# FAST, HIGH POWER, OCTAVE BANDWIDTH, X-BAND WAVEGUIDE MICROWAVE SWITCH

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## Abstract

A new SPST microwave switch capable of switching 250 Watts CW power in 50 ns has been developed. Switch element and microwave circuit designs, driver requirements, SPST test results and projected multithrow results will be presented.

## Introduction *

The current work is directed toward increasing the speed, power handling and bandwidth capabilities of semiconductor waveguide window switches. Previous efforts[1,2] had produced switches with micro-second switching speeds, waveguide bandwidths, and average power capabilities of about 50 Watts. The earlier units achieved switching by a uniform injection of a hole-electron plasma from doped contact regions on either side of a slab of silicon. The silicon was mounted perpendicular to the waveguide axis and behaved as a "transparent" dielectric window when no plasma was injected and an "opaque" conductive lumped shunt element when carriers were injected by forward biasing the p and n doped injection metallization pattern.

The present improvements in switch performance are the result of:

1. Reducing the active semiconductor volume by about two orders of magnitude to reduce the amount of control charge required.

2. Improving the thermal design of the element mounting structure using BeO as a heat transfer material.

3. Optimizing the microwave circuit tuning of the switch element's capacitances to permit broadband tuning of additional susceptance.

4. Developing semiconductor processing techniques to make the fabrication of the device possible.

## Switch Element Design

In order to achieve the switching speed desired (50 ns), the switching charge (Q) available to the switching element is limited as follows:

$$Q \leqq IT \qquad (1)$$

where I is the switching current and T is the switching time or time for build-up of the controlling charge. If a maximum value of I is assumed to be 20 amperes, then,

$$Q \leqq 10^{-6} \text{ coulohms} \qquad (2)$$

Also, as the silicon volume switches between a dielectric transmission state and a conductive isolation state, it is found that the silicon conductivity ($\sigma$) in the isolation state must be greater than approximately 5 mhos/cm in order to achieve sufficiently high isolation state conductance and maintain a sufficiently low transmission state susceptance.

$$V = \frac{Q}{\sigma}(\mu_e + \mu_h) \leqq 3.7 \times 10^{-4} cm^3 \qquad (3)$$

The design chosen uses 600 PIN diodes fabricated in a single silicon slice as the active silicon element. Each diode measures 1 x 1 x 12 mils for a total switched volume of $1.18 \times 10^{-4} cm^3$. The diode layout is shown schematically in Figure 1.

The control bias input is brought in from the left as shown in Figure 1 with all diodes connected in parallel by the metallic bias conducting lines. The lines are perpendicular to the microwave electric field direction and are therefore decoupled from the microwave signal. Connection to the driver is accomplished by a low impedance ($\sim$2 ohm) transmission line (Teflon glass) which is connected to all bias lines.

Low thermal resistance between the switching element and the waveguide walls has been achieved by mounting the switching element on a 7 mil thick slab of BeO. The high thermal conductivity of BeO along with its low dielectric constant allow an equivalent thermal resistance of approximately 1 3/4$^\circ$C/Watt to be realized with a total normalized capacitive susceptance for the switch and heatsink of approximately 1.5.

Figure 2 shows a completed switch from the silicon side. The 1 mil high diodes are located between the bias lines where they look almost like a continuous path of metal from the top to the bottom waveguide walls.

The bias metallization is inlayed into the surface of the silicon a distance of 1 mil. This was achieved by using selective etching techniques to define the silicon device area prior to diffusion and metallization.

## Microwave Circuit Design

As the silicon element switches from a dielectric shunt across the waveguide in its transmission state to a resistive shunt across the guide in its isolation state, the overall circuit can be analyzed as a lumped element across a transmission line. To achieve broadband performance, it is required to tune out the window susceptance over the entire operational frequency band.

The circuit to achieve wideband performance was developed using the computer program OPTINET. The dispersive characteristics of waveguide in both

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impedance and propagation velocity were included in the computer analyses. The resulting circuit is shown in Figure 3. The inductor L is added in shunt with the window switch to achieve midband resonance. The two tuning capacitors, $C_t$, spaced 1/8 wavelength from the window plane in waveguide, provide in excess of octave bandwidth for the completed component. They tune out the excess capacitive susceptance at the window plane at frequencies above midband and the excess inductive susceptance at frequencies below midband. At midband, of course, they only serve to reduce the impedance at the window plane slightly.

