CHARACTERISTICS AND EFFECTS OF CW HIGH POWER BREAKDOWN IN WAVEGUIDE

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Abstract

Characteristics of arcs resulting from high power breakdown at microwave frequencies have been determined as a function of CW power level. The power absorbed in, reflected from, and transmitted through arcs as well as the travel velocity of arcs were determined. The effect of arcs on waveguide devices was evaluated empirically and visually, and the capabilities of these devices to impede arc propagation was ascertained.

Introduction

The electrical and physical properties of high power arcs at X-band microwave frequencies and the resulting impact on various types of microwave devices were determined in a series of experiments. Areas of investigation included measurement of the velocity of an arc and of the power reflected from, transmitted through, and absorbed by an arc. Additionally, the characteristics during voltage breakdown of such microwave components as ferrite circulators, diplexers, bandpass filters, directional couplers, waveguide switches and various types of pressure windows were measured. All the devices tested were constructed from either WR-90 or WR-112 waveguide.

The test position utilized for the experiments reported here is illustrated in Figure 1. The incident RF power level was coupled from the transmitter to the microwave device under test. The introduction of high power reflections during the initiation of RF arcs could result in erroneous results. Therefore, a high dc voltage was discharged across two probes which were mounted in and isolated from a section of rigid WR-112 waveguide. The voltage discharge ionized the air in the waveguide, and the applied average power sustained the ionized cloud. Before each test, the device was purged of the ionized air that resulted from the previous arc and filled with ambient air to guarantee controlled conditions. A pressure of 14.7 psia was utilized for all tests.

Measured Arc Characteristics

The characteristics of an arc were measured as a function of CW power level in the test setup described previously. Representative plots of the power transmitted through and reflection from an arc are presented in Figures 2 and 3, respectively. As expected, linear responses were observed. The RF power levels being measured were continuously monitored through directional couplers of high directivity connected to crystal detectors, and the voltage levels measured were recorded on film. The power absorbed in an arc was then determined by subtraction of the reflected and transmitted power levels from the incident power level. A representative plot of absorbed power is provided in Figure 4. It can be seen that the percentage of power absorbed by an arc is basically constant and that the effective voltage standing-wave ratio from an arc is also constant.

The velocity of an arc was measured with the use of two photosensitive arc detectors separated by a precise distance. As indicated by the plot of Figure 5, the velocity of arc travel was found to be directly proportional to the average power level being transmitted.

Effect of Arcing on Microwave Devices

The effect of arcing was evaluated on several types of rigid and flexible waveguide, various microwave devices, and high power pressure windows of various materials. Results are summarized in Table I and discussed briefly below.

Both three-and four-port ferrite circulators were examined. Each device was placed in series with the arc generation equipment, and the reflected power level was monitored continuously during arc travel. None of the circulators was found to impede the travel of high average RF power arcs, and none of them was damaged by the arcs when the CW power rating of the device was not exceeded. That is, the rated power level of the devices must be approximately the transmitted power plus the reflected power from the arc.

The effect of arcs on high power microwave windows made of quartz, Kovar, alumina, ceramic, mica, Kapton, and teflon-laminated fiberglass was measured in a manner similar to that utilized for the circulators. All the windows were destroyed by the high power arcs; the arc would travel to a window, hang up at the window, and then destroy it as a result of heat dissipation.

Flexible waveguide sections as well as rigid waveguide sections fabricated from different materials were exposed to high power arcs and the results observed. The flexible waveguide was fabricated from silver-plated beryllium-copper. The rigid waveguide materials were aluminum, brass, and brass plated with electroless nickel. An arc track was observed at the center of both broadwalls of all the waveguide sections. The black discoloration visible in the flexible waveguide (Figure 6) was found by analysis to be due to the formation of silver oxides; the discoloration in the brass waveguide (Figure 7) was similarly found to be due to copper oxides. Very slight pitting was observed in the iridited aluminum waveguide (Figure 8) and in the electroless-nickel-plated brass waveguide. The copper oxides formed in the brass waveguide increased the insertion loss of these sections; there was no deleterious effect on the other waveguide sections as a result of the arcs.

