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HIGH-POWER 2-9 GHz SOLID STATE SWITCH

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Abstract

A fast high power solid state switch has been developed using optimized epitaxial silicon PIN chips. It is capable of switching over 360 watts of CW of power from 2-9 GHz and switching in 400 ns.

Introduction

The microwave industry is in need of a fast high power solid state switch for use in airborne EW jammers and communications systems. Present designs use electromechanical or ferrite switches, but their speed or size limits their usefulness. For one particular application, a fast (500 ns) high power single-pole, two-throw switch was needed to cover the 2-9 GHz band. In addition, primary considerations included small size and long operating life while running continuously at an input power of up to 320 watts CW anywhere in the band, at any temperature from -54°C to +100°C.

Using the computer aided design and a multi-discipline team approach, we were able to develop a PIN diode switch which met and exceeded all the requirements. Although the all-shunt diode approach we used seems quite conventional, specialized components were required at critical locations to reduce temperature rise which would otherwise reduce reliability. Of particular importance was the special PIN diode developed jointly with our Semiconductor Division (formerly GHZ Devices).

In this paper, we will describe briefly our design approach, the approach to the development of the PIN diode, and other components, and finally some test results and thermal analysis of the completed switch.

Design Approach

As an overall design philosophy, we chose to concentrate primarily on reducing power dissipation in critical components rather than concentrating on improved heat sinking. After considering a variety of designs and weighing the factors of size, cost, reproducibility and reliability, we decided to concentrate on an all-shunt PIN design. Ordinarily, this type of design would be narrow band because each diode must be approximately a quarter wavelength from the common junction. However, by using a multi-section transformer to a lower impedance at the diode, wider bandwidths can be realized. In addition, the RF voltage at the diode is reduced, allowing the use of faster diodes (thinner I-region) with higher capacitance and lower thermal resistance.

To optimize the design, a microwave circuit analysis program was used. Since the reverse biased PIN diode was considered the most critical element, the optimization was keyed to the temperature rise in the diode. That is, the impedance and electrical length of the transformer section were adjusted to keep the RF current through the reverse-biased PIN diode as low as possible across the entire band while keeping the diode capacitance as large as allowed by the required switch bandwidth. An additional consideration was the harmonic power, which is only 8 dB below the fundamental at some frequencies. The optimized design, shown in Figure 1 resulted in a power dissipation of less than 3.5 watts of fundamental and 2.2 watts of harmonic RF power across the band in the "off" diode (in the "on" arm) for a diode having a capacitance of .50 pF and a series resistance of 0.5 ohm. The conducting diode (0.4 ohm) would dissipate less than 2.2 watts of fundamental and 2.3 watts of harmonic RF power across the band.

(a)

(b)

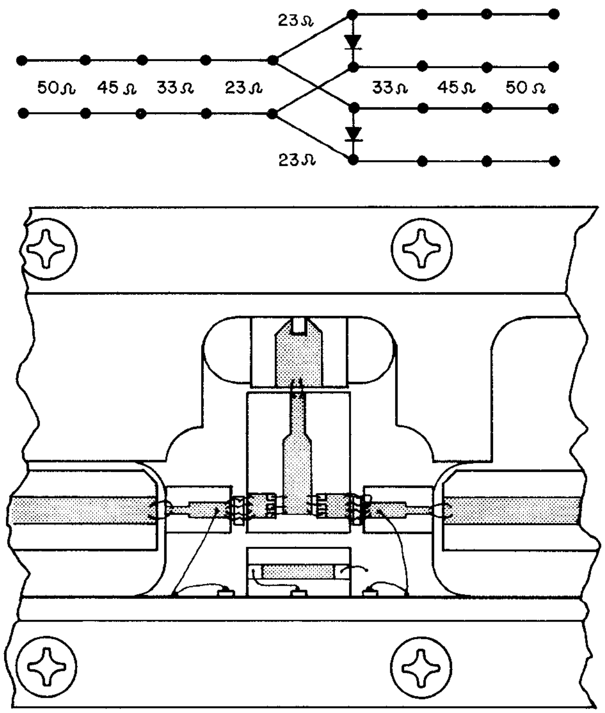

Fig. 1 - Optimized High Power PIN Switch
(a) Schematic Diagram
(b) Drawing of Completed Switch Module

Realization

In order to minimize size, the lowest impedance transformer sections were realized in alumina microstrip. After a thermal and loss analysis of a variety of dielectrics, different dielectrics were chosen for the other sections and the 50 ohm lines. DC blocking capacitors were placed in the 23 ohm line, and diodes were biased through bias inductor wires. The width of the 23 ohm line section allowed the active area of the diode chip to be divided into four separate junctions to reduce inductance and increase isolation in the off arm, and reduce the thermal resistance of the diode. Figure 1 shows the final microstrip configuration of the switch.

PIN Diodes

The requirements of the high power switch required the design of a very special PIN diode. In order to avoid excessive temperature in the diode in the off arm, low forward Rs is required. For low

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dissipation in the on arm, high breakdown voltage combined with low reverse Rs are required.

