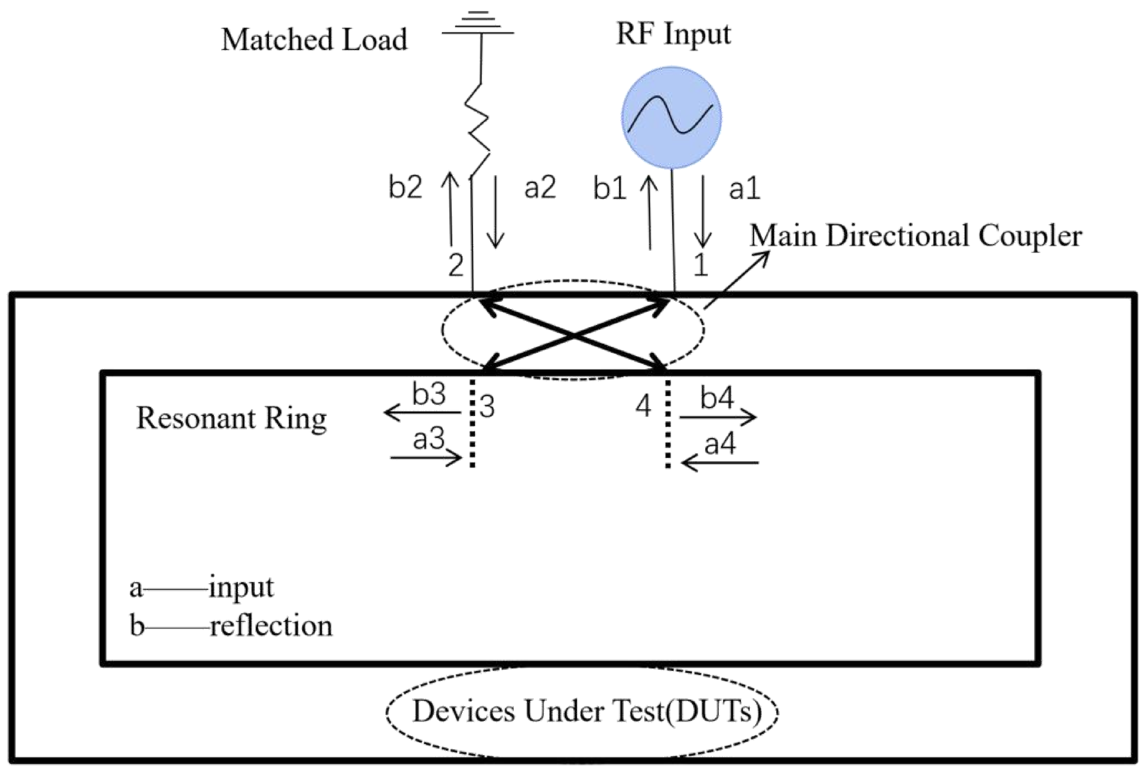

Figure 1 Basic Resonant Ring Circuit

Power is initially input to port 1 and then coupled into the ring through port 3. Uncoupled waves continue through port 2, which is typically terminated by a load, while the waves within the ring travel through ports 3 and 4. With the appropriate ring length and matching, these waves add constructively, resulting in a voltage increase that functions as power gain within the ring. Since power meters can easily measure the ring's performance, it is often the loop power "gain" that is of primary interest, which is proportional to the square of the voltage gain.From V. Veshcherevich [2],when the ring is in resonance,power gain M is:

$$M = \frac{C^2\left(1-e^{-\alpha L}\sqrt{1-C^2}\sqrt{1-r^2}\right)^2}{\left(1-2e^{-\alpha L}\sqrt{1-r^2}\sqrt{1-C^2}+e^{-2\alpha L}(1-C^2)\right)^2}$$

where C is the coupling coefficient of the directional coupler; r is the reflection coefficient in the ring; $e^{-\alpha L}$ is the attenuation in the circuit; α is the effective attenuation coefficient; L is the length of the ring.

The length of the ring must be an integral number of guide wavelengths of coupled wave,which will reinforce previously coupled energy and place the ring in a state of resonance [3].

