A 2-KILOWATT AVERAGE POWER X-BAND RECEIVER PROTECTOR FOR THE LINCOLN LABORATORY SOSI RADAR*

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Abstract

A 2-kilowatt average power receiver protector with a 5,000-hour operating life has been developed. The design is of the gas plasma diode hybrid type which heretofore could provide only one-tenth the power handling for equivalent operating life. Predicted life is based on experimentally obtained molecular sorption coefficients performed at 2-kW average power in X-band.

The device has been developed for use as a receiver protector in the high-resolution SOSI radar at Lincoln Laboratory. This radar will transmit 200 kW average power at X-band and consequently requires a high average power receiver protector.

Introduction

The period over which a hybrid gas plasma/diode type receiver protector (RP) can adequately limit RF power is dependent on the net rate at which gaseous ions are actively diffused (sorbed) into the solid surface adjacent to the plasma during the discharge time (figure 1). Increasing RF power levels tend to increase the ion flux and ion velocities toward the solid surface, resulting in higher sorption rates; this particle loss lowers the gas pressure until a point is reached where one of the critical RP parameters significantly degrades. Because of the above, the limitation on RP life generally depends on the stage that experiences the highest RF power level.

The objective of this work is to increase the RF power handling of X-band RP's by 10:1 to 2 kW average power; also to provide an operating life at that power level of 5,000 RF hours. Consequently it is necessary to replenish the trapped ions in the input stage at a rate equal to their loss rate in order to maintain constant gas pressure; or, alternatively, to provide a molecular reservoir away from the discharge area so that pressure decreases due to trapped ions in the solid are significantly slowed.

To determine the number of molecules to be stored in the reservoir for a selected pressure drop over a specified operating period in the input plasma limiter stage requires that, among other parameters, the discharge area at the gas plasma/solid interface and the net ion flux across this interface be known. These parameters can neither be measured nor predicted for the geometries and operating conditions of this design with a useful degree of accuracy. However the theory of gas cleanup during a discharge gives the relationship between RF average power, reservoir volume (number of stored molecules) and discharge time so that short term cleanup experiments can be used to predict long term life.

From the theory[1] one may compute the reservoir volume V_2 necessary for a 5,000 hour RF operating life:

$$V_2 = \frac{\Delta p_1}{\Delta p_2} \left[\frac{P_2}{P_1} \cdot \frac{t_2}{t_1} \right]^{1/2} V_1$$

where

Δp_1 = Change in pressure during the cleanup sorption run.

Δp_2 = Allowed change in pressure for a 5,000 hour lifetime. This number is based on the lowest pressure that the vial stage can operate at without seriously degrading performance.

P_1 = Incident power used during the sorption experiment.

P_2 = Incident power on the vial stage over operating life.

t_1 = Elapsed time of the short term sorption experiment.

t_2 = Lifetime of the vial stage; set to 5,000 hours.

V_1 = Volume of the quartz-stainless steel manifold used in the sorption experiment.

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[1] This equation is derived from equation 5 of H. S. Maddix, "Cleanup in TR Tubes," IEEE Transaction on Electron Devices, pp 98-104, February 1968. A constant duty of one half and constant discharge area are assumed.

The theory predicts cleanup rate coefficients proportional to $\Delta p/\sqrt{t}$; as shown below, this was found to be the case for the experiments performed. The selection of Δp_2 (initial gasfill pressure minus the pressure at which RF performance significantly degrades) was based on a series of variable gas pressure experiments at high RF power levels discussed below. The present theory does not account for a decrease in the molecules sorbed as the lattice voids are filled and thus would yield a conservative operating life. This latter phenomenon would indicate that an initial RF aging process at high chlorine pressures would provide longer operating life by packing molecules in the solid prior to final vial tipoff.

Experimental Apparatus

The short term sorption coefficients were measured by the experimental apparatus shown in figure 2. It included the input stage quartz vial inserted in a water-cooled aluminum mount tuned to 9.8 GHz, a Baratron precision pressure gauge, quartz tubing assembly, and stainless steel valves necessary to connect to the vacuum system and chlorine source. The entire assembly was bakable under vacuum. The volume V_1 of this assembly was measured by two independent methods as 56.5 milliliters. A 50 dB gain klystron power amplifier supplied up to 2 kW of average power at 9.8 GHz and 0.5 duty.

