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SHORT COMMUNICATION

Cascade Protector for Hardening Electronic Devices against High Power Microwaves

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ABSTRACT

Since the increasing front part of incident microwave pulses may pass through plasma limiter before it generates plasma (the breakdown time of low pressure *Xe* in plasma limiter is 10 ns), single plasma limiters are not adequate for protecting sensitive electronic components against high power microwaves (HPM). A cascade protector, which consists of a plasma limiter and a PIN limiter in waveguide, is proposed. The numerical results show that under HPM attack (10 GW, 1GHz, and 100 ns pulse width), the microwave power leakage through the cascade protector is about 0.4 W. In the same electromagnetic environment, the power leakage through single plasma limiter is approximate 347 W.

Keywords: Plasma limiter, PIN diode limiter, microwave power leakage,hardening against high powermicrowave

1. INTRODUCTION

At present, various types of plasma limiters and semiconductor diode limiters are employed for hardening communication and radar systems incorporating solid state electronic components against high power microwave (HPMs)[1].Plasma limiters have rather high power handling capability [2,3], and this capability allows them to be used to protect transmitters and receivers from HPM attacks. However, the increasing front part (or dropping tail) of incident microwave pulses may leak through the plasma limiter due to its long response times.The semiconductor diode limiters respond quickly to low power pulses, but are easily damaged by high-power pulses[2].A cascade protector with high power handling capability, low-leakage power (< 0.4 W) and sub-nanosecond breakdown times is presented.

2. STRUCTURE OF THE CASCADE PROTECTOR

As shown in Fig.1, the cascade protector is a combination of plasma limiter and PIN diode limiter in a rectangular waveguide.

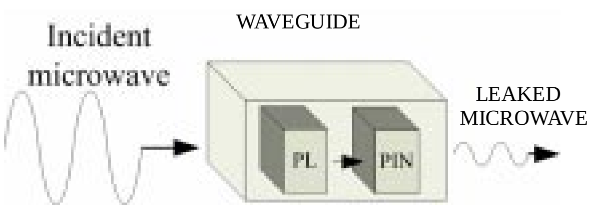

Figure 1. Schematic diagram of the cascade protector. PL represents plasma limiter (pre-protector); PIN represents PIN diode limiter (post-protector).

3. LEAKAGE OF POWER THROUGH A SINGLE PLASMA LIMITER

The plasma limiter in Fig. 1 is a gas chamber with dielectric (nr=1.7) walls. The incident microwave is the energy source to generates plasma in this limiter.

3.1 Breakdown Parameters of a Plasma Limiter

The breakdown electric field intensity and breakdown time of gas were analysed in detail[2]. The breakdown electric field intensity E_{BL} under low pressure is:

$$E_{BL} = \sqrt{\frac{m\phi_i}{3}\frac{kT\omega}{e\sigma P\Lambda}} \tag{1}$$

where m is the mass of the electron, ϕ_i is the ionisation potential, ω is the frequency of microwave, Λ is the characteristic diffusion length, P is the gas pressure, σ is the collisional cross section, T is the gas temperature, k is Boltzmann constant, and e is the electron charge.

The breakdown time[2] t under low pressure is:

$$t = \frac{m(\nu_m^2 + \omega^2)\phi_i}{e^2E^2\nu_m}\ln(\frac{\gamma n}{n_{e0}}) \tag{2}$$

where ν_m is the collision frequency, ω is the frequency of microwave, E is the electric field intensity, n is the gas density, n_{e0} is the density of seed electrons, and γ is the ionisation degree.

One calculates E_{BL} and t of Xe under low pressure (0.01 torr~1 torr, 1 torr~133.32 Pa) in the single plasma limiter as follows:

The plasma limiter (filled with *Xe* pressure 1 torr, thickness d =50 mm) is placed in a rectangular waveguide (a=72.14 mm, b=34.04 mm), its threshold breakdown electric field

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intensity E_{BL} is approximate 70.78 V/m from Eqn (1).

