Review and Development of Nanosecond Pulse Generation for Light Emitting Diodes

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Abstract – The electrical characteristics of Light Emitting Diodes (LEDs) are considered. The standard circuits used for creating LED pulses in the nanosecond region are reviewed. Additional design work on the electronic circuits has been carried out and the results from the developed circuits are shown.

I. INTRODUCTION

Pulsed Light Emitting Diodes (LEDs) are often employed in calibration of optical systems. They are an excellent source for such applications because they use electronic driver circuits that are simple, compact, stable and inexpensive. In the majority of cases the light sources are required to produce a flash of light where pulse width and height are not critical. As the timing is normally not the most crucial parameter, the simplicity of the light source driver is guaranteed. However, certain specialist requirements for light pulses of the order of a few nanoseconds create the need for more exacting circuitry. Also, an important factor in such applications is the device's ability to generate very fast light pulses. The characteristic width of these optical pulses is ultimately dictated by the physical characteristics of the LED itself.

Some of the published techniques employed for the creation of light pulses in order of a few nanoseconds are reviewed. We also look at the methods that are, or could be, exploited for development of improved LED drivers. We attempt to utilise some of the techniques disclosed. The resulting pulse characteristics are presented and discussed.

II. HIGH SPEED SWITCHING OF A LED

When an ideal electrical pulse is applied to a purely resistive load, the voltage developed across the load is expected to closely follow the input signal with respect to time. However, if reactive components are introduced into the circuit, the response of the complex load changes the characteristics of the pulse shape. This latter point must be considered when fast changing electrical signals are used to drive LEDs. The LED electrical diode model differs from the ideal representation of a diode, which behaves as a perfect resistive switch. When a practical model is considered, then it is the internal capacitance of the diode and the small lead inductance that are responsible for deviation from the ideal case. This internal capacitance is a combination of diode junction capacitance and diffusion capacitance. Printed Circuit Board inductance and component lead length contribute to the complex load effectively presented by the LED. Additionally, the electrical rise time and the magnitude of the current pulse also play a significant role in the diode's 'turn on' characteristics.

To optimise the transfer of energy from the driver circuit to the LED, the dynamic load characteristics of the LED must be matched to the drive impedance of the output circuit. In these circumstances the diode should present as a resistive component at the instant when the current starts flowing. If impedance matching is correct, the current flowing in the LED circuit will be optimised. The subsequent removal of the driving pulse does not cause the instantaneous disappearance of the diode current and the optical emission it generates. The decay of the diode current, after withdrawal of the driving pulse, depends on diode internal recombination processes. Thus, this decay is exponential, as predicted by theory.

The diode's response to an electrical pulse is general limited by the minority radiative carrier lifetime. By dynamically matching the LED electrical characteristics to the drive circuit the optical output pulse is optimised for 'turn on' and 'turn off'.

III. REVIEW

Early high-speed light sources included spark gaps and crater lamps. The spark is caused between two electrodes by a high voltage pulse. This ionises the gas and causes the emission of optical radiation. The emitted optical pulse is normally in the order of a few microseconds duration. The light emission is caused by the fast moving electrons ionising the gas and the subsequent decay of the excited states to their ground state. The neon crater lamps were developed to produce fast, repeatable light sources for the development of early television equipment and facsimile techniques. Electronic flash lamps evolved from these early high speed light sources. However, since the discovery of LEDs and solid-state lasers, these new semiconductive devices have dominated the area of ultra fast light sources.

Early LEDs were primarily used as optical indicators and displays. They also played a crucial role in the development of optical isolators. The further advances in the technology resulted in LEDs becoming more bright, efficient and reliable.

Their modern day brightness levels as well as their ability to provide true colour (using red, green and blue light) confirm the dominance of the devices in the indicator and display area. However, there is a range of applications (e.g. telecommunications, fluorescence, calibration, etc.) where LEDs are used in a pulsed mode.

A. Pulse generators

One of the simplest and most reliable family of circuits that produce reliable pulses are multivibrators [1, 4 – 8] and their derivatives. These circuits generate pulses whose width can be accurately controlled. They are split into three groups: bistable, monostable and astable. Schmitt Triggers are also considered to be a part of this family. The quasi-stable states of these circuits are determined by the passive components in the circuit. Regardless of how long these states are active, their existence will inevitably come to an end with no external stimulation. Hence if triggered (in the monostable case) the pulse will terminate automatically at the end of the timing period determined by the time constant of the circuit. One of the primary uses of monostable multivibrators is the creation of pulses which are well defined in amplitude and duration [5]. This characteristic can be exploited for the creation of drive circuits for LEDs.

A variant of the early monostable is the high speed emitter-coupled monostable [1, 4, 8 – 14] which has greatly improved switching speeds and stability. Again pulsed timing is controlled by passive components. Patents [11-14] indicate sub-nanosecond pulses can be achieved.

B. Avalanche Transistors

When the reverse bias voltage across a p-n junction is increased to the junction breakdown level, the junction conducts very large current. Even though this process is not necessarily destructive, the maximum current must be limited in order to avoid excessive junction heating [15].

Reverse bias provides increase of the depletion layer electric field. This electric field causes sweep of the minority carriers across the junction (and hence saturation current). If an electron (minority carrier in p type material) is attracted by the electric field, it accelerates across the depletion layer. Electrons collide with crystals (or impurity) atoms in the depletion region delivering their kinetic energy to the atoms they collide with. However, if the electric field is increased so that the electron gains enough energy to break covalent bonds [16] the newly formed pair gains more energy from the electric field thus causing creation of more electron-hole pairs. The process continues in an avalanche manner for as long as the avalanche conditions are maintained. It is this serial multiplication process that allows the creation of very fast transitions.