POWER GAIN

The lower the attenuation and the reflection in the resonant ring are, the higher is the power gain. Figure 2 illustrates the behavior of the M parameter for the ring with no reflection (r = 0).

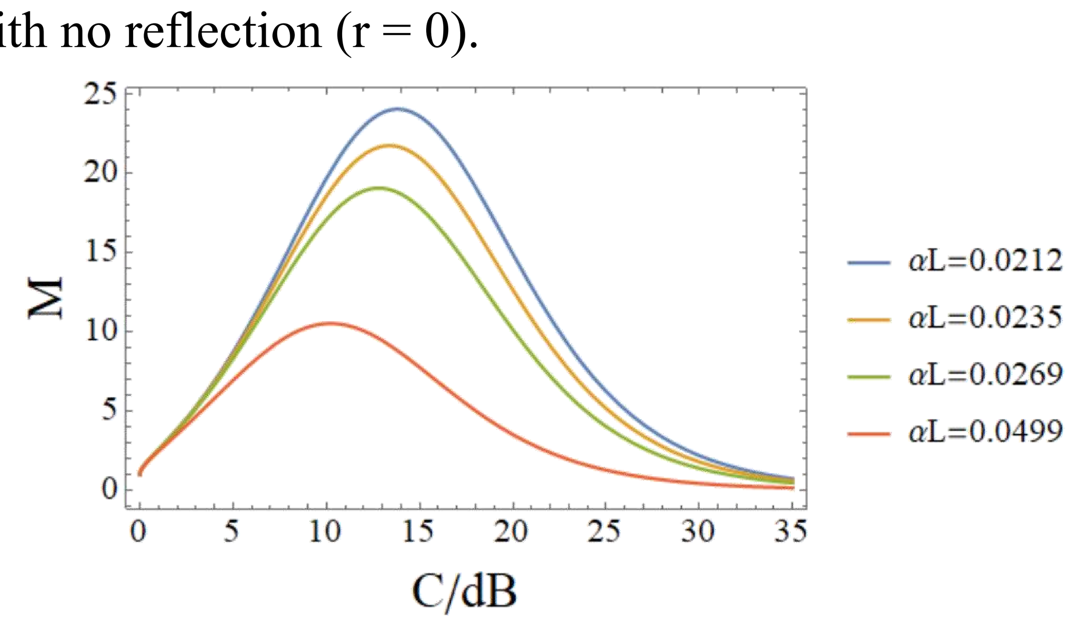

Figure 2 Power gain of a resonant ring with no reflections

For each attenuation value, there exists the optimal coupling coefficient C_{opt}, for which the power gain is maximal. For no reflection case, C_{opt} is

$$C_{opt} = \sqrt{1-e^{-2\alpha L}}$$

and the maximal power gain is

$$M_{max} = \frac{1}{C_{opt}^2} = \frac{1}{1-e^{-2\alpha L}}$$

Attenuation coefficient for a rectangular waveguide is

$$\alpha_w = \frac{R_{sw}}{Z_0}\frac{1+\frac{2h}{w}\left(\frac{\lambda}{2w}\right)^2}{h\sqrt{1-\left(\frac{\lambda}{2w}\right)^w}}$$

where R_{sw} is the surface resistance of the waveguide wall material, Z_0≈377Ohm is the free space impedance, h is the height of the waveguide, w is its width, λ is the wave length in free space.

Table 1 shows the calculation results of 1.2 Mega-Watt P-band Travelling Wave Resonant Ring.The maximal power gain M_{max}=24 and the maximal power gain M_{max}=10.5.

Table 1 Theoretically Results of P-band TWRR

Waveguide	WR1500
Attenuation coefficient α_w	3.6×10^{-3} dB/m
Length of the ring	9.28m
Insertion loss of windows	0.05-0.3dB
Minimum total attenuation αL_{min}	0.0204
Maximum total attenuation αL_{max}	0.0499
C_{opt} at αL_{min} /C_{opt} at αL_{max}	–14dB/–10dB
M_{max}/M_{min}	24/10.5

The coupling coefficient and the power gain assuming ideal matching in the traveling wave resonator.In fact, reflections strongly affect the parameters of rings. Figure 3 illustrates this effect for the 1.2 MW P-band TWRR with αL = 0.0499.