The computer optimization indicated that the best compromise of diode and circuit characteristics would be represented by the following specifications:

Vb = 300 V minimum

Cj = 0.50 pF @ 25 V reverse

Rs = 0.4 ohms @ 250 mA forward

Rs = 0.5 ohms @ 25 V reverse

T_L = 400 ns

θ = 5°C/W

Of these requirements, the most difficult is the reverse bias Rs. Available epitaxial and double-diffused PIN diodes fail to meet the requirements by nearly an order of magnitude, so it was decided to develop special epitaxial PIN chips.

Calculations indicated that an I-region resistivity over 500 ohm-cm was needed to keep the punch through voltage under 20 V in the required 40 µM layer, and that an arsenic doped substrate would be required for low spreading resistance. An optimized epitaxial procedure was developed which produced 1000 ohm-cm layers on .002 ohm-cm arsenic doped substrates, with a very abrupt interface. A profile of the epitaxial layer is shown in Figure 2.

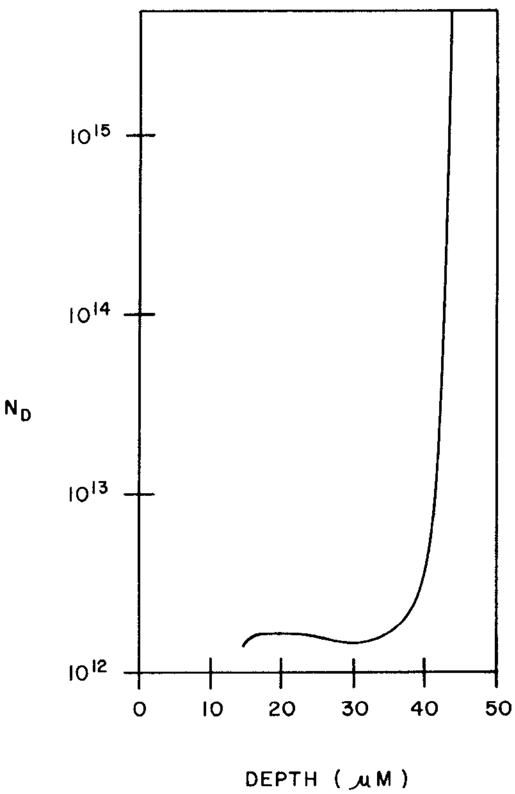

Fig. 2 - Doping Level Profile of the Epitaxial Layer used for the PIN Chips.

A four-mesa chip design was selected for optimum voltage breakdown combined with low thermal resistance and low inductance. Passivation was with CVD deposited SiO_2. After the wafer fabrication process was optimized, chips from the final wafer were bonded in a standard pill package and Q was measured at approximately 7 GHz using a transmission null method. The result is shown in Figure 3 for various reverse bias voltages. This Q corresponds to a series resistance of less than 0.2 ohm, exceeding the requirement by more than a factor of two. This reduction of Rs combined with the reduction in thermal resistance due to dividing the junction into four parts reduced the estimated temperature rise in the off diode to 5°C at the full 320 watts rated power.

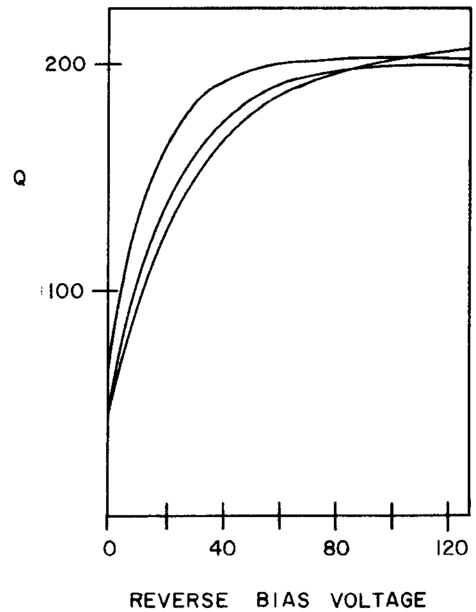

Fig. 3 - Q of Several PIN Chips at 7.2 GHz Vs. Bias Voltage.

Thermal Analysis

As expected from the above analysis, the design of the circuit combined with the special diode design virtually eliminated the risk of diode failure. This was verified by a thermal scan of the diodes during operation and confirmed by high power testing. However, the thermal scanner indicated serious problems with the capacitors and the feedthrus in the early models of the switch. In the case of the capacitors, a different physical location on the 23 ohm line eliminated the problem, but the feedthrus had to be redesigned because of failures due to a thermal runaway problem in the latter. Results of thermal scanner measurements on the final design are given in Figure 4.

COMPONENT	INCIDENT POWER	FREQUENCY (GHz)		
		2.5	5.0	7.5
ON DIODE	100 W	4	2	1.5
	200 W	9	3	3
OFF DIODE	100 W	2	2	2.5
	200 W	4	4	6
50 OHM LINE	100 W	12	18	18
	200 W	25	36	39

Fig. 4 - Temperature Rise (°C) in Various Components at 100 W and 200 W incident RF Power.

