# A X-BAND RESONANT RING AND GAS BREAKDOWN EXPERIMENTS

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Abstract

An electroformed X-band resonant ring has been constructed to conduct breakdown experiments with dielectric gases. This paper introduces the design and techniques employed in the fabrication of the resonant ring, and presents gas breakdown results obtained to date using nitrogen and sulphur hexafluoride.

## Introduction

The Transmitter Group at NASA's Jet Propulsion Laboratory designs and builds microwave transmitters in the power range of 20-kW to 500-kW CW at X-band frequencies. A design for a radio-astronomy radar transmitter at 1 MW has been completed [1], and future requirements may dictate yet higher power levels. In this power range, waveguide breakdown becomes an important concern. One method for preventing waveguide breakdown without any of the complications of a hard-vacuum system is through the use of a dielectric gas to pressurize the waveguide, allowing operation at higher electric field levels than possible with an air dielectric.

A conservative design of high-power waveguide components using dielectric gases depends to a large extent on the knowledge of the fill gas properties; namely, the quantitive improvement that can be obtained in power-carrying capacity through the use of a dielectric gas to fill the waveguide rather than air. An analytical solution of this problem is both complex and somewhat unreliable due to the difficulty of including all the breakdown parameters in a reasonable model. It is for this reason that the actual improvement in waveguide power breakdown level due to a fill gas must be determined experimentally, particularly for systems operating near the theoretical power-handling capacity of the waveguide.

One method of performing these experiments is to use a resonant ring, (see Fig. 1) which is a tuned closed waveguide loop fed by a microwave power source and is capable of power multiplication. Several references [2],[3] treat the operating principle of a resonant ring in a thorough manner, but in simple terms a resonant ring functions by setting up a traveling wave in the waveguide loop of such a magnitude as to cause the full input power to the ring to be dissipated as resonator waveguide wall losses. Given this property, and the relatively low value of waveguide insertion loss, it may be seen that the power level of the travelling wave must be much greater that the input power to

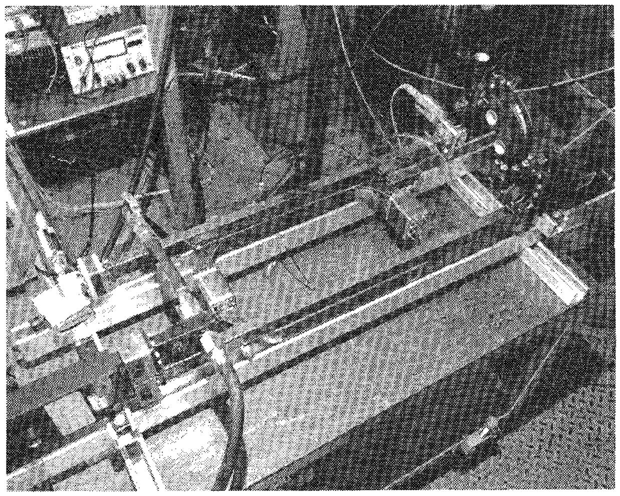

Figure 1. Electroformed X-band Resonant Ring

the resonator. It must be realized that to maintain conservation of energy, the resonator must produce only a short discharge in case of an internal arc, making this test method duplicate CW power only in the magnitude of the electric fields present.

## Resonant Ring Design and Fabrication

Having power sources at 7.1 and 8.5 GHz, it was desired to design a resonant ring that would operate at both frequencies. To achieve this, a loop waveguide length was chosen to be an integer number of wavelengths long (a condition for resonance) at both frequencies. Another design parameter is to make the loop as short as possible, thereby maximizing the gain of the resonator by minimizing the total insertion loss of the device. Additionally, enough straight waveguide length is required for the placement of signal injection and a sampling directional couplers in the resonator walls. Using these parameters, a resonant ring was designed with a loop length of 41.625" (105 cm). The non-standard WR-125 (3.17 X 1.59-cm) waveguide size was chosen for compatibility with the power sources available.

Fabrication techniques become of fundamental importance at the operating power levels required of this device. An earlier resonant ring [4] suffered numerous operating problems due to the relatively large number of waveguide flanges, and the poor internal surface finish of standard waveguide. To avoid these

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CH3141-9/92/0000-1003$01.00 © 1992 IEEE

problems, it was decided to fabricate the resonator by electroforming from oxygen-free, high-conductivity copper. This process yields parts with seamless internal structures, of a high surface finish (approximately 5 microinch RMS), and allowed the fabrication of the resonator with only two waveguide flanges.

## Breakdown Experiment Design

The dielectric gas to be characterized using the resonant ring is sulphur hexafluoride ($SF_6$), which is a relatively inert and nontoxic gas commonly used to pressurize waveguide. Molecular nitrogen ($N_2$) would be used as a control gas, since it is cheap, readily available, and widely used as a waveguide filler to inhibit oxidation. Because of possible degradation of the high internal finish of the resonator through oxidation, the use of air pressurization was not planned (air and nitrogen have essentially equivalent breakdown levels).

Since a properly operating resonant ring dissipates the full drive power applied in its waveguide wall, cooling becomes a problem when pumping the device with CW sources in the 100+ kW range. It was found in prior experiments [4] that these large power dissipations detuned the ring through waveguide thermal expansions to the extent that frequency-compensating feedback had to be employed in the test system to allow operation in addition to forced liquid cooling. For this reason, and to obtain breakdown data free from thermal effects, it was decided to operate the resonator in a pulsed fashion with 1-microsecond pulses and 0.1% duty cycle. This low duty cycle allows air convection cooling of the resonator structure.