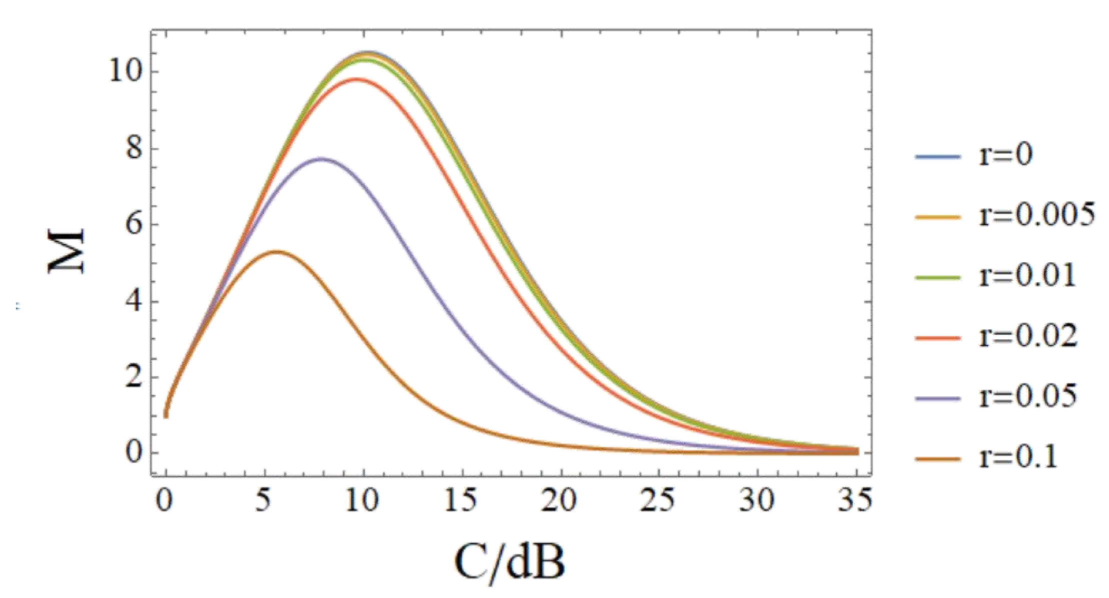

Figure 3 Power gain of a resonant ring with reflections (αL = 0.0499)

Figure 4 presents dependence of the power gain on circuit attenuation for the resonant ring with given coupling and different reflection values.It is obvious that the reflection coefficient should be below 0.02 to obtain a considerable power magnification.