Diplexers, bandpass filters, directional couplers, waveguide switches, and arc detector assemblies were similarly subjected to high power arcs and the results noted visually. In general, there were no visible effects on these devices.

Discussion of Results

The effect of the arcing on the microwave components was very minor and had no effect on their electrical performance except for components fabricated from brass. The insertion loss increased for the brass waveguide sections because of the formation of copper oxides.

High average power arcs travel toward the RF source at speeds determined by the level of power and are not impeded by any of the microwave components evaluated. The arc hangs temporarily at the pressure windows, destroys them because of heat dissipation, and then travels to the RF source.

Approximately 50 percent of the incident power was found to be absorbed in the arc and about 50 percent to be reflected. Therefore, receiver protection devices used with three- or four-port circulators must be capable of handling at least half the transmitter output power level under fault conditions.

The photosensitive arc detectors were found to be very reliable. Because an arc travels toward the source, these components will provide valuable protection for high average power traveling-wave-tube amplifiers.

TABLE I. EFFECT OF HIGH POWER BREAKDOWN

Component	Voltage Breakdown Effect
Rigid waveguide	
Electroless-nickel-plated brass	No effect
Aluminum	Pitting
Brass	Formation of copper oxides
Flexible waveguide (silver-plated Beryllium-copper)	Formation of silver oxides
Windows	
Quartz	Fractured and melted
Kovar	Melted
Alumina	Melted
Ceramic	Melted
Mica	Burned
Kapton	Burned
Teflon-laminated fiberglass	
Circulators, 4-port/3-port	No effect*
Miscellaneous waveguide components	
Diplexers	No effect*
Filters	No effect*
Arc detectors	No effect*
Switches	No effect*
Directional couplers	No effect*
Rotary joints	No effect*
Power dividers	No effect*

*Minor pitting could be observed.