A significant problem in achieving the above design was found in implementing the inductive componet, L. An inductive iris was used to provide about half of the required tuning susceptance. This reduced the width of the window and consequently the amount of switching charge required. It was found, however, that if the inductive iris was used to tune a midband capacitive susceptance of 1.5 to resonance, the loaded Q of the resulting resonant circuit was about twice the expected value. This would prohibit wideband operation.

This difficulty was overcome by RRC's development of a non-interactive broadband waveguide inductor. The photograph of Figure 4 shows the BeO side of the high-speed switch. The metallized pattern of eight conductive paths on the beryllium oxide heatsink supplies approximately 1/2 of the required tuning susceptance. This type of inductor does not cause excess capacitive energy to be stored in nearby non-propagating waveguide modes.

The entire SPST switch circuit is mounted in reduced height flat guide. This medium supports propagating waves, $TE_{10}$, in the low half of the operating bandwidth and both $TE_{10}$ and $TE_{20}$ in the high half of the operating bandwidth. The $TE_{20}$ mode is, however, not excited by the switch due to the symmetrical design of the component. Transitions from the flat guide medium to double ridge waveguide on the input and output ports of the switch permit conventional single mode waveguide techniques to be used over the greater than octave bandwidth of the switch.

## SPST Test Results

Two semiconductor switch elements were designed, processed, and fabricated during this research effort. It was not possible to cycle through redesign, etc., with the resources available. Nonetheless, the results obtained were very close to the original design goals.

A 1 dB absolute insertion loss was obtained over greater than an octave bandwidth. Figure 5 shows a swept transmission measurement on a relative frequency scale for both the untuned switch and the switch tuned with capacitive irises.

The isolation obtained in the opaque state was less than the design objective of 19 dB or greater at all operating frequencies. The isolation varied from approximately 12 dB at midband to 17 dB at band edges. Figure 6 shows swept isolation data obtained from both the untuned and tuned microwave switch. It is anticipated that higher isolation is feasible and will be obtained with design optimization.

Capacitive discharge switching speed tests were made which substantiated the speed capability of the switch and bias input circuit for both diode turn-on (transmit to isolate switching) and diode turn-off. The turn-on tests showed greater than 11 dB isolation from a 40 volt capacitive discharge in 27 ns. The turn-off test from a 4 ampere forward bias showed recovery to less than 3 dB in approximately 35 ns. Thus, by using high speed driver transistors with sufficient current gain, a composite driver-switch speed of 50 ns should be obtainable.

High power CW testing was performed on one device which successfully dissipated 50 Watts of matched CW power with a flange temperature stabilized at $53^{o}C$. This corresponds to a switching capability of over 179 Watts for the unit tested or over 250 Watts CW for a unit operating at 19 dB isolation. The unit was also tested as a switch (no matching) with 100 Watts of input power with significantly lower temperature rise.

## SPDT Operating Projections

Design calculations indicate that a 4 to 1 power handling advantage is realized in a low VSWR switching application. Thus, two 19 dB switching elements mounted in an appropriately designed fixture should be capable of 1 kW CW microwave power switching. A power handling increase factor of less than 4 will be realized in the SPDT arrangement if the VSWR in the transmission arm increases excessively.

## References


1. K. Mortenson, A. Armstrong, J. Borrego and J. White, "A Review of Bulk Semiconductor Microwave Control Components", IEEE Proc., Vol. 59, No. 8, August 1971, pp. 1191-1200.

2. K. Mortenson, J. Borrego, P. Bakeman, Jr., and R. Gutmann, "Microwave Silicon Windows for High Power Broadband Switching Applications", IEEE J. Solid-State Circuits, Vol. SC-4, December 1969, pp. 413-421.

