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ABSTRACT

As part of a study of the application of communication satellites to educational development, certain technical aspects of such a system were examined. A current controlled bistable switching element using a CW Gunn diode is reported on here. With modest circuits switching rates of the order of 10 MHz have been obtained. Switching is initiated by current pulses of short duration (5-10 nanoseconds). Rise times of the order of several nanoseconds could be obtained. The apparent mechanism which allows the bistable operation of the Gunn diode is the reduction in the mobility of the GaAs active layer due to device heating. (Author/JY)

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A CW GUNN DIODE BISTABLE SWITCHING ELEMENT

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Abstract

A current controlled bistable switching element using a CW Gunn diode is reported. With modest circuits switching rates of the order of 10 MHz have been obtained. Switching is initiated by current pulses of short duration (5 - 10 ns). Rise times of the order of several nanoseconds could be obtained. The apparent mechanism which allows the bistable operation of the Gunn diode is the reduction in the mobility of the GaAs active layer due to device heating.

A CW Gunn Diode Bistable Switching Element

M. Hurtado[+] and F. J. Rosenbaum[+]

The use of long, heavily doped samples of GaAs as pulse generators[1-3] and pulsed logic elements has been reported by many workers.[4-11] The purpose of this letter is to describe the use of CW Gunn diodes as bistable switching elements.

The well known static characteristic of GaAs, its average velocity versus electric field, exhibits a region of negative slope.[12, 13] Consequently, the terminal dc current-voltage characteristic of a CW GaAs diode can also exhibit a corresponding negative differential resistance region which will depend on the device characteristics, the bias circuit configuration, and the microwave circuit loading on the device. For example see Ref. 14. A suitable load line determined either by the series or parallel connection of the device with an external load resistor can be made to intersect the static i-v curve in three points as shown in Fig. 1. Point a is below the threshold voltage and the device is quiescent there. Microwave power is generated when the device is biased at point (b).

The i-v curves of numerous devices were measured with the diodes mounted in a tunable X-band waveguide holder. The

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device active layer lengths were nominally 10 μm and the doping densities were near 1×10^{15} cm^{-3}.

Figure 2 shows a typical terminal i-v characteristic as displayed on a curve tracer swept at 60 Hz. Negative differential resistance behavior is clearly seen. The shape of the curve could be drastically altered by the microwave tuning, in some instances showing multiple regions of negative slope. For some tuning conditions several hundred milliwatts of X-band power could be generated.

The most striking feature of Fig. 2 is the presence of a hysteresis-like loop. The upper trace occurs during the increasing part of the voltage cycle; the lower trace occurs after the maximum voltage has been applied and the voltage is decreasing. This loop is not due to a phase difference or delay in the measurement circuits. Notice that the maximum current on the lower trace is less than that on the upper trace.

Our explanation for the hysteresis loop is the difference in the operating temperature of the device at each point along the i-v characteristic. During the increasing portion of the applied voltage cycle the operating temperature of the device is rising. The maximum dissipation occurs at the maximum applied voltage, since the decrease in current from threshold to this point is rather small, (about 20%), while the applied voltage has doubled. On the downswing the device begins to cool. Notice that at any voltage the device is hotter on the downswing than on the upper trace.

To corroborate this presumed temperature effect the i-v characteristics of several devices were observed when the heat sink temperature was varied from 27.3° to 83°C. The hysteresis loop was maintained but the current was reduced at all voltages as the heat sink temperature was increased.

Devices exhibiting the largest current drop-back between threshold and maximum voltage were selected and tested in the experimental switching circuit shown in Fig. 3. The load resistor R_L is chosen from the curve tracer results to yield a load line which intersects the i-v curve below threshold and at a high voltage ($10 < V < 15$ volts). The device is current-biased slightly below threshold. When a positive current pulse is added the device switches to its high voltage, lower current stable point. The amplitude of this current pulse must be such that the total current delivered to the circuit exceeds the device threshold current. A current pulse of opposite polarity which exceeds the minimum device current switches the device back to its original high current, low voltage operating point.