Determining Δp_2

The pressure range over which adequate protector performance occurs is important with respect to predicting RF operating life of the input vial stage. To obtain this it is necessary to measure all RP parameters as a function of gas pressure in order to determine which parameter degrades first as gas density drops.

Tests were run from 1 to 50 torr. Below 4 torr, firing power was excessive; above 24 torr, striations in the discharge occurred which led to long recovery period with accompanying strong local hotspots at the quartz surface/plasma interface region. Thus Δp_2 = 20 torr was selected as the allowed pressure drop over operating life.

Determining V_2

Four experiments were performed to determine the short term cleanup rates $\Delta p_1/\sqrt{t_1}$. The pressure change as a function of time at zero RF power did not vary more than ±0.2 torr over a 6 hour period in a check on system pressure calibration and instrument drift. Figure 3 gives the pressure drop data when RF power was applied to the quartz vial. Figure 4 shows the square root cleanup rates as predicted by the theory to be proportional to $\Delta p_1/\sqrt{t_1}$.

Calculated from the data of figure 3, the reservoir volumes V_2 necessary for 5,000 hours of operating life are:

Based on Δp = 20 torr		
Run No.	Initial Pressure (torr)	Computed Reservoir Volume (liters)
1	24	0.54
2	24	0.65
3	24	0.54
4	24	0.57
Average of Four Runs	24	0.58

In analyzing the sorption data it was seen that the initial and final pressures, which were used to calculate the above reservoir volumes, may not yield the correct volume because the decrease in gas pressure is less initially and increases with increasing time. This is probably due to ion-induced desorption of trapped gases at the solid surface which were not removed during the 800°C 16-hour vial bake. The base pressure to which the quartz vials were evacuated was 10^{-8} torr. Upon initial RF discharging, the quartz is heated, and gas atoms are both removed from the surface, increasing gas pressure, and sorbed into the surface, decreasing gas pressure, as shown by the smaller initial slopes in figure 4. After this initial transient period is over, sorption dominates and the pressure decreases. The sorption characteristic should then follow a square root cleanup rate as $\Delta p_1/\sqrt{t_1}$. The initial cleanup slope due to ion-induced desorption has been neglected in this computation of V_2.

Calculating from the data of figure 4, the reservoir volumes V_2 for a single-vial stage, neglecting the initial cleanup slope, are:

Based on Δp = 20 torr		
Run No.	Initial Pressure (torr)	Reservoir Volume (liters)
1	24	0.9
2	24	1.2
3	24	0.9
4	24	0.8

Reviewing Δp = 20 torr data in the table, it is seen that the reservoir volume falls between 0.54 and 0.65 liter for the former and between 0.8 and 1.2 liters for the latter. Based on this data, 1.2 liters was selected as the vial stage design value.

Protector Electrical Characteristics

Based on the 1.2 liter value, an experimental RP of the gas plasma/diode type was fabricated as shown in figure 5. Loss over 1 GHz bandwidth in X-band is 0.7 dB. The higher power RP characteristics are given below under the following conditions: 9.8 GHz; 1 kHz PRR, 0.5 duty, 1 gal/min waterflow, 1.3 ft^3/min of airflow on the resonant slot, and 0.2 μsec RF pulse risetime.

Elapsed Time (hr)	Peak Incident Power (kW)	Spike Leakage Power (mW)	(nsec)	Flat Leakage (mW)	Recovery Time (0.25 dB) (nsec)	Gate Bias (volts)
1	2	25	20	16	6	0
14	2	34	23	16	8	0
15	3	34	20	16	12	0
23	3	28	16	0.1	6	+6
24-50	3.6	38	16	18	38	0

Tests using the 1.2 liter reservoir with both copper and aluminum mounts as the input stage of the receiver protector showed no deterioration in 100 hours at power levels between 1,000 and 1,750 watts average, the latter power level being the highest available in the laboratory.

