RESONANT RING FOR TESTING OF ACCELERATOR RF WINDOWS

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Abstract

A klystron-driven resonant ring has been designed and assembled at the Los Alamos National Laboratory for use in the Accelerator Production of Tritium Project (APT). The ring was built to test rf windows for the 700 MHz section of the APT accelerator. The ring has been designed to apply an effective power of approximately 1 MW on test windows. Details of ring design, operation and performance will be presented.

1 INTRODUCTION

A resonant ring, also known as a traveling wave resonator, is a loop of waveguide which can amplify apparent power through the coupling of waves at its input. Resonant rings can be used for high power breakdown tests, unidirectional filters, or pulse-shaping techniques. The Lansce-5 group at the Los Alamos National Laboratory has built a resonant ring to test radio frequency windows at high powers for the Accelerator Production of Tritium (APT) project.

The first step in this experiment is the characterization of the resonant ring at low power. The ring was designed for a power gain of 12.5, allowing for the application of an effective power of approximately 1 MW on test windows with currently available 700 MHz klystrons. With the impending delivery of 1 MW, 700 MHz klystrons to APT, windows and other rf components could be tested at extremely high rf power levels.

Power gain, at low power levels, has now been measured as a function of ring attenuation. The insertion of various microwave absorbers into the ring mimicked the attenuation of rf windows and components under test in the ring. These low power tests have increased confidence that the ring will operate as designed in high power testing.

2 THEORY

Figure 1 shows a basic resonant ring circuit.

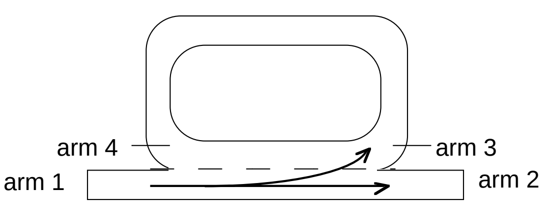

Figure 1: Basic Resonant Ring Circuit

Power is input to the first arm and then coupled into the ring through the third arm. Uncoupled waves continue through the second arm, which is usually terminated by a load, and the waves in the ring continue to travel through the third and fourth arms. With the proper ring length and matching, the waves add constructively. This creates a voltage increase and acts as a power gain in the ring.

Several variables factor into the ring's performance: loop gain, coupling coefficient, attenuation in the ring, transmission coefficient, and electrical length. Some of these variables are dependent on one another.

The transmission coefficient is the ratio of the voltage of the wave that passes through a junction to the voltage before the junction. In the ring the "junction" is the load imposed upon the ring by attenuation which causes the voltage to drop.

If the electrical length of the ring is properly related to the frequency of the coupled energy, it will reinforce previously coupled energy and place the ring in a state of resonance [1]. In order for this to occur, the length of the ring must be an integral number of guide wavelengths of coupled wave.

The amount of power input to the ring from the primary arm is determined by the voltage coupling coefficient. The coupling coefficient (usually designated as C) is defined as the ratio of the voltage coupled into the ring to the incident voltage from the main guide when all arms but the one with incident voltage are terminated in matched loads [2].

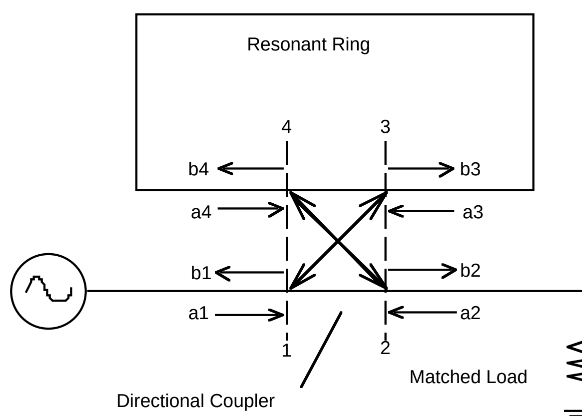

Figure 2: Forward and Reflected Waves in a Resonant Ring Circuit

To calculate the coupling coefficient it is necessary to make use of the scattering matrix of a directional coupler. The matrix can be derived from one

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solution to the standard transmission-line differential equations for the voltage and current as a function of distance along such a line. From Miller [3], the total loop power gain $(b_3/a_1)^2$ is found by using the fact that $a_4=b_3 e^{-\gamma l}$, where $\gamma=(\alpha+j\beta)$.

