VI-4. THE ARC LOSS OF MULTIMEGAWATT GAS DISCHARGE DUPLEXERS

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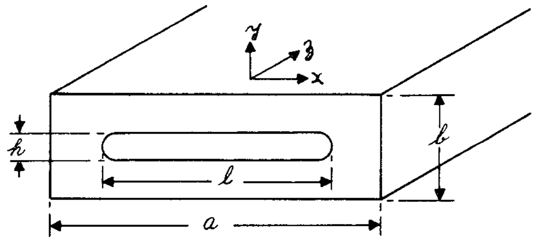
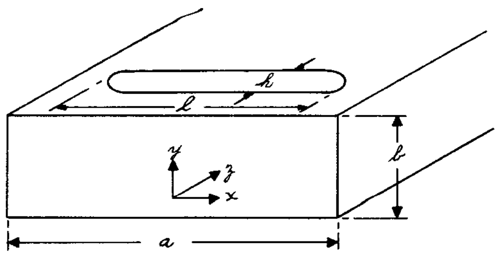
The arc loss of multimegawatt microwave gas discharge duplexers is the subject of this paper. It is shown that the discharge at these power levels can be considered as a lossy conductor of fixed surface area and varying thickness, given by the skin depth which varies with peak incident power. Since the skin depth is always smaller than the discharge container dimensions, the analysis is greatly simplified as compared with other treatments (Reference 1). These small skin depths are always realized in multimegawatt switching applications

In high power microwave gas duplexers the discharge normally occurs immediately behind a resonant window iris, and for the purposes of switching, this structure can be placed either in series or in shunt with an appropriate waveguide. Two cases have been considered: (1) a discharge window terminating a waveguide as shown in Figure 1a and, (2) a window mounted in the E-plane of a waveguide as shown in Figure 1b. Because the discharge loss is normally less than 0.1 db, the window



1(a) WINDOW TERMINATING A WAVEGUIDE



1(b) WINDOW IN E-PLANE OF WAVEGUIDE

Figure 1. Shunt and Series Waveguide Windows

iris structure can be quite compact. It consists of a precision bored mount into which a discharge tube has been inserted. The tube is typically about half the waveguide height in diameter and extends the full waveguide width in length (Reference 2). Even though the window iris is of the order of a wavelength in size, distortion of the waveguide fields by the iris can be neglected. This is because the discharge immediately behind the iris is very nearly a perfect short circuit; when high microwave power is incident on the window iris, the resulting discharge is so intense that virtually all power not dissipated in the discharge is reflected. Furthermore, the resulting visible discharge is very thin - on the order of a few hundredths of an inch in thickness. Under these conditions the discharge can be treated as a thin strip of lossy conductor whose surface area equals that of the iris.

Arc loss is defined as the ratio of power absorbed to power incident and for a discharge terminating a waveguide, the above approximations lead to the expression

$$A_T = \frac{4R_s}{Z}\frac{h\ell}{ab}\left(1 + \frac{a}{\pi\ell}\sin\frac{\pi\ell}{a}\right),$$

where

R_s = discharge surface resistance

Z = characteristic waveguide impedance.

This equation predicts that arc loss should vary linearly with iris height and it is found that this is indeed the case as shown by the experimental data on Figure 2.

$$R_s = \left(\frac{\omega m\mu_o}{2e^2}\frac{\nu_{eff}}{n}\right)^{\frac{1}{2}}$$

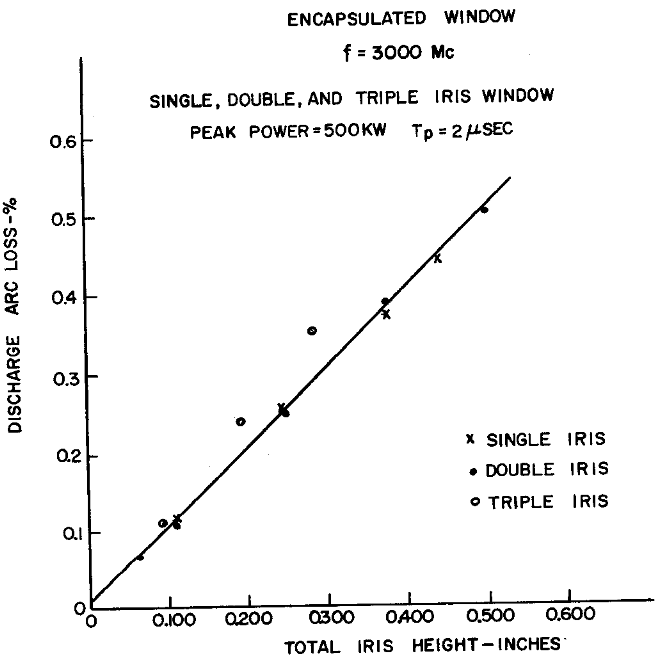


Figure 2. Gas Discharge Arc Loss versus Total Iris Height

In this equation ω and μ_o are respectively the radian microwave frequency and free space permeability - m and e, the mass and charge of an electron The effective collision frequency, ν_{eff} is proportional to gas pressure and includes the effects of both electron-atom and electron-ion collisions in the discharge. Both surface resistivity and arc loss are seen to vary inversely with the square root of electron density and this is shown on Figure 3 where the arc loss for a given waveguide size, frequency, and ℓ/a ratio is plotted versus electron density for three different gas pressures. The slight departure from this electron density variation at percentage ionizations above 1 percent is due to electron-ion collisions.