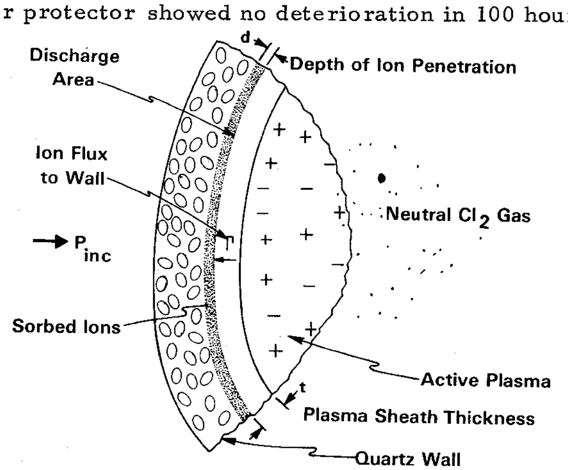

Figure 1. Dynamics of Electrodeless Discharge at the Plasma-Solid Interface Region

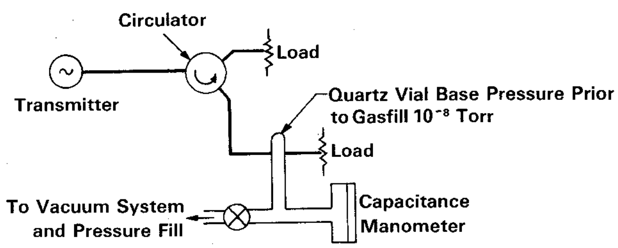

Figure 2. Diagram of Experimental Apparatus

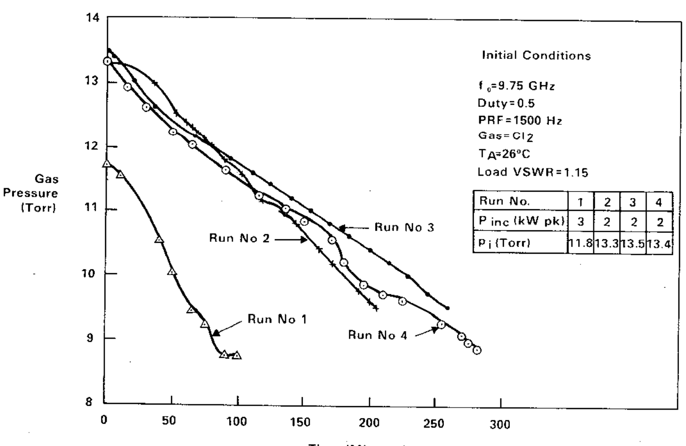

Figure 3. Single Vial Pressure Drop Cleanup Experiment

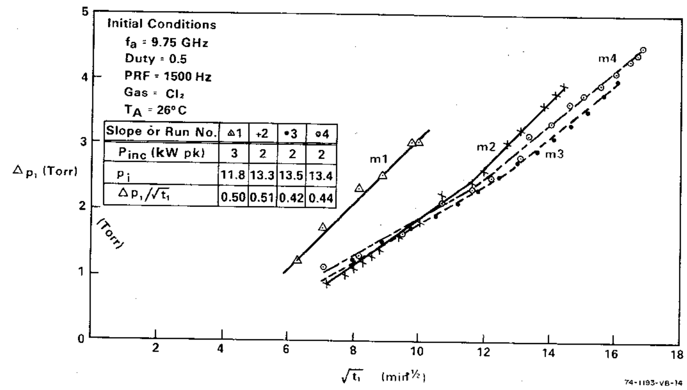

Figure 4. Single Vial Square Root Cleanup Rates

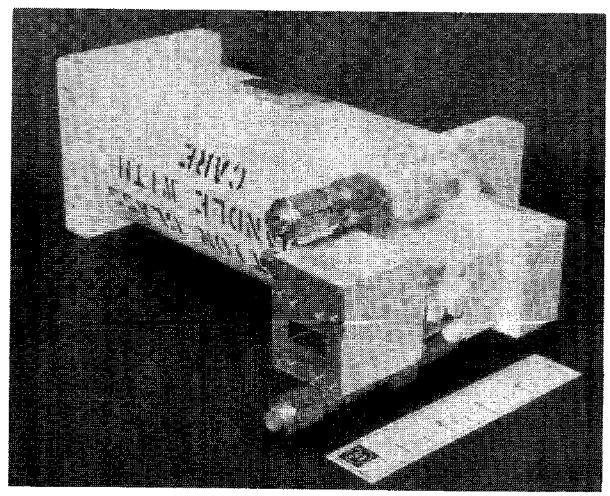

Figure 5. RP Prototype