When incident electric field intensity[4] is 9×10^3 V/m with frequency 1 GHz and gas pressure of *Xe* is 1 torr, density of seed electrons is 10^{16} m^{-3}, and ionisation degree is 0.0001, the breakdown time *t* of plasma limiter is approximate by 14 ns from Eqn (2).

3.2 Power Leakage Through the Plasma Limiter Before *Xe* Breakdown

The relationship between electric field intensity *E* and power density *S* is:

$$S = \frac{E^2}{377} \tag{3}$$

In this paper, high power microwave weapon (power 10 GW, frequency 1 GHz, and pulse width 100 ns) is assumed to be placed 5 km away from the target (its parabolic antenna area is 100 m^2)[4]. The power density reaching the limiter is 22 W/cm^2, i.e., the power is 462 W.

To calculate power leakage of the limiter, one simplifies its geometry as shown in Fig. 2. Incident HPM P_0 is reflected at vacuum-dielectric boundary, dielectric layer 1-gas boundary, attenuated by gas, then reflected at gas-dielectric layer 2 boundary, and dielectric layer 2-vacuum boundary respectively. In the end, partial power, P_t, is transmited through this limiter.

The power P_r, reflected by vacuum-dielectric boundary (layer 1-layer 2) and dielectric-gas boundary (layer 1-layer 2), is described by the Fresnel formula[5]:

$$\frac{p_{r1}}{p_1} = \left|\frac{1-n_r}{1+n_r}\right|^2 , \quad \frac{p_{r2}}{p_2} = \left|\frac{n_r-\sqrt{\varepsilon_r}}{n_r+\sqrt{\varepsilon_r}}\right|^2 \tag{4}$$

where p_1, p_2 are incident powers at vacuum-dielectric boundary and dielectric-gas boundary, P_{r1}, P_{r2} are the reflected powers respectively, and ε_r is the plasma dielectric constant.

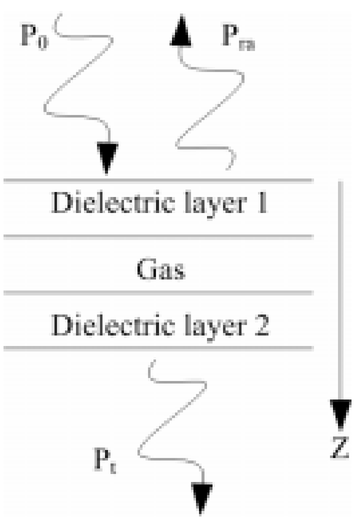

Figure 2. Schematic diagram of plasma limiter.

When wave propagates in uniform plasma[5], $P(z)$ is the power at z:

$$P(z) = P'\exp(-2\alpha z) \tag{5}$$

The attenuation constant[6] α is:

$$\alpha = k_0\{\frac{1}{2}[-(1-\frac{\omega_p^2}{\omega^2+\nu^2}) + ((1-\frac{\omega_p^2}{\omega^2+\nu^2})^2 + (\frac{\nu}{\omega}\frac{\omega_p^2}{\omega^2+\nu^2})^2)^{1/2}]\}^{1/2} \tag{6}$$

where P' is the power that enters plasma at $z = 0$, and k_0 is the parameter of plasma.

One denotes P_{ra} as total reflected power, P_a as total attenuation power during propagation, and calculates P_t on the assumption that some seed electrons exist in gas (deal with the gas as uniform plasma) and no reflection occurs inside it. The conditions for calculation using formulae (4) and (5) are as follows:

- The peak power of incident HPM pulse $P_0 \cong 462$W and its front part of pulses can not generate plasma (Fig. 2).
- The transmitted power (power leakage) $P_t = P_0 - P_{ra} - P_a$ is approximately 347 W in breakdown process (about 14 ns).

4. PERFORMANCE OF THE CASCADE PROTECTOR

When the incident intensity is < 70.78 V/m (below the threshold breakdown electric field intensity of *Xe*), or the time is <14 ns (the response time), incident microwave would leak through plasma limiter. Because the leaked power is higher than hundred watt, it could damage the sensitive electronic devices that followed the limiter.

To improve the protective performance of HPM limiter, a PIN limiter is put after plasma limiter in a waveguide (Fig.1).

