

A Pulsed LED System for Schlieren Flow Visualisation

David R Buttsworth and Tony L Ahfock

buttswod@usq.edu.au

<http://www.usq.edu.au/users/buttswod/>

March 18, 2003

Faculty of Engineering & Surveying Technical Reports

ISSN 1446-1846

Report TR-2003-01

ISBN 1 877078 03 4

Faculty of Engineering & Surveying

University of Southern Queensland

Toowoomba Qld 4350 Australia

<http://www.usq.edu.au/>

Purpose

The Faculty of Engineering and Surveying Technical Reports serve as a mechanism for disseminating results from certain of its research and development activities. The scope of reports in this series includes (but is not restricted to): literature reviews, designs, analyses, scientific and technical findings, commissioned research, and descriptions of software and hardware produced by staff of the Faculty of Engineering and Surveying.

Limitations of Use

The Council of the University of Southern Queensland, its Faculty of Engineering and Surveying, and the staff of the University of Southern Queensland: (1) do not make any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in these reports; or (2) do not assume any liability with respect to the use of, or for damages resulting from the use of, any information, data, method or process described in these reports.

Abstract

Schlieren flow visualisation can be performed using light emitting diodes (LEDs) operated with a strong pulse of current (typically a few amps can be passed through the LED for a number of microseconds). Commercial systems are available to produce such pulses, but they are prohibitively expensive. This report provides details of a low cost pulsed current circuit which can be used to drive LEDs in flow visualisation systems. The aim of this work is to improve the accessibility of schlieren and shadowgraph flow visualisation in laboratories with significant financial constraints. The LED drive circuit provides a 12 A (maximum) current pulse with a selectable duration of between about 1.5 and 38 μ s. The optical performance of two LEDs operated with the high current pulses produced by this circuit is also discussed. A sample of the visualisation results obtained with a hot air jet is also presented to demonstrate the success of the schlieren system.

Contents

1	Introduction	3
2	Pulsed Current LED Drive Circuit	3
2.1	Arrangement and Operation	3
2.2	Circuit Performance	5
2.3	Optical Performance of Pulsed LEDs	5
3	Schlieren System	8
4	Conclusions	10

1 Introduction

Light emitting diodes can produce sufficient light for typical flow visualisation applications if they are driven with a high current (several amps). However, to avoid destruction of the LED, the current must be applied for a relatively short period (typically less than $100 \mu\text{s}$). Examples of flow visualisation using LEDs driven in this manner have been presented by [1] and [2].

Commercial devices such as those produced by Avtech Electrosystems (Ottawa, Canada) are available to control the current pulse delivered to the LEDs. However, as these devices are relatively expensive (around \$ 7600, US), a more cost effective system was sought.

The present approach differs from the system for multiple channel LED pulsing reported by [3] in that the triggering of the current pulses is controlled by an external source.

2 Pulsed Current LED Drive Circuit

2.1 Arrangement and Operation

Details of the pulsed current drive circuit are presented in Fig. 1. The current pulse is triggered by a +5 V (TTL) signal which switches on the NPN transistor (TIP31C - a general purpose high power bipolar transistor) which in turn, switches on the PNP transistor (TIP32C - a general purpose high power bipolar transistor). The $0.1 \mu\text{F}$ capacitor (C) rapidly goes to 15 V and the voltage on the output side of the capacitor decays at a rate determined by the selected resistor value (R). A pulse is produced by the 4081 CMOS device (quad 2-input AND gates), the width of the pulse being determined by the RC time constant on the input side of the 4081 device. Both AND gates in the 4081 device are used in parallel to improve the current gain, and further current boost for rapid switching of the power MOSFET (BUK553 - $I_D = 12 \text{ A}$, $V_{DS} = 100 \text{ V}$) is provided by the paired TIP31C/32C transistors.

A 1Ω resistor is provided at the drain of the power MOSFET so that the current flow through the LED can be monitored. The LED can be operated in a low current continuous mode (for alignment and optimisation of the visualization system) by closing the manual switch which bypasses the BUK553. The magnitude of the continuous current supply through the LED is determined by the value of the 0-50 V supply and the current limiting resistor ($1 \text{ k}\Omega$). However, before switching to the continuous mode of LED operation, the bank of $220 \mu\text{F}$ capacitors should first be discharged by operating the other manual switch that isolates the 0-50 V supply and discharges the capacitors through a 3 terminal adjustable regulator (LM317T) in series with a LED indicator. Once the capacitors are fully discharged, the BUK553 can be safely bypassed (by closing the switch for continuous operation) and the 0-50 V supply switched back on for low current continuous operation of the LED. In the continuous mode of operation, the capacitors do not get charged up to the full supply voltage because of the continuous flow of current through the LED.