Referring to Figure 2, voltage loop gain, or multiplication, is defined as the ratio of the voltage of b_3 (the forward traveling wave in the loop) to the voltage of a_1 at the input arm of the coupler. Since power meters can be easily used to measure ring performance, it is often the loop power "gain" that is of interest (proportional to the square of the voltage gain).

$$\text{Power Gain} = \left|\frac{b_3}{a_1}\right|^2 = \left|\frac{jC}{1-e^{-\gamma l}\sqrt{1-C^2}}\right|^2$$
$$= \frac{C^2}{\left|1-Te^{-\beta l}\sqrt{1-C^2}\right|^2}$$

T is the transmission coefficient and accounts for the attenuation in the circuit (attenuation = $e^{-\alpha l}$). When the ring is in resonance, βl will be an integral number of 2π and the $e^{-j\beta l}$ phase shift term will drop out, leaving:

$$\text{Power Gain} = \frac{C^2}{\left|1-T\sqrt{1-C^2}\right|^2}$$

Because this equation relies on three variables, the coupling coefficient, the ring attenuation, and the desired power gain, it can be plotted in several different ways. In Figure 3, gain is plotted versus attenuation for two different values of the coupling coefficient.

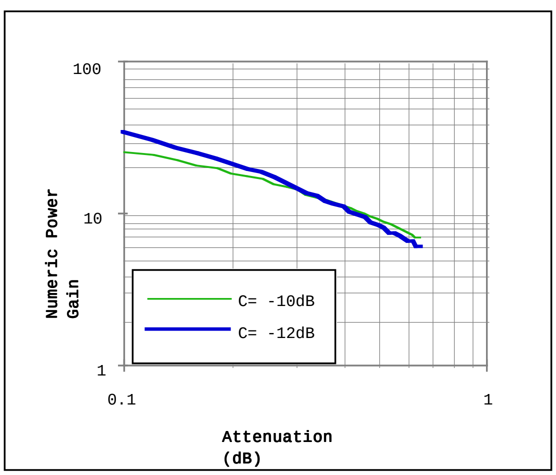

Figure 3: Power Gain vs Attentuation

3 RESONANT RING DESIGN

A klystron-driven resonant ring was designed as shown schematically in Figure 4. 3 1/8 inch coax is used at the outputs of the klystrons and also to connect to the water loads. The coax is connected to waveguide through transition pieces. The waveguide sections are WR1500 which operates in a frequency range of 490 MHz - 750 MHz. Straight waveguide sections are used to connect the other waveguide components (such as the sweeps and couplers) in order to give the traveling wave some settling space. These pieces are made at least one wavelength long. The 50 Ω water loads in the ring can handle up to 300 kW. A circulator is used to protect upstream devices in a circuit, such as amplifiers, that could be damaged by reverse power.

The ring loss can be estimated by summing the losses of the individual components along the length of the ring. It is estimated that the rf windows will contribute 0.1 dB of loss. Based on the manufacturer's test data for the loss of the ring components, the total loss of the ring can be approximated as 0.3 dB. The two 700 MHz klystron transmitters now available can deliver 80 kW CW of rf power to the resonant ring. The desired power level in the resonant ring is 1MW. This is a numeric power gain of 12.5.