4.1 Performance of PIN limiter

The *SiC* diode sub-circuit model[7] is applied to passive PIN limiter consisted of two *SiC* diode (Fig. 3). This PIN diode has a 50 μm I-region width 6H-SiC with 3eV band gap, 1.2×10^6 V.cm^{-1} critical breakdown electric field, 140 ns carrier lifetime, and 1.3V built-in voltage. The reverse breakdown voltage V_B is 3000 V, and epilayer doping concentration

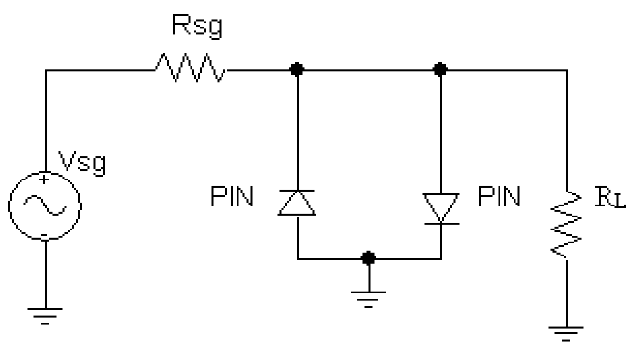

Figure 3. Circuit of PIN limiter (R_{sg}=R_L=50 Ω).

Table 1. Attenuation process in the cascade protector

Incident power at pre-protector (plasma limiter)	Transmitted power through single plasma limiter	Post-protector (PIN limiter) output power
462 W	347 W	< 0.4 W

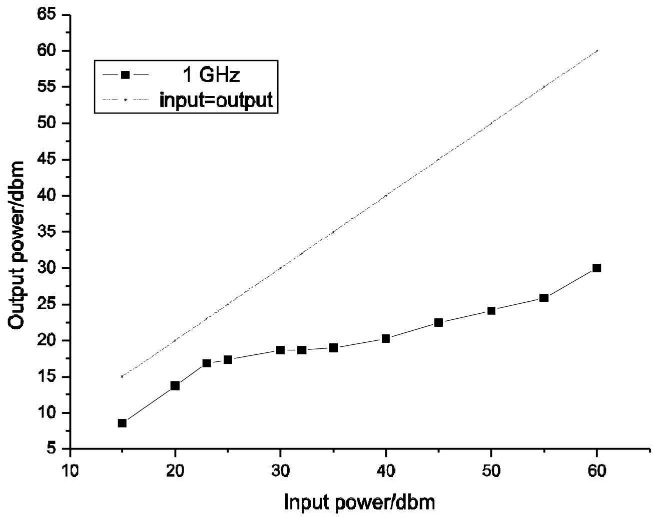

Figure 4. Simulation results of PIN limiter.

N_D is 10^{15} cm^{-3}, calculated using $V_B = w.Ec/2$ and $N_D = \varepsilon.Ec^2/2qV_B$, respectively (q is the electron charge, ε is dielectric constant, and ω is the I-region width)[7].

The P_{spice} simulation results are shown in Fig. 4: for input signal between 23 dBm to 60 dBm (1 GHz) the output-power is suppressed below 30 dBm by the PIN limiter. When input power is 55 dBm (350 W), the output power of PIN limiter is about 26 dBm (0.4 W).

4.2 Comparison of single limiter with cascade protector

As shown in Table 1, the power leakage of single plasma limiter is approximately 347 W (< 350 W). Without further protection, this leaked power can disturb or destroy electronic components. With the post-protector (PIN limiter), the final leakage power through cascade protector is < 0.4 W.

On the other side without the pre-protector (plasma limiter), single PIN limiter would be destroyed under a direct HPM attack.

5. CONCLUSION

A parametric study of the power leakage caused by limited response times of plasma limiter has been conducted. With combination of plasma limiter and PIN limiter, the pre-limiter has broad range of operating frequencies, high power handling capability, and the PIN limiter provides post-protection to attenuate the leaked power with fast turn-on time. The simulation results show that, when HPMW (10 GW, 100 ns pulse) is 5 km away from the cascade protector, common types of electronic components cannot be damaged.

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