Electrical Performance

The final version of the switch was tested for insertion loss and isolation from 2 GHz to 8 GHz at power levels up to 360 watts CW, over the full temperature range. Switching speed was under 500 ns from full isolation to full on and vice versa. To test for a possible reliability problem under accidental hot-switching conditions, the switches were thermal-scanned with 100 watts CW incident during switching. The transient temperature rise in the diodes after hot switching was no more than twice the normal rise, not enough to cause a serious problem. Figure 5 shows the insertion loss and isolation curves, and Figure 6 shows the comparison of the sampled RF amplitude to the drive waveform. Presently, units have survived full operating flight test and are scheduled to begin life test at the completion of the flight test report.

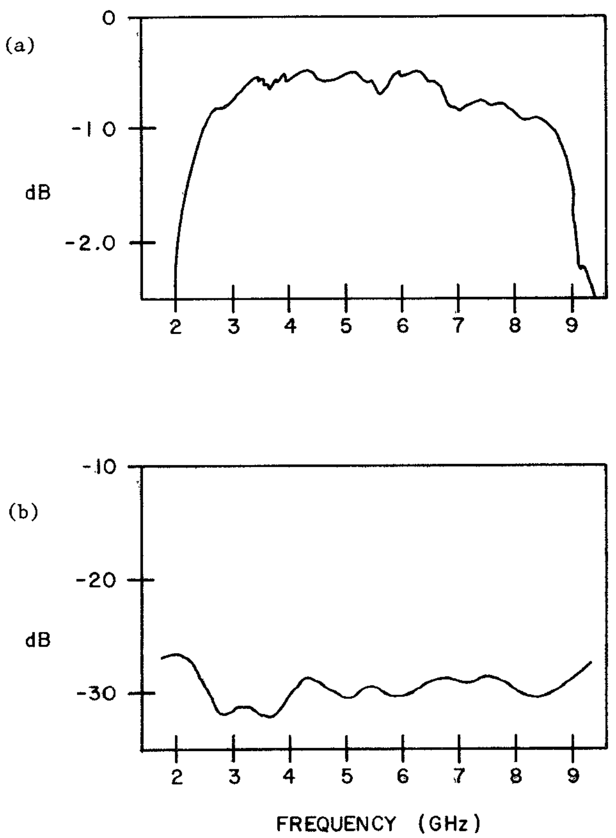

Fig. 5 - Insertion Loss (a) and Isolation (b) of the High Power Switch.

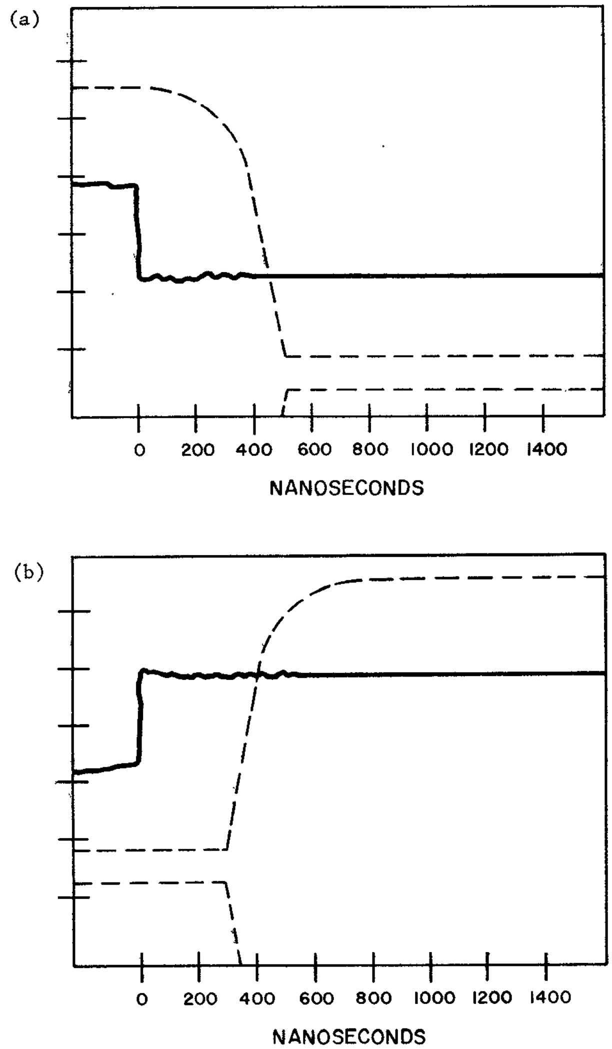

Fig. 6 - Switching Characteristics of Completed Switch. The solid line is the drive waveform, and the dashed line represents the RF envelope at the output.

(a) Insertion Loss to Isolation
(b) Isolation to Insertion Loss