IV-3. A DC Triggered High-Speed High-Power Microwave Spark Gap Switch

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A previously reported high-speed microwave spark gap switch[1] is triggered with a flash of intense ultraviolet light, but requires the applied rf power level to be close to the self-breakdown value of the gap. For this reason, the reliable use of the *u-v* triggered switch is restricted to rf pulse widths which are less than the formative time for an rf discharge (0.25–0.50 microseconds).

On the other hand, the dc triggered switch to be described here can be used to switch microwave power over a much wider range of power levels and pulse widths. The rapid switching is produced by the sudden application, across the gap, of a pulsed high dc field of about 10 nanoseconds duration parallel to the rf field. This pulsed field is sufficiently intense to break down the gap without any assistance from the rf field; once the gap is broken down, however, the discharge can be indefinitely maintained by the rf power alone at high powers, or a reduced dc field at lower powers. The dc triggered switch can therefore operate over a much wider range of power levels and pulse widths than the *u-v* triggered unit. Both types of switch have essentially the same turn-off time, which is determined by the deionization time of the gas.

A schematic of the switch is shown in Fig. 1. With this configuration an intense, concentrated spark is obtained. The resulting channel of ionized gas converts the equivalent lumped capacitance of the central gap region to

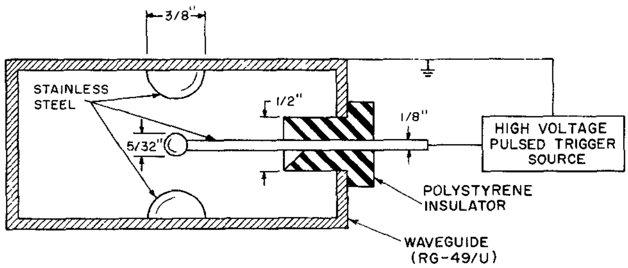

Fig. 1 Schematic of dc triggered microwave spark gap.

an inductance. This sudden change in circuit reactance accounts for the good microwave switching characteristics of the gap configuration.

There are a number of ways in which one or two switching elements can be incorporated into a microwave circuit to form a switch of a specified kind. The test arrangement shown in Fig. 2 forms one possible circuit, in which

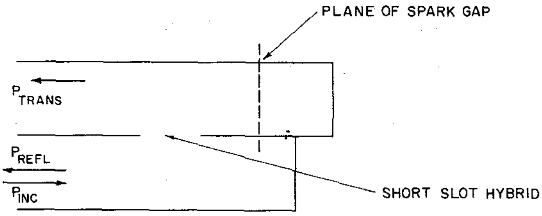

Fig. 2 Test arrangement for dc triggered microwave spark. Terminating shorts are arranged so P_{trans} is maximum in absence of spark. When spark is triggered, P_{trans} drops and P_{refl} rises. Isolation is defined as 10 log (P_{inc}/P_{trans}) and arc loss as 10 log (P_{inc}/P_{refl}) for switch in triggered state.

the spark gap, backed up by a shorting plate, acts as a reflecting device whose voltage reflection coefficient can be shifted in phase by 180 degrees on triggering a discharge. It may therefore be used in association with a hybrid junction and a second (properly positioned) shorting plate in the adjacent arm of the hybrid to give transmission of power from port 1 to port 2 in the untriggered state and reflection of power back to port 1 when triggered. The definitions for arc loss, "cold" insertion loss, and isolation can be understood in terms of this test arrangement. The switch data are summarized in Table I.

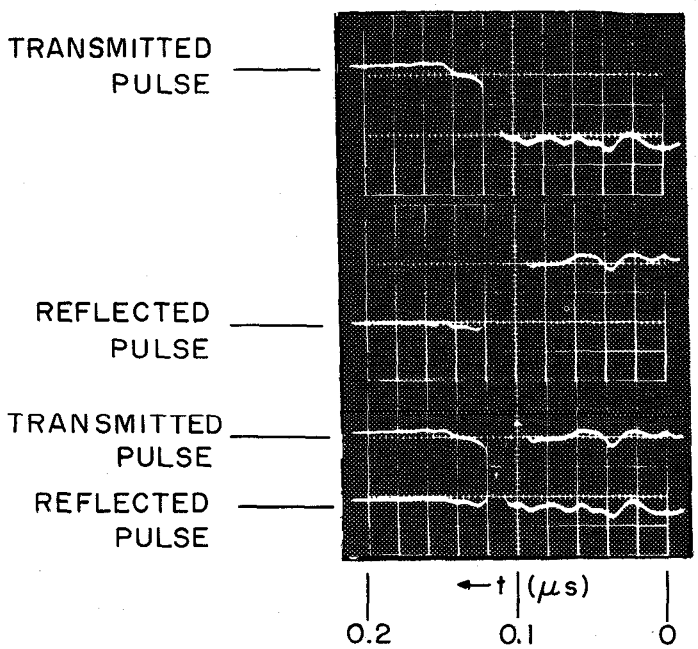

Fig. 3 Oscillograms of switching by dc triggered microwave spark. RF power = 600 kw; dc trigger = 15 kv; scope = Tektronix 545A; sweep time = 20 nanosec/cm.

