Improving Ring Resonator Efficiency

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***Abstract*—This project examines ring resonators and how to efficiently build one from laser cut acrylic to operate in the UHF band. The final system provides 15 dB gain at the resonant frequency with the ring compared to without the ring.**

Keywords—waveguide, ring resonator, evanescent field coupling

I. Introduction

The aim of this project is to design and build a ring resonator which will pick out a frequency from an acrylic waveguide.

A. *Motivation*

In class, we learned the theory of dielectric waveguide and ring resonator. However, the lab on this issue was gotten rid of based on the fact it did not work last year. Therefore, we decided to build an effectively working ring resonator.

B. *Related Work*

Waveguides and photonic filters that are made of ring resonators are used in many networks for their low loss and adaptability to optical networks. Those structures are often very small, but we decided to build a similar system in a much bigger scale.

II. Approach

The three key concepts in designing our system are dielectric waveguides, ring resonators, and coupling. A waveguide supports a standing wave and transmit wave to the other end. For a wave with a certain frequency to resonate in a ring, the ring's circumference should be the multiple of the wavelength so that constructive interference occurs. When a wave reflects in a dielectric medium, an evanescent field forms outside of the material. By having two materials close to each other, the evanescent field overlaps and the wave couples into the other material.

A. *Single waveguide and multiple ring resonators*

The plan was to build a single waveguide and ring resonators. Only the wave with the right wavelength couples back into the waveguide with pi phase shift so the ring resonator acts as a notch filter.[1] Combining multiple notch filters can make a band-stop filter. However, the signal generator available was not able to operate at a low enough frequency to keep the ring resonators big enough to fabricate. Thus, changed the plan to build a single ring resonator to pick out a certain frequency. Also, coupling back into the waveguide is hard, so we decided to couple into another waveguide instead to the original one.

B. *Straight waveguides and ring resonator*

We built two straight-line-waveguides that can support the first mode at 7 GHz. The ring resonator was designed to pick out 4.5 GHz. The end of one of the waveguides was bent slowly so that the can antennas don't face to each other. The test showed that the wave was not coupling into the waveguides.

C. *Wave-shaped waveguides and ring resonator*

To make coupling easier, the new waveguide was designed to wrap partially around the ring providing moving more of the evanescent field close enough to the ring to effectively couple.

The most important dimensions are as listed below, with the intuition behind them following:

- Waveguide: 3 cm width, acrylic thickness 5 mm
- Ring resonator: outer diameter 24.7 cm, inner diameter 18.2 cm, middle diameter 21.5 cm, acrylic thickness 5 mm

For a rectangular waveguide we have the following[2]

$$\omega_c = \frac{1}{\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2}$$

We will operate in the TE_{10} mode, so $m = 1$ and $n = 0$ yielding

$$\omega_c = \frac{1}{\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{\pi}{a}\right)^2 + \left(\frac{0}{b}\right)^2} = \frac{c}{\sqrt{\varepsilon_r}}\sqrt{\left(\frac{\pi}{a}\right)^2}$$

Substituting the waveguide's width with the largest ring we could fabricate given the materials available to us:

$$\omega_c = \frac{3\times10^8}{\sqrt{2.8}}\sqrt{\left(\frac{\pi}{3.25\text{ cm}}\right)^2} = 17.3\times10^9$$

$$f_c = \frac{\omega_c}{2\pi} = \frac{17.3\times10^9}{2\pi} = 2.76\text{ GHz}$$

This means that the waveguide will not propagate effectively at frequencies lower than 2.76 GHz. To increase the coupling into the ring, we want to increase the evanescent field around the waveguides above and below it. Since we also still want wave to propagate in the waveguide direction, we must choose the operation frequency slightly above the cutoff frequency. We next need to find the nearest whole number of wavelengths that will fit in the 21.5 cm diameter ring without going below f_c[1]

$$\lambda_c = \frac{v}{f_c} = \frac{c}{f_c\sqrt{\varepsilon_r}} = \frac{3\times 10^8}{2.76\ \text{GHz}\sqrt{2.8}} = 6.5\ \text{cm}$$

$$21.5\ \text{cm} = \frac{n * \lambda_{\text{operation}}}{\pi} = \frac{n_{\text{lowest}} * 6.5\ \text{cm}}{\pi}$$

$$n_{\text{lowest}} = 10.37$$

Since we know that n must be a whole number greater than n_{lowest}, we achieve the lowest operating frequency with $n = 11$, which as shown below equates to 2.94 GHz.

$$d = \frac{n * \lambda_{\text{operation}}}{\pi} \underset{n=11}{\Longrightarrow} \frac{11 * \lambda_{\text{operation}}}{\pi} = 21.5\ \text{cm}$$

$$\lambda_{\text{operation}} = 6.1\ \text{cm};\ f_{\text{operation}} = \frac{v}{\lambda_{\text{operation}}} = 2.94\ \text{GHz}$$

To increase the coupling into the ring from the upper and lower waveguides, we want to increase the evanescent field around the waveguides above and below it. We do this by designing it for a frequency a bit beyond where we plan on operating. This means that the width of these waveguides should be lower than the one on the resonator. In our case, we chose a round number of 3 cm.

The setup looks as Fig. 1:

Fig. 1. Final setup in the lab.

III. Results

Because there was no easy way to mount the can antennas, they need to be held up to the acrylic each time the system is used. We expected that this would be a large source of variation in our measurements since returning them to the exact same position would be hard, but after three reset cycles realized that we were seeing only a couple of dB difference between trials.

A. *Gain with and without ring*

The final system is fairly lossy, almost certainly due to inefficiencies at its many interfaces. Despite this, between the antennas there was a loss of 35 dB with the ring and 50 dB without at the resonant frequency of 2.94 GHz. Therefore, the ring provided 15 dB of gain.

We also tested at one of the other higher frequency harmonics with the ring at 4.53 GHz ($n = 17$; $\lambda = 3.96$ cm, use equations from part II and vary n with whole numbers to find other higher resonant frequencies). Here, the system achieved 10 dB of gain with the ring, going from -53 dB to -43 dB.

B. *Changing separation between waveguide and ring*

Finally, we wanted to measure the drop in coupling as we further separate the ring from the interface. This was done at the 4.53 GHz harmonic, as the field decays over a shorter distance. To do this, we only adjusted the interface on the receiving end by the amounts shown in Table I.

TABLE I. Gain with ring separation

Distance from ring	***Gain***
Very small, ~0 mm	-40 dB
15 mm	-47 dB
25 mm	-51 dB

This is also working as expected, with an increase in the distance between interfaces leading to a decrease in gain. We didn't expect to see the gain of 2.5 cm away be lower than without the ring at all at the 4.53 GHz harmonic, but this verified with multiple trials. It could be explained by wave losing to the strings attached to the ring resonator.

IV. Conclusion

This project was a success. Despite the switch from two rings to one and the concern after the first round of waveguides failed to direct enough energy, the final version worked significantly better than we expected, producing a clear 15 dB increase in gain with the ring in place.

References

[1] Robus, Dominik G, Integrated Ring Resonators –The Compendium, 3rd ed., vol. 2. Springer, 2007, pp.3-40.

[2] Herman A. Haus, James R. Melcher, Electromagnetic Fields & Energy, in Magnetism, Massachusettes Institute of Technology 1999, chapter 13