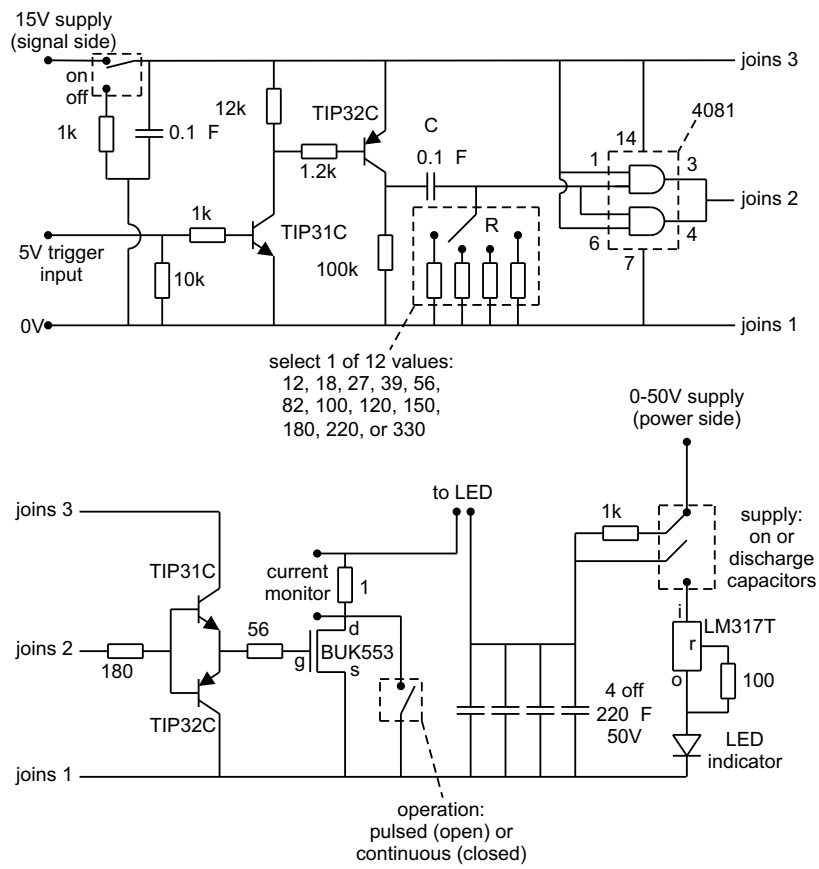


Figure 1: Illustration of the pulsed current circuit.

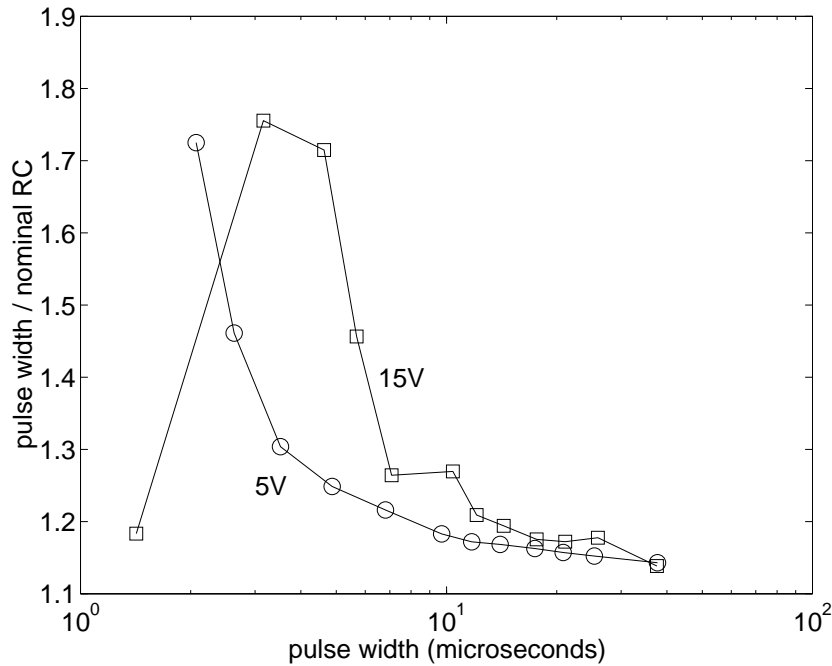


Figure 2: Current pulse width produced by the circuit.