Because high fill gas pressures place large stress on some transmitter components such as feedhorn windows, the initial testing was conducted at a low gas pressure (10" water equivalent, 0.25 kPA). This pressure is high enough to ensure complete filling of the waveguide against atmospheric pressure while minimizing stress on fragile components.

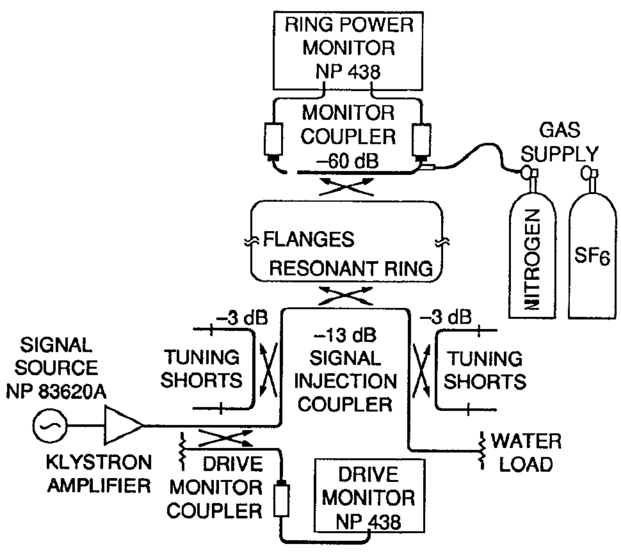


Figure 2. Gas Breakdown Determination Configuration

A test system (see Fig. 2) was then assembled, consisting of the resonator, a microwave power source (klystron amplifier) and power measuring and control instruments. Optical detection of arcs inside the resonator was provided through a series of leak-tight fiber optic ports in the periphery of the resonant ring.

## Operation

Initial operation of the resonant ring took place at 7.16 GHz with a 20-kW klystron (Varian 876P) as the power source and nitrogen filling the waveguide. The output power of the source was increased to its maximum, resulting in a resonator power of approximately 700 kW. No arcing was detected at any time, and the resonant ring operated in a stable fashion. This low-power operation served to calibrate the ancillary instrumentation, as well as to determine the actual resonant frequency of the ring. A 150-kW klystron (Varian VA879G) was then substituted as the pump source, and operation was resumed with nitrogen at a pressure of 10 inches of water as the fill gas. With this system, repeatable breakdown of the waveguide was detected at a resonator power level of 2.5 MW and a frequency of 7.145 GHz. It should be noted that the optical arc detection system proved unnecessary, as breakdown at this power level is apparent acoustically immediately. Sulphur hexafluoride was then substituted for nitrogen, at the same pressure. The output power of the pump source was raised to its maximum of 112 kW at 7.145 GHz (this klystron being tuned to 7.167 GHz), resulting in a resonator power of 4.15 MW. The resonant ring was operated at this power level for 30 minutes with no evidence of arcing at any time.

Having a higher output power klystron available (250-kW Varian VA949J) testing was resumed at 8.5 GHz with nitrogen at 10" water pressure filling the resonator waveguide. Due to time constraints, the resonator was operated to only 850 kW with nitrogen before switching to sulphur hexafluoride fill. Using $SF_6$, the output power of the klystron was raised to its maximum, with a resultant resonator power of 4.5 MW. The resonator was again operated at this level for 30 minutes with no arcing detected. This klystron is not designed for pulsed operation and is thus not capable of dissipating the full beam power in its collector at the rated beam voltage for CW operation, where about 35%-40% of the beam power is removed from the amplifier as RF output. This constraint required operating the klystron at a derated beam voltage with a maximum output power of 216 kW.

## Results and Conclusion

For designing components, the power density in the waveguide at or near breakdown is a more generally useful measure of the power-carrying enhancement due to dielectric gases than the absolute breakdown power level mentioned above. This figure allows the calculation of operating margin of components having other than the full waveguide cross-sectional area. Expressed as a power density, the results obtained are as follows:

(1) Breakdown in nitrogen at 2.5 MW is equivalent to a power density of 1.01 $MW/cm^2$.

(2) In sulphur hexafluoride at 7.145 GHz, operation was sustained at 4 MW (1.59 $MW/cm^2$) with no breakdown.

(3) In sulphur hexafluoride at 8.5 GHz, operation was sustained at 4.5 MW (1.79 $MW/cm^2$) with no breakdown.

The above power densities take into account the peak-to-average power ratio of 2:1 in a rectangular waveguide and $TE_{01}$ mode which halves the effective cross-sectional area of the waveguide.

It should be stressed that the power densities obtained in sulphur hexafluoride were drive-power limited and not breakdown-limited. The actual improvement derived by using sulphur hexafluoride over nitrogen is at any case at least 1.8:1 and very likely higher. Future experiments will take place with two VA949J klystrons in parallel as the pump source, to obtain a better determination of the power densities that may obtained in operation using sulphur hexafluoride.

The electroforming of the resonant ring has been shown to be an entirely satisfactory construction technique.

Acknowledgment

The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

References

[1] A. Bhanji, et al., "Conceptual Design of a 1-MW CW X-band Transmitter for Planetary Radar," *IEEE MTT Proceedings,* 1990.

[2] V. Milosevic, "Traveling Wave Resonators," *IRE Transactions on Microwave Theory and Techniques,* 1958.

[3] Maltzer and McCune, "A 250-kW X-band Travelling-Wave Resonator," *Microwave Journal,* February 1964.

[4] D. Hoppe and R. Perez, "Operation of an X-band Resonant Ring at 450-kW CW," *TDA Progress Report 42-93,* 1988.