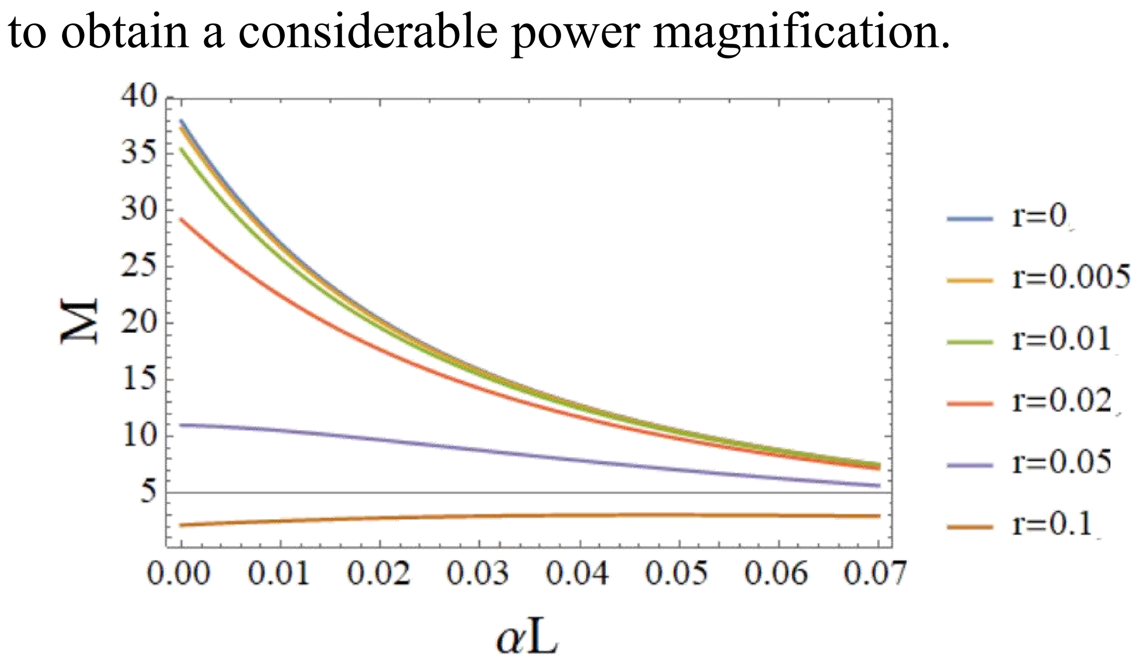

Figure 4 Power gain of a resonant ring with coupling coefficient C = –10 dB

MAIN DIRECTIONAL COUPLER

To couple the traveling wave resonator to the main transmission line, the ring requires a directional coupler with a coupling coefficient of C = –10 dB that has low reflection when the the attenuation is maximal.Scattering coefficients of that directional coupler are calculated by CST MWS[4] are presented in Figure 5. It can be observed that the directivity (S_{41} – S_{21}) of the directional coupler is better than 30 dB.

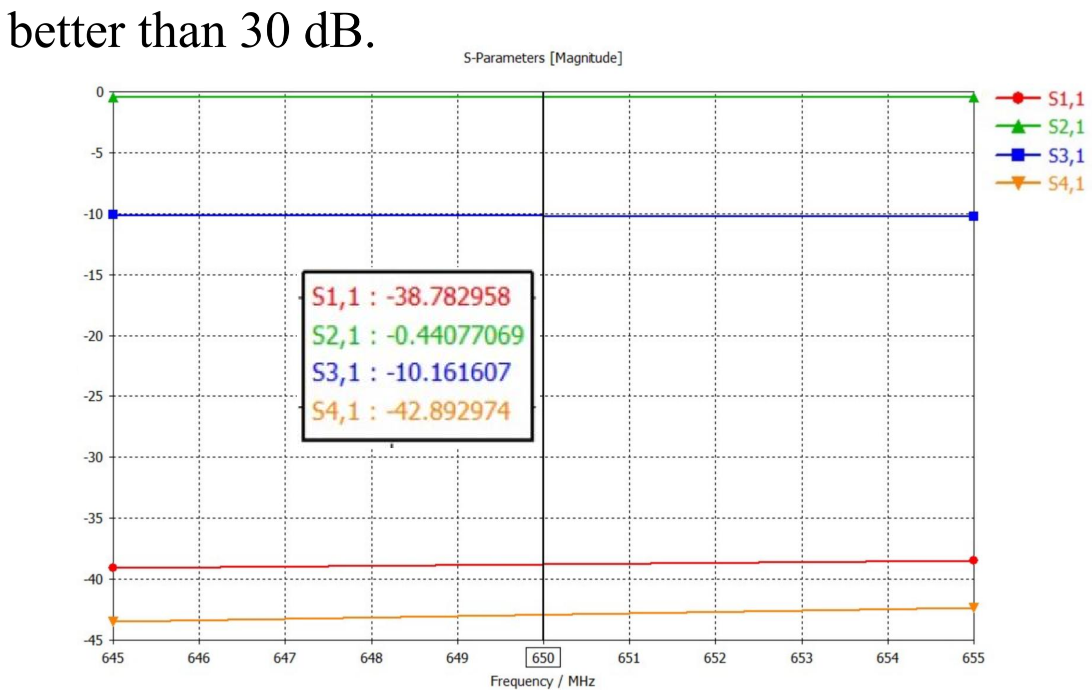

Figure 5 Main directional coupler response in CST MWS

RESONANT RING FOR WINDOW TESTS

P-band resonant ring consists of a WR1500 waveguide part, a main directional coupler, a directional coupler for power detection,a three-stub tuner for matching purposes,devices under test(DUTs), and a matched load. Configuration and the direction of power flow inside the TWRR. are showed in figure 6 and figure 7.