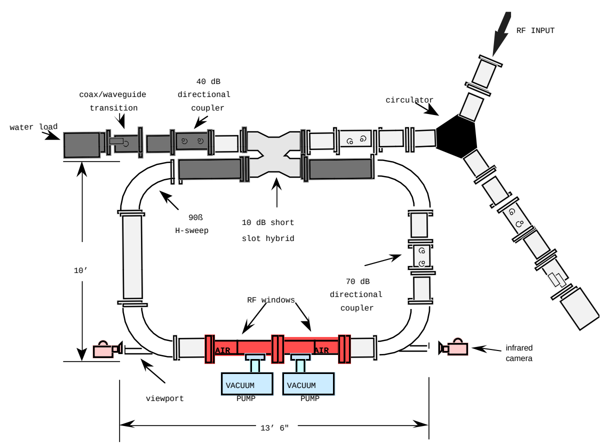

Figure 4: Resonant Ring Test Stand

4 RESULTS

The objective of this work was first to derive mathematically how the ring should behave and then prove it experimentally. For a ring attenuation of 0.3 dB and a power gain of 12.5, the information in Figure 3 indicates that a 12 dB coupler would be a better choice than the 10 dB coupler. However, the 12 dB coupler falls off faster than the 10 dB coupler for larger values of ring loss. Since the ring loss was approximated to have a least 0.3 dB of attenuation due to the uncertainty of the rf test windows and other components, the 10 dB short slot coupler was chosen.

From the graph of the power gain equation, it was evident that only 0.2 dB to 2 dB of attenuation would be useful. Graphite, nickel, and tin first seemed like good choices for coating the inside of the ring, but after running these conductivities, permeabilities, and permittivities through the attenuation calculations, it was shown that even if the entire ring were coated, not enough attenuation would be provided. Finally, one-inch thick sheets of graphite-coated "horsehair" were chosen as the microwave absorber. To obtain different attenuation values, different sizes of absorber sheets were placed into the resonant ring.

To test the circuit, the ring was first tuned to resonance by finding the frequency which produced the most forward power in the ring. The resonant frequency varied from about 704 to 706 MHz. The daily temperature flux of the laboratory contributed to this variation. The empty ring's Q-factor was high enough that a few degrees of temperature change could change the resonance by 0.5 MHz or more. Once the data were gathered, the measured power gains were plotted versus the inserted attenuation. Using the forward power in the ring divided by the input power as the power gain produced the following graph (Figure 5).

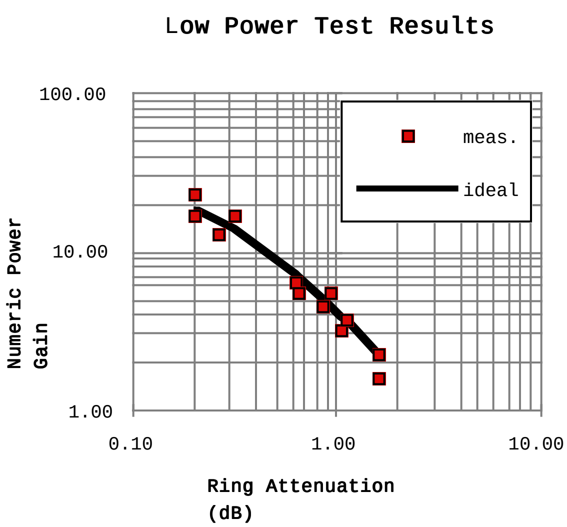

FIGURE 5 : Measured and Ideal Results

5 CONCLUSIONS

As can be seen from Figure 5, the resonant ring did follow the theoretical predictions of the power gain equation. The low power resonant ring test improves confidence that the resonant ring will have sufficient gain to test rf windows at high apparent power. The deviations from the ideal values could have been caused by any number of measurement errors, however it is apparent that these errors are quite small. The next step in this project is to operate the high power resonant ring test stand for the testing of rf windows and other rf components.

6 ACKNOWLEDGEMENTS

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REFERENCES

[1] "Theory and Application Instruction Manual for the Resonant Ring" I-T-E Circuit Breaker Company, Special Products Division, Philadelphia 34, Pennsylvania.

[2] R. Veltrop and W. Shelton, "Application of a traveling wave resonant ring circuit for voltage-breakdown testing of microwave components."

[3] S. J. Miller, "The Traveling Wave Resonator and High-Power Microwave Testing," The Microwave Journal, Vol. x, No. x, September, 1960, pp. 50-58.