TABLE 1: SWITCH DATA

peak rf holdoff power (at atmospheric pressure)	about one megawatt (at 4 μsec pulse width, 100 pps in arrangement of Fig. 2)
rf switching time	< 10 nanoseconds
"cold" insertion loss (unfired condition)	0.1-0.2 db
isolation (as defined in Fig. 2)	~ 20 db
arc loss (fired condition)	0.2-0.3 db (at rf levels above 30 per cent of switch holdoff power capacity)
jitter	none could be observed on a Tektronix 545A scope operated with a horizontal sweep of 20 nanosec/cm

The dc trigger characteristics are: pulse amplitude = 10 to 15 kv; pulse shape = half sinusoid of 10–15 nanoseconds; pulse rise time = 5 nanoseconds (estimated). The dc trigger unit is capable of supplying a 35 kv pulse, and so can be used to operate the switch at higher than atmospheric pressures.

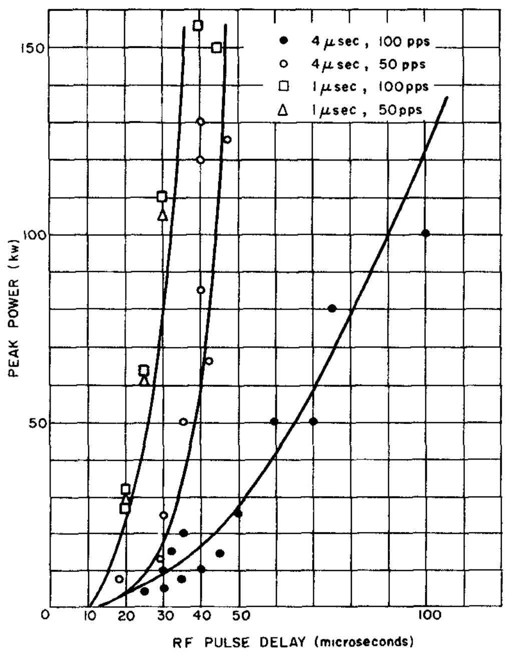

Fig. 4 Threshold curves of rf switching—peak power vs time delay behind dc spark discharge. *Note*: Switching of an rf pulse can occur when the pulse is delayed with respect to the dc spark discharge. The region to the left of each curve gives the allowable delay for almost complete switching and no distortion. For longer delays, there is incomplete switching plus distortion of the switched pulse. Each curve represents the threshold for switching for a given pulse width or repetition rate.

Switching action during a 2 μsec rf pulse is illustrated in Fig. 3 for a peak rf power level of 600 kw. (Because of the expanded time scale, the beginning and end of the rf pulse cannot be seen.)

The data presented are for shorting plates adjusted for optimum performance at a given frequency. Impedance data taken for various positions of the plates indicate that a ±5 per cent bandwidth may be expected.

Pressurization of the switch at three atmospheres raised the peak power holdoff to about 2 mw as limited by breakdown at the pressure window and the insulating bushing for the trigger electrode. Additional aspects of switch operation are given below.

RF Self-Switching and Recovery Time. The decaying plasma of a spark discharge can produce self-switching of high rf power and attenuation, or distortion of low rf power incident on the spark gap, shortly after the discharge is over. The first effect is illustrated in the "threshold" curves of rf switching of Fig. 4. The region to the left of each curve gives the delay between the incident pulse and a dc induced discharge within which self-switching (distortionless reflection) of the rf power can occur. This time delay increases with increasing rf level. The second effect is illustrated in