Figure 4 shows the voltage across R_L as a function of time as the device is being switched between its two states at 500 ns intervals. The lower voltage is 5 volts and the upper voltage is 8 volts. Also noticeable in the figure are the positive and negative switching pulses, whose pulse width is about 100 ns. The maximum switching rate which was obtained was 10 MHz. Switching could be initiated with pulses as short as 5-10 ns. Rise times of the order of several nanoseconds have been observed.

One factor that limits the rise time is the bias circuit oscillations which are often excited during the switching period[2]. This may be due to the mechanical arrangement of our waveguide, bias, and pulse circuits. It is expected that the use of a microstrip circuit would reduce the many parasitic reactances and improve the performance of the device.

An interesting logic feature of this bistable switch is the microwave signal that is generated in the high voltage state. It could be detected to provide a non-destructive read out of the state of the switch, or used for other logic operations which might require a bit stream of microwave pulses.

The switch could be set indefinitely in either of its two states in contradiction to the prediction of Englemann and Heinle.[15] In a recent paper Thim[16] suggested that a stationary field configuration could be initiated in overcritically doped samples ($nL \geq 10^{12}$) which would result in a bistable switching element. That device would not produce any microwave oscillations however. The observations reported here lead us to conclude that it is the reduction of the mobility of the GaAs active layer, caused by the dc power dissipation, which gives rise the bistable characteristic with microwave power generation in the high voltage state.