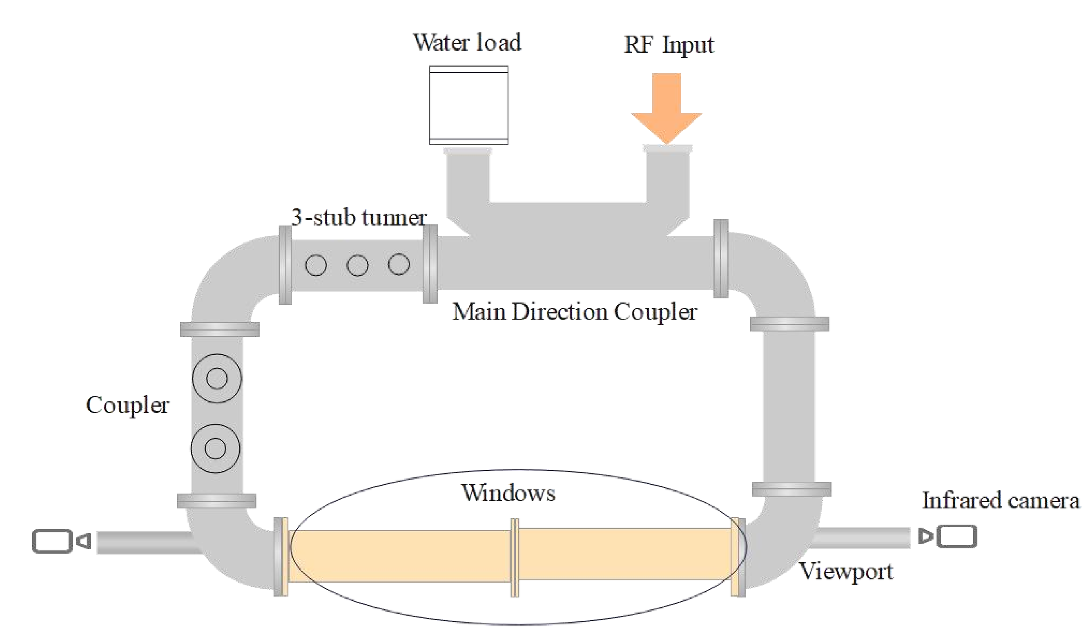

Figure 6 Configuration of P-band TWRR

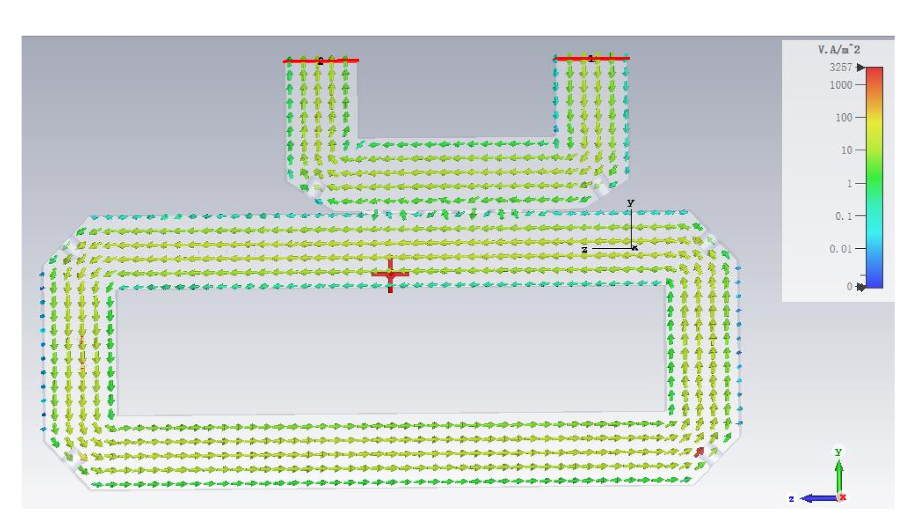

Figure 7 Power flow in P-band TWRR

SUMMARY AND OUTLOOK

This paper presents the development of a 1.2 Mega-Watt P-band Traveling Wave Resonant Ring. The power gain is analyzed theoretically, and the main directional coupler is identified. In the next phase, we will complete the design of the three-stub tuner, along with a thermal analysis of the ring.

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† email address: zhouzs@ihep.ac.cn