2.2 Circuit Performance

Various current pulse widths that can be obtained with this system, depending primarily on the selected value of resistance (in combination with the $0.1 \mu\text{F}$ capacitor). However, the actual value of the power supply voltage also has an effect for pulse widths less than $10 \mu\text{s}$ as illustrated in Fig. 2. The actual value of the pulse width remains between about 1.1 and 1.8 times larger than the RC value on the input side of the 4081 device. For the results in Fig. 2, the pulse width was defined using a temporal full-width half-maximum criterion applied to the measured current signal.

The impedance of the high current supply circuit depends on the particular LED in the circuit. This is indicated in Fig. 3 by the fact that each LED curve has a different slope. The supply voltage intercept in Fig. 3 is at approximately 2.3 V for each LED, as expected. The power MOSFET (BUK553) is expected to have a resistance, $R_{DS} \approx 0.2 \Omega$ (for $V_{GS} = 5 \text{ V}$). For the HLMP-DL08, the impedance given by the (inverse) slope of the line in Fig. 3 is about 3.5Ω leaving a 2.3Ω contribution from the LED when the 1Ω series resistor and the MOSFET are taken into account.

2.3 Optical Performance of Pulsed LEDs

The optical performance of two LEDs under pulsed conditions was studied in some detail. The two LEDs were: 1) LXHL-BD01 is a Luxeon Emitter with a dominant wavelength of about 640 nm and a typical luminous flux of 25 lm at 350 mA; and 2) HLMP-DG08 is a Hewlett Packard device with a dominant wavelength of 626 nm and a typical luminous intensity of 6500 mcd at 20 mA. The emissions from the LEDs were measured using silicon PIN photodiode: PDA55 from Thorlabs. The PDA55 was set to the lowest gain, for which the quoted bandwidth is 10 MHz.

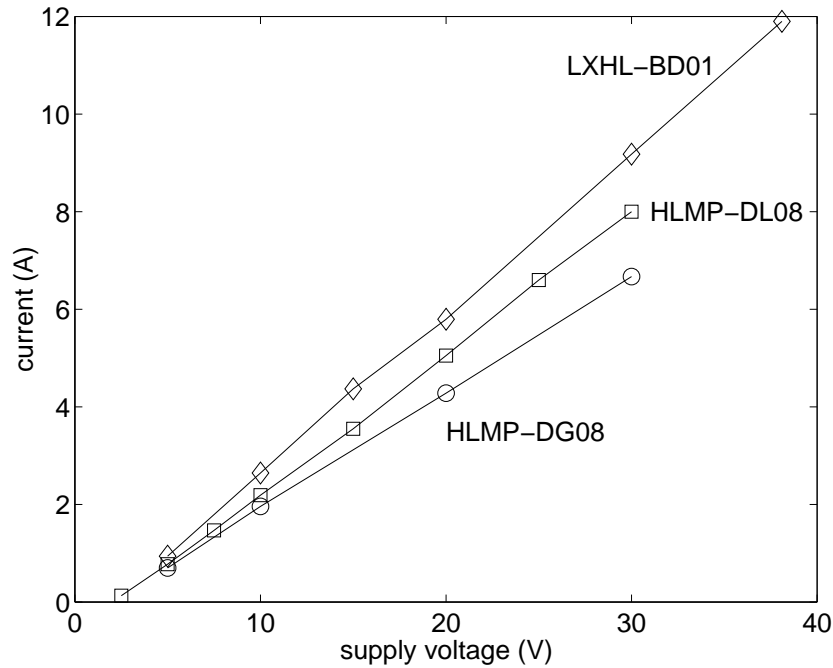


Figure 3: LED current variation with supply voltage.