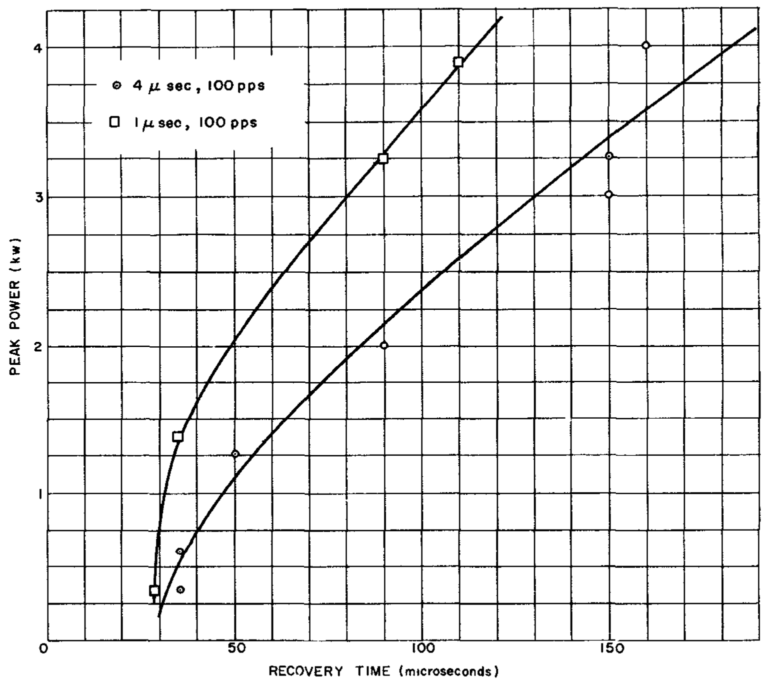

Fig. 5 Recovery time threshold curves. *Note:* The recovery time is a measure of how soon an rf pulse may be applied after the initiation of a dc discharge without experiencing distortion or attenuation because of residual ionization from the discharge. The region to the right of each curve gives the allowable time interval between discharge and rf pulse resulting in no distortion or attenuation of the rf pulse. For shorter time intervals, there will be some distortion or attenuation.

Fig. 5, which shows recovery time as a function of rf level. This is the minimum delay between discharge and signal required to obtain distortionless and unattenuated transmission of the signal. The recovery time decreases with decreasing signal level and approaches 30 microseconds below 100 watts.

Switching Time. When dc and rf fields are superposed, the joint effect in producing breakdown can be related to an equivalent field which is a function of both types. The equivalent field for air at atmospheric pressures has been calculated for different combinations of the superposed fields, applying the method of Gould and Roberts,[2] and can be used to predict the maximum switching time by using the results of Fletcher.[3] Experimental work to verify this analysis is under way.

Use in Switching Power out of a Cavity. The switch was used in conjunction with a transmission line cavity to form a high-power rf pulse compression circuit (see Fig. 6). The switch assembly in the unfired state

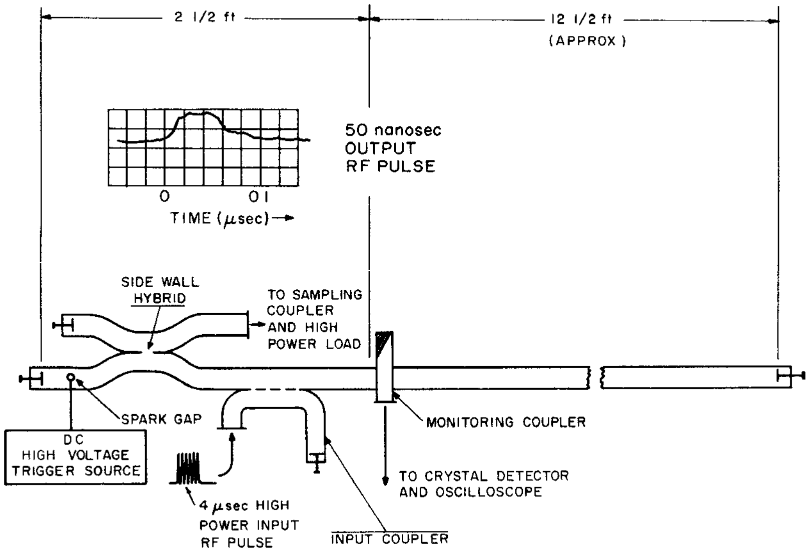

Fig. 6 Arrangement for switching rf power out of cavity resonator.

simply acts as a terminating short for one end of the cavity and discharges the stored energy of the cavity into a high power load when fired. Power in the form of a 4 μsec, 50 kw peak pulse was coupled into the cavity, and a 0.5 mw output pulse of 10 nanoseconds rise time and 45 nanoseconds duration was obtained on triggering the switch.

ACKNOWLEDGMENT

The work reported here was performed at the Polytechnic Institute of Brooklyn, Long Island Graduate Center, Farmingdale, N. Y., under Rome Air Development Center contract No. AF-30(602)-2135.

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