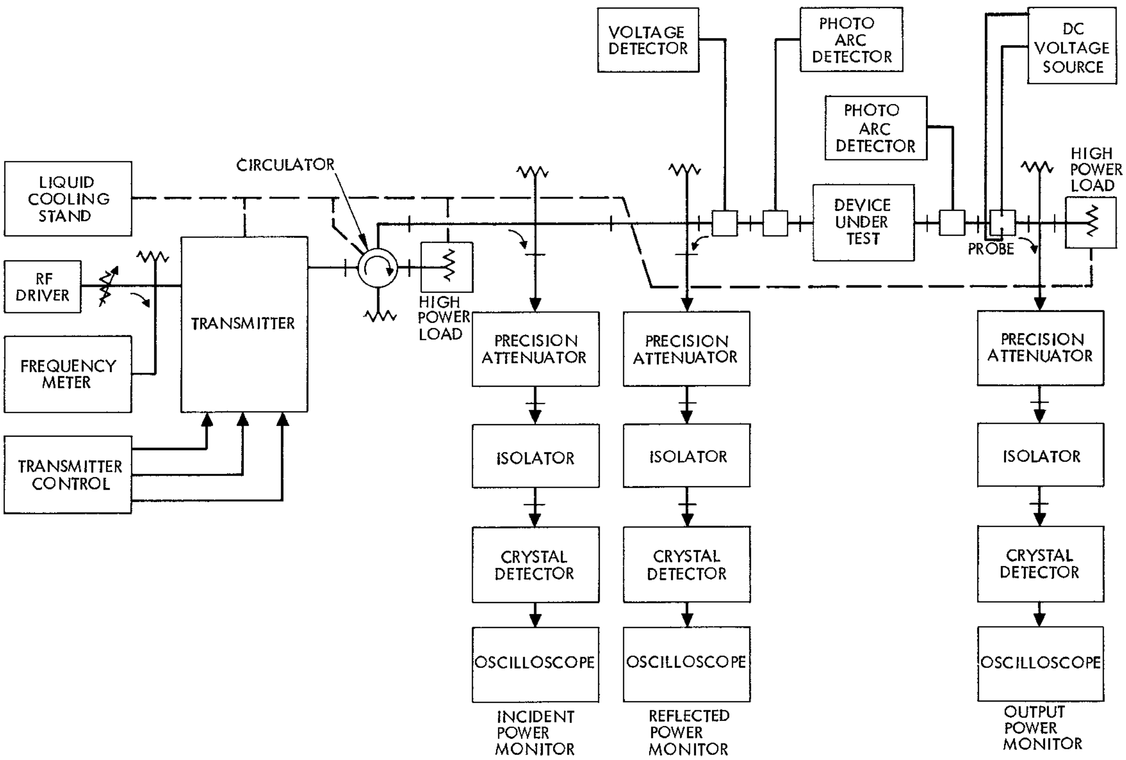

Figure 1. High power breakdown test position.

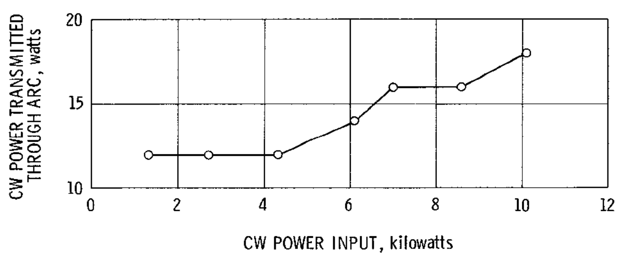

Figure 2. Power typically transmitted through an arc.

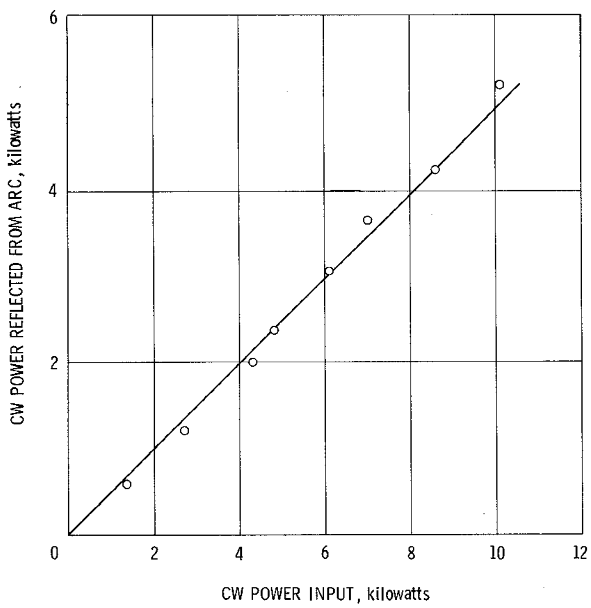

Figure 3. Power typically reflected from an arc.

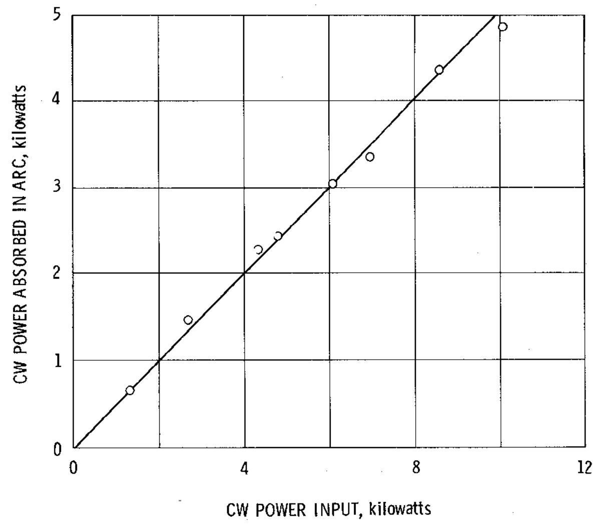

Figure 4. Power typically absorbed in an arc

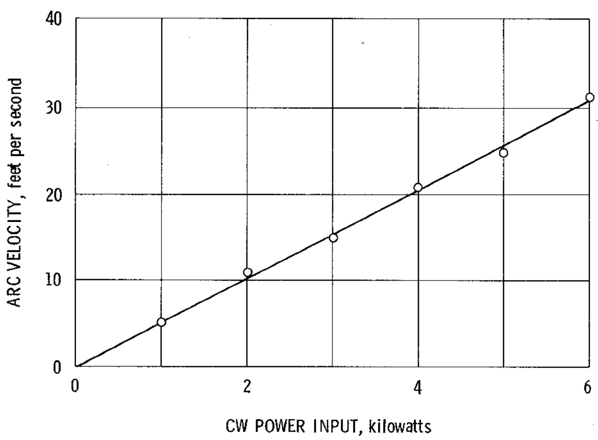

Figure 5. Typical arc velocity as a function of CW power input.