Sample measurements of LED intensity as a function of time are presented in Figs. 4 and 5. For these measurements, the longest available pulse width (approximately $38 \mu\text{s}$) was used. In these figures, the intensity has been normalised by the estimated intensity that would have been produced with a drive current of 20 mA.

The intensity produced by the LED decreases with increasing junction temperature, and substantial increases in junction temperature are expected for the present operating conditions. Temperature effects are probably responsible for the temporal decay in intensity observed in Figs. 4 and 5. The HLMP-DG08 appears to be more sensitive to thermal effects than the LXHL-BD01. In the normal operating mode of the LXHL-BD01 (350 mA continuous), the metallic slug which emerges from the back of the LXHL-BD01 package requires heat sinking to maintain the LED junction temperature below 230°C . It is probably the relatively good thermal connection between the junction and this slug that allows the junction of LXHL-BD01 to remain at modest temperatures while the junction temperature of the HLMP-DG08 increases more rapidly.

Figure 6 summarises the intensity measurements obtained with the LXHL-BD01 and HLMP-DG08 LEDs. Each data point (the symbols in this figure) corresponds to the value of intensity measured $5 \mu\text{s}$ after the start of the pulse. The vertical bars indicate the variation in intensity from the start of the pulse to the end of the pulse (approximately $38 \mu\text{s}$ later). The differences between the two LEDs apparent in Fig. 6 (including the shorter vertical bars are associated with the LXHL-BD01) arise because of its superior heat sinking characteristics as discussed previously. It is interesting to note that while no further gains in intensity are obtained at $5 \mu\text{s}$ when the HLMP-DG08 is driven with a current higher than 4 A, substantial intensity increases can still occur with this LED at times less than $1 \mu\text{s}$ from the start of the current pulse.

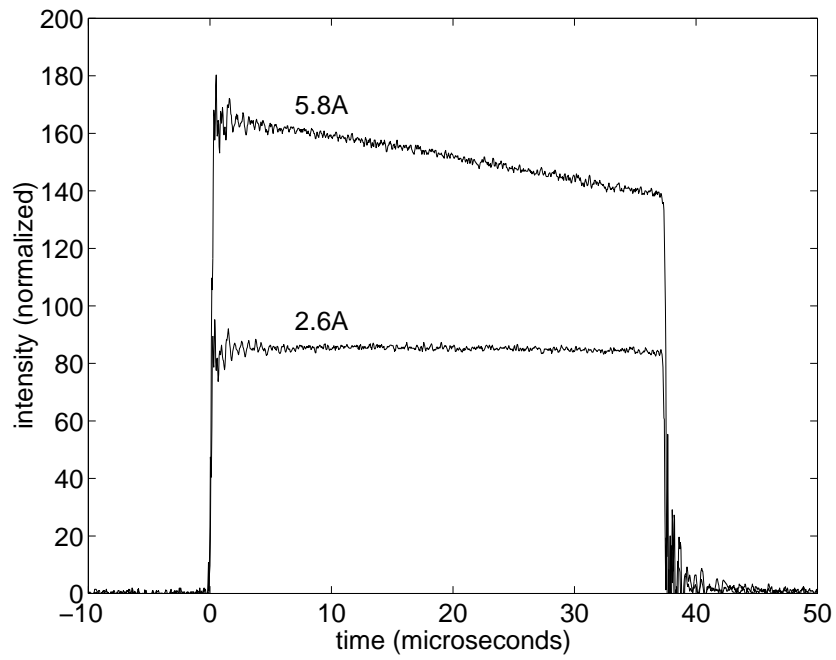


Figure 4: Temporal response of LXHL-BD01 intensity for different values of drive current.