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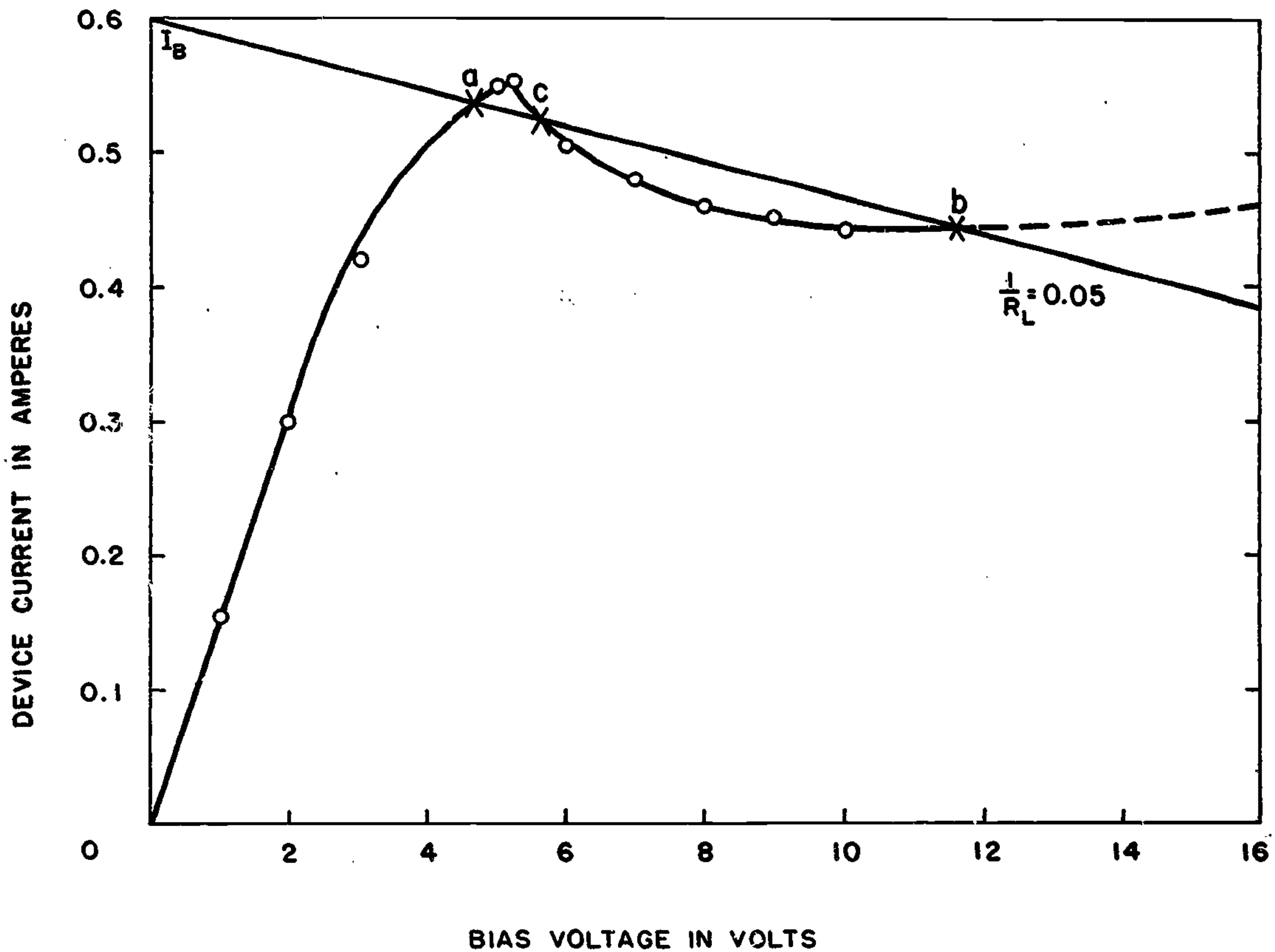
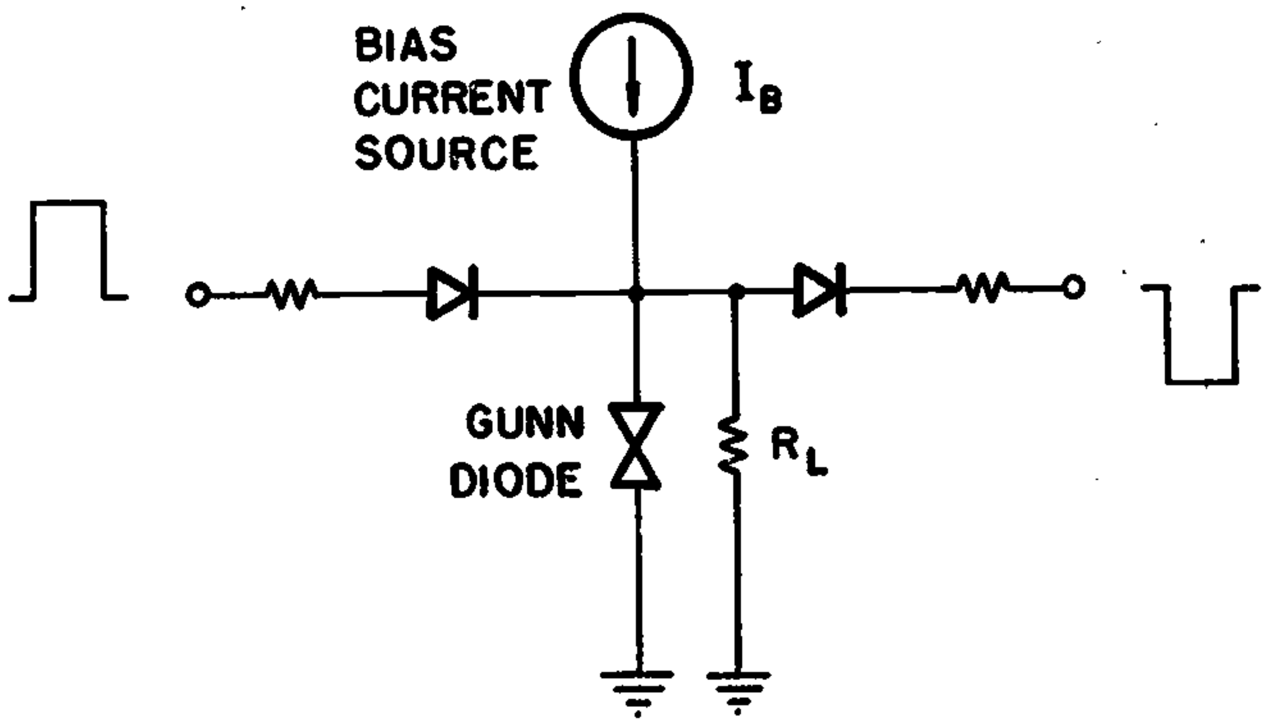
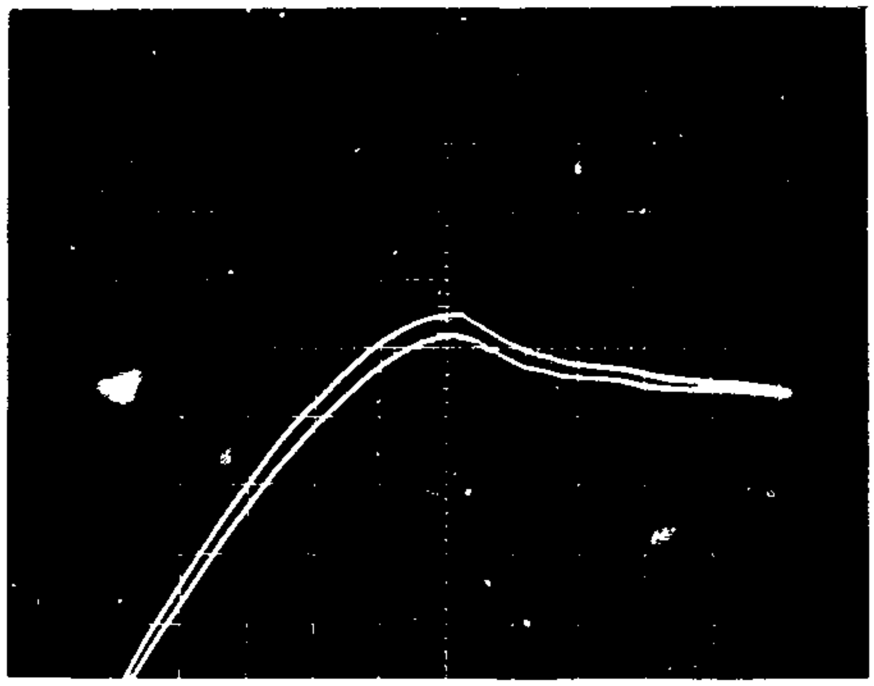
Load Line.