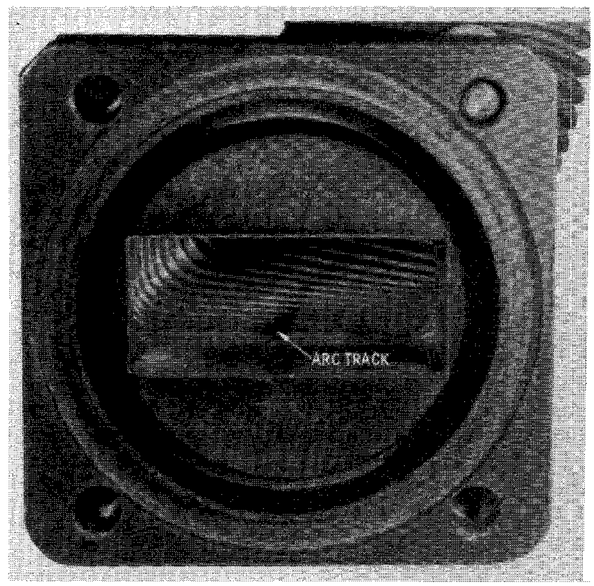

Figure 6. Effect of arc on flexible waveguide.

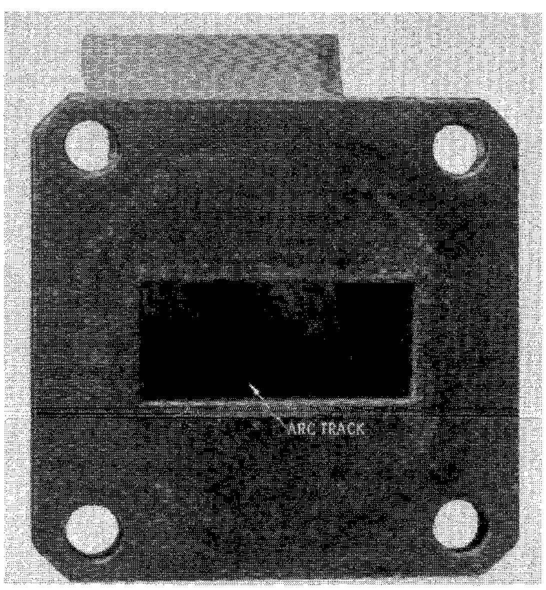

Figure 7. Effect of arc on brass waveguide

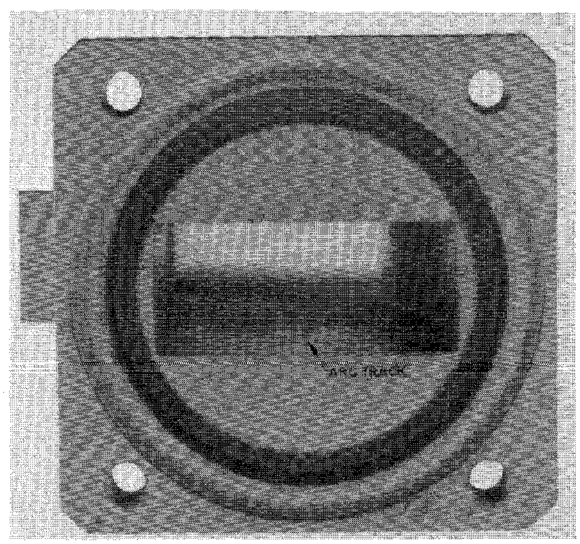

Figure 8. Effect of arc on aluminum waveguide.