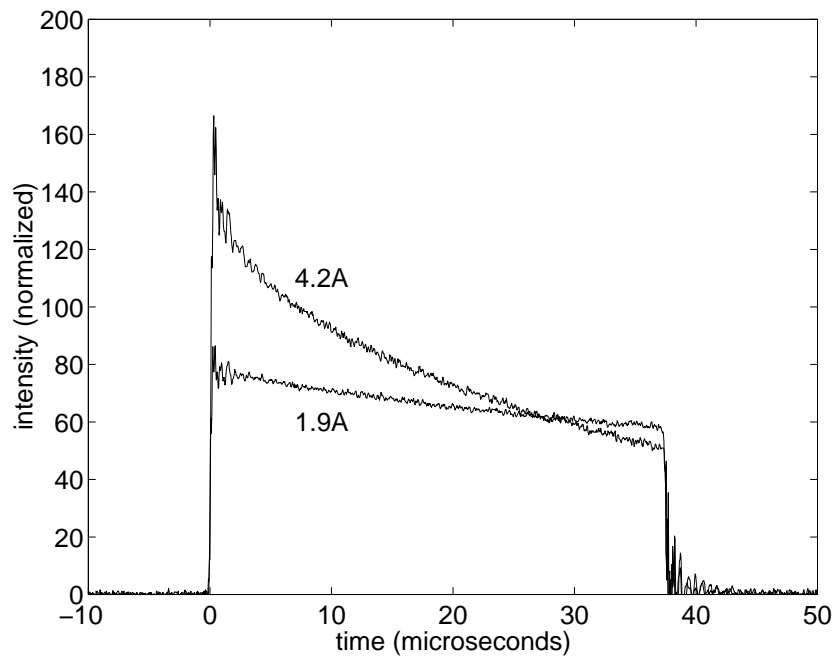


Figure 5: Temporal response of HLMP-DG08 intensity for different values of drive current.

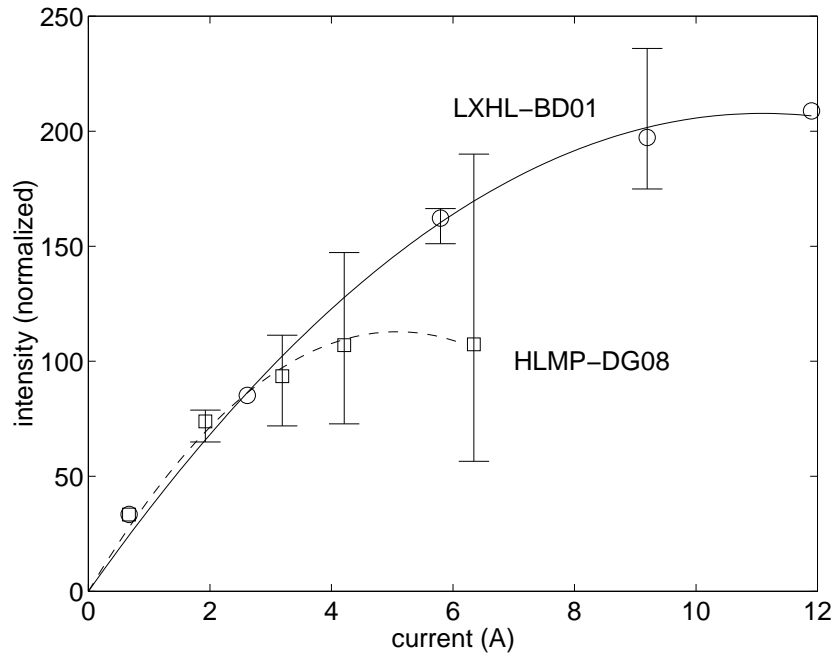


Figure 6: Variation of LED output intensity with drive current.

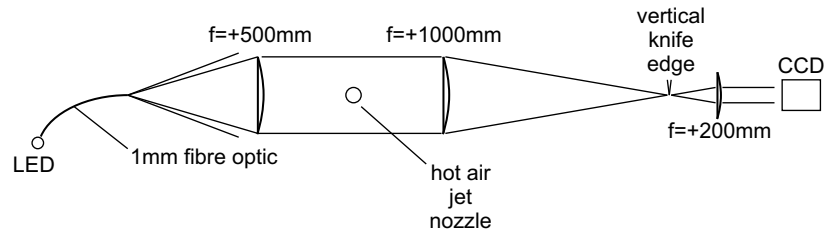


Figure 7: Illustration of the schlieren system arrangement (top view).

3 Schlieren System

The schlieren system developed in this work is illustrated in Fig. 7. The LXHL-BD01 was coupled to a plastic fibre (1 mm diameter, polymethyl methacrylate core, $NA = 0.46$, acceptance angle = 55° , attenuation < 0.25 db/m at 650 nm). The end of the fibre was positioned at the focal point of a $f = +500$ mm, 100 mm diameter lens. The collimated beam traversed a hot air jet (provided by a heat gun) and was focussed onto a vertical knife edge by a $f = +1000$ mm, 100 mm diameter lens. The heat gun had a nozzle exit diameter of approximately 28 mm. An objective lens ($f = +200$ mm, 50 mm diameter) was used to focus the image onto the CCD array of a Nikon E2N digital still camera.