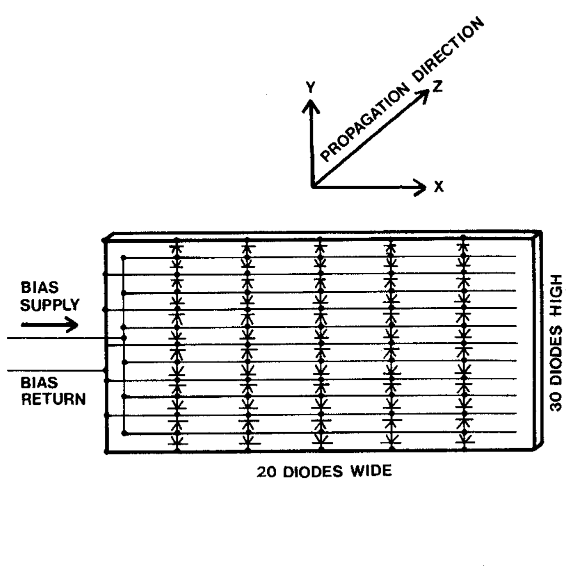




FIGURE 1. Schematic of Diode Layout on Silicon Switching Element

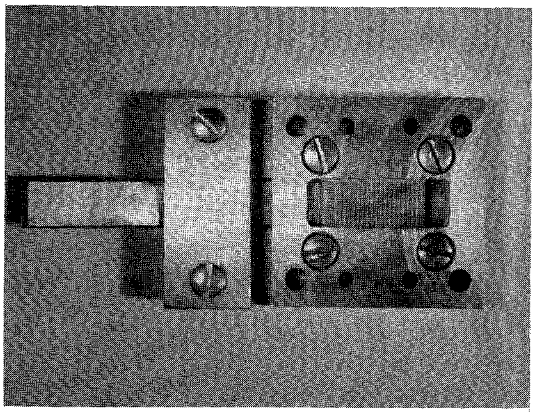
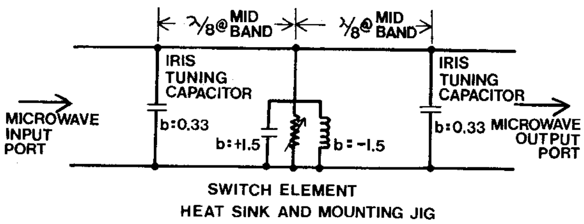


FIGURE 2. High Speed Window Switch - Silicon Side




NOTES: 1. Normalized susceptance values are at mid-band frequency.

2. The transmission medium is rectangular waveguide.

FIGURE 3. Schematic of Switching Element in Microwave Circuit

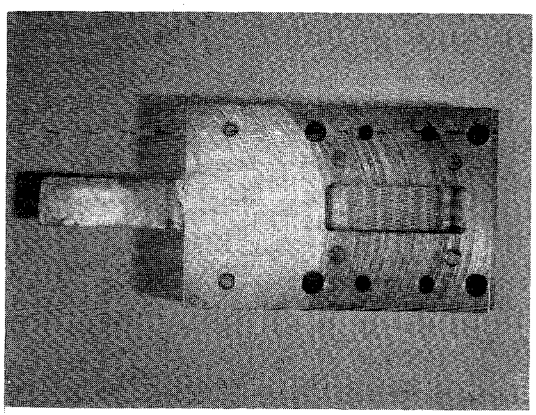


FIGURE 4. High Speed Window Switch - BeO Side

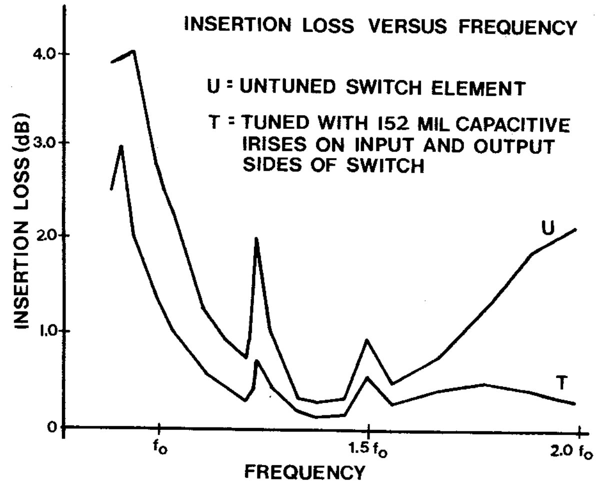



FIGURE 5. Transmission Microwave Measurement Switch No. 74FS1

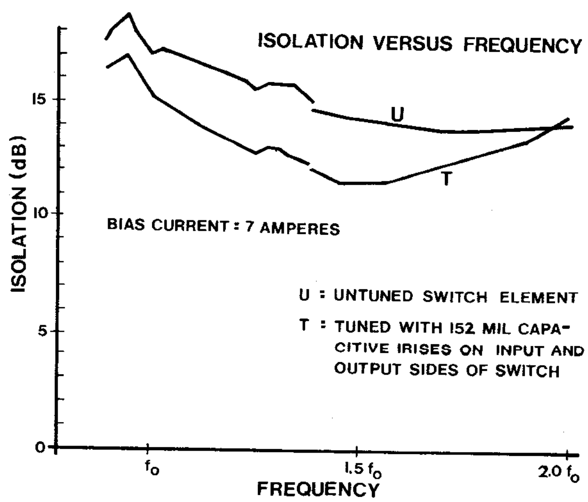



FIGURE 6. Isolation Microwave Measurement Switch No. 74FS1 - 7 Amperes