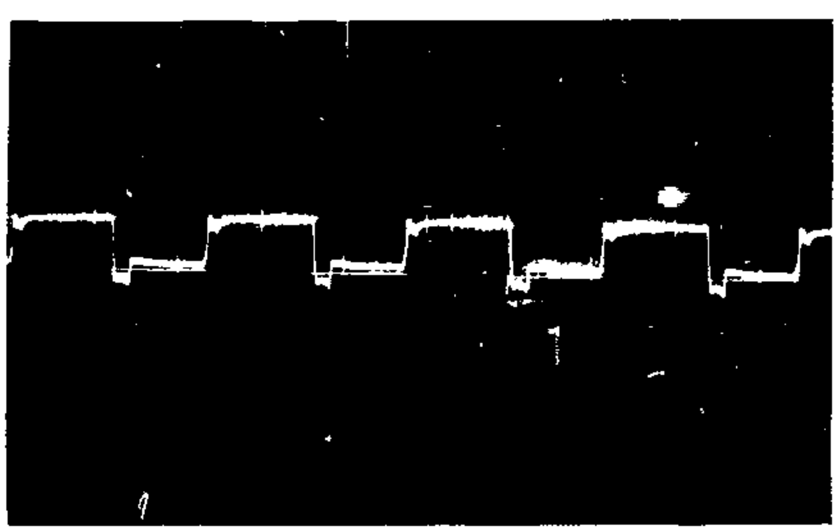
1. Typical CW Gunn Diode Current-Voltage Characteristic and Load Line.



3. Schematic of Experimental Switching Circuit.



2. Diode i-v Characteristic Displayed on Curve Tracer. Vertical Scale: 100 mA/div; Horizontal Scale: 1V/div.



4. Output Voltage Waveform Showing Bistable Operation. Vertical Scale: 5 V/div; Horizontal Scale: 0.5 μsec/div.