The CCD in the Nikon camera is $8.7 \text{ mm} \times 6.8 \text{ mm}$ and contains 1280×1000 pixels. The sensitivity was set to 'high' meaning the equivalent film speed was ISO 1600. The shutter was set to $1/8$ second and the LED source was pulsed at approximately half way through this period. The pulse width was $10.4 \mu\text{s}$. The turbulent characteristics of the vertical hot air jet are clearly visible in the schlieren image presented in Fig. 8.

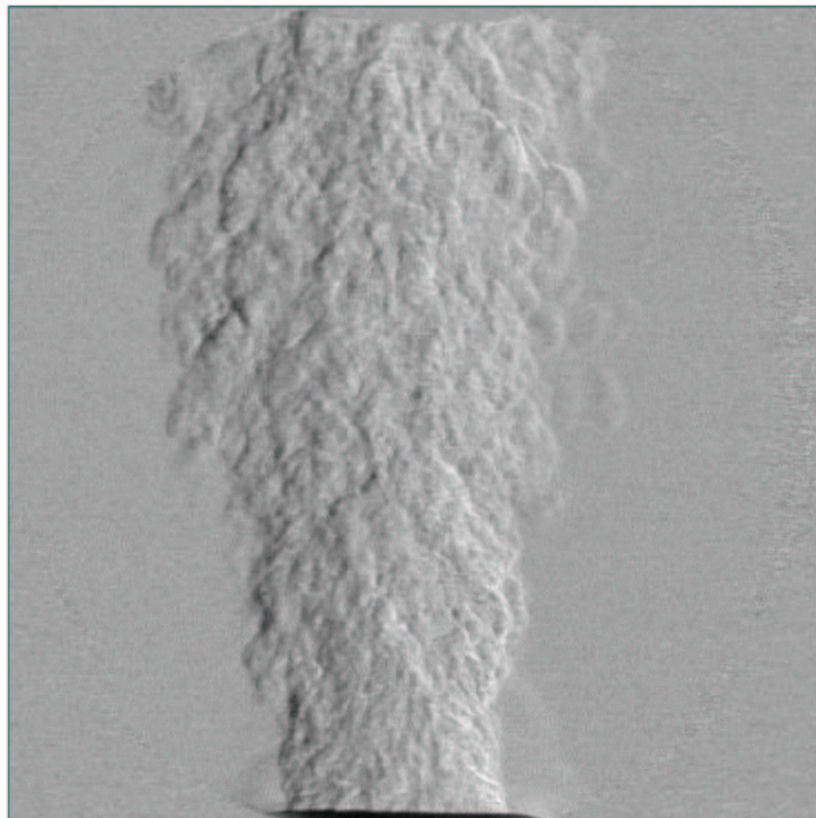


Figure 8: Vertical knife edge schlieren image of a hot air jet.

4 Conclusions

The pulsed LED system reported in this work provides a cost effective solution for flow visualisation using a single LED as the light source. It can be used in single-shot or stroboscopic applications as the current pulse is triggered by a TTL input signal. The present arrangement can be extended to create a Cranz-Schardin system which involves firing multiple LEDs in rapid succession by duplicating the current drive circuit for the required number of LEDs and synchronizing the triggering of each pulse with a microprocessor.

References

- [1] F K Lu, X Zhang, and X Liu, “Visualisation of confined shock-bubble interactions”, in *Proceedings of the 21st International Symposium on Shock Waves*, A F P Houwing et al., Eds., Great Keppel Island, Australia, July 1997, Paper No. 3680.
- [2] C Y Tsai and R J Bakos, “Shock tunnel flow visualisation with a high speed schlieren and laser holographic interferometry system”, in *20th AIAA Advanced Measurement and Ground Testing Technology Conference*, Albuquerque, NM, USA, June 1998, AIAA Paper 98-2700.
- [3] W Brouwer, *Time Resolved Imaging in Compressible Flows Using a Cranz-Schardin Camera*, Honours dissertation, Department of Physics, The University of Queensland, Brisbane, Australia, 1999.