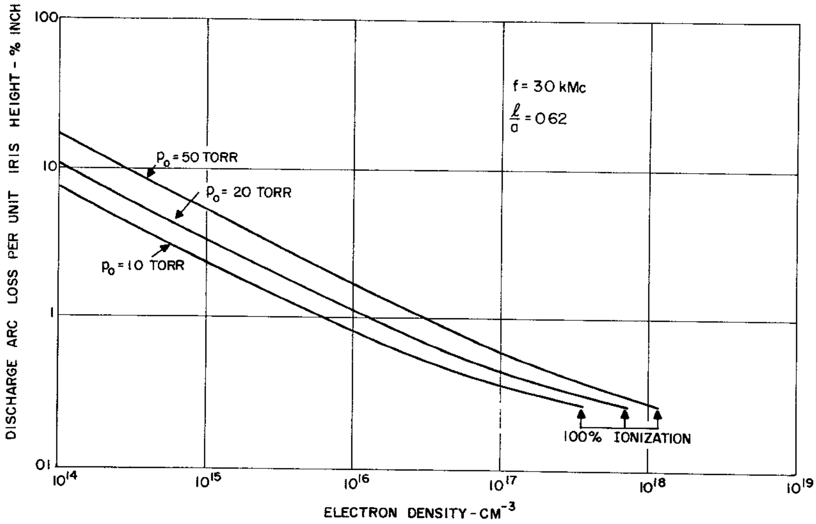


Figure 3. Discharge Arc Loss per Unit Iris Height versus Electron Density

If the electron density is assumed to be directly proportional to the waveguide current, then arc loss should vary inversely as the one fourth root of peak power. This is experimentally found to be the case as shown by the data on Figure 4 where the theory has been normalized to the data at only one point, indicated by the arrow. Excellent agreement with theory is seen for power variations over better than two orders of magnitude.

In the series discharge case, as shown on Figure 1b, the arc loss expression contains an additional term due to the fact that both longitudinal and transverse currents are present

$$A_E = R_s \frac{\ell h}{ab} \left[\frac{Z}{\eta^2 (f/f_c)^2} \left(1 - \frac{a}{\pi \ell} \sin \frac{\pi \ell}{a}\right) + \frac{1}{Z} \left(1 + \frac{a}{\pi \ell} \sin \frac{\pi \ell}{a}\right)\right]$$

Here η is the impedance of free space, and f/f_c is the ratio of operating frequency to cut-off frequency for the principle waveguide mode.

A quantity of particular interest to the duplexer design engineer is A_E/A_T, the ratio of series to shunt arc loss. A knowledge of this ratio allows test results on discharge windows terminating a

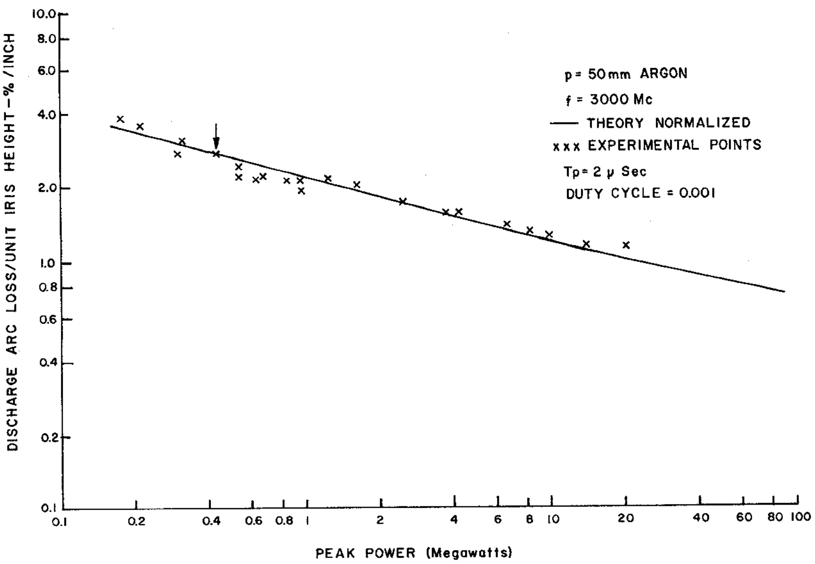


Figure 4. Arc Loss versus Peak Power

single channel waveguide to be extrapolated to predict the high power performance of balanced structures using series switching elements. For a given peak power this ratio is always less than one, regardless of window dimensions, clearly indicating that series switching elements have lower high-power loss than shunt elements. In the limit of zero iris length, this ratio has a minimum value of approximately 0.5 when both longitudinal and transverse current terms are included.

$$\frac{A_E}{A_T}\bigg|_{\frac{\ell}{a}\to 0} = \frac{1}{4}\left[1 + \frac{Z^2}{\eta^2\,(f/f_c)^2}\right] \sim 0.5\ .$$

However, if attention is focused only at the window center where high power thermal failure occurs, then the transverse current is zero and the limiting value of this ratio is 0.25, indicating that a balanced ATR duplexer with series switching elements should have four times the power handling capability of a balanced TR duplexer.

It has been shown that the arc loss of multimegawatt gas discharge duplexers can be analyzed in the approximation that discharge skin depth is small compared to the discharge tube dimensions. In agreement with this analysis it has been shown experimentally that: (1) arc loss varies linearly with iris height; (2) arc loss varies inversely with the one fourth root of average peak power; (3) for a given power level, series arc loss is always less than shunt arc loss. These results have been of great value in predicting the loss and power handling capability of extremely high power balanced TR and ATR duplexers from tests on simple shunt mounted discharge windows.

ACKNOWLEDGMENT

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