It is documented that the exploitation of the transistor avalanche effect for LED driving makes it possible to obtain sub-nanosecond light pulses [8, 17 – 20]. Avalanche transistors can be used in series in order to achieve the required pulse driver conditions [19, 20].

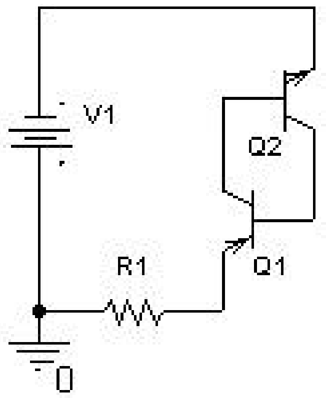

Figure 1. – Simple Regenerative Switch

C. Complementary Pair Regenerative Switch

A complementary pair regenerative switch (Fig. 1) is a form of a switch where the complementary pair of the transistors are cross-coupled in such a way that the transistors are both always in either an ‘on’ or ‘off’ state [4, 8, 9, 26, 27]. This combination provides a quiescent current equal to almost zero while its on state provides high current capability. The advantage of this circuit is that it has few components and the rising pulse shape is dictated by the regenerative switching action of the complementary pair. Current levels are limited only by the transistor ratings [9].

The configuration shown in Fig. 1 shows that the collector current of the PNP transistor is also the base current of the NPN transistor. At the time when this current is rising, then the collector voltage of the NPN transistor is being pulled negative. This concurrently switches the PNP transistor on. When either of the two transistors is caused to switch off the feedback loop causes both transistors to switch hard off [4]. The complementary pair regenerative switch is occasionally used for representation of NPNP devices (such as thyristors) [9, 27].

A successful light pulse generator based on complementary pair regenerative switch is reported by Kapustinsky et al. [21]. The LED driver (Fig. 2) has applications in the calibration of scintillation counters [21 –24]. The dc component of the trigger pulse of this circuit charges a storage capacitor C2. The trigger pulse needs to be wide enough to allow the capacitor to fully charge. The falling edge of the trigger pulse is differentiated using a RC network (R1 and C1). This differentiated edge triggers the complementary regenerative switch. This action in turn creates a low impedance path for the capacitor C2 to discharge its stored energy through the LED. This fast discharge provides a fast current pulse to activate the LED. However, the optical pulse does not follow the electronic signal closely. The width of the decaying optical signal is reduced by an inductor connected in parallel with the LED. The voltage induced by this inductor opposes the charge

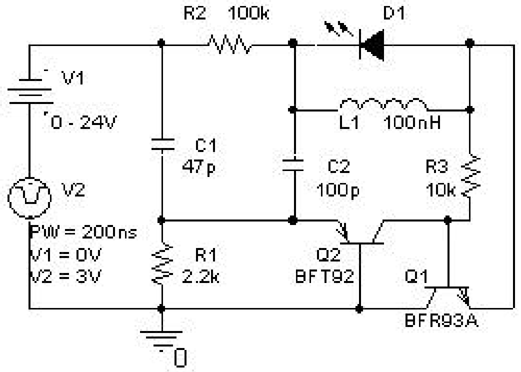

Figure 2. LED drive circuit based on complementary pair regenerative switch [21]

released by the storage capacitor C2, hence reverse biasing the LED and helping its trapped charge carriers to be swept away from the depletion layer. The inductor L1 introduced to the LED is reported to reduce the fall time of the decaying light pulse from 100ns to 12.5ns [21].

IV. DRIVER DEVELOPMENT

The simplest way to generate pulses is based on capacitor discharge into a load [25]. This is also a relatively inexpensive method. A suitable candidate for such switching action is the regenerative switch (as described in previous section). The output from the regenerative switch produces a very fast rising pulse dependant on the transistor characteristics. Clearly, faster switching times are obtainable with the use of microwave transistors. We have experimentally confirmed that the falling edge of the pulse needs to be improved. The decay time of the generated pulses is dependant on the storage capacitance, switch on-resistance and load resistance (Fig. 3). It should also be noted that the maximum power transfer from the storage capacitance to the load is obtained when the switch on-impedance and the load impedance are equal. Since the load impedance is of a dynamic nature, dynamic impedance matching can be exploited for the improvement of the power transfer and pulse shape.

Techniques can be exploited in order to obtain desired pulse characteristics. One of the basic techniques is differentiation with RC or RL networks. This method is extremely simple and reliable. It can be implemented with the use of very few passive components. Unfortunately, the main disadvantage of this method is energy loss in the load. Pulse differentiation certainly improves the trailing edge of the pulse. The leading edges are defined by the switching characteristics of the active devices used for switching. Possible improvements to the transistor switching action could be achieved through the use of speed up capacitor-resistor combinations to increase base drive current. In the same way as this component combination aids LED current shaping, it also improves transistor switching characteristics. The effect of the increased base current is expressed in the form of faster charging of the junction capacitance. This causes reduction in the turn on time [5]. Also the removal of the charge stored by the junction capacitors is desired prior to transistor being switched on in order to perform faster switching action [28]. If these capacitances are charged in the reverse direction, then they need to be discharged before the base-emitter voltage can become positive. This charge removal is also achieved by the use of the same parallel capacitor-resistor combination in the transistor base current path [3, 5, 8, 9, 28, 29]. A danger that arises from overdriving the transistor is the increment of the storage time. However, the capacitor-resistor combination only overdrives the transistor during the rising edge transient. Also this method allows for the reduction of the storage time and fall times as it provides reverse bias conditions to the base-emitter junction during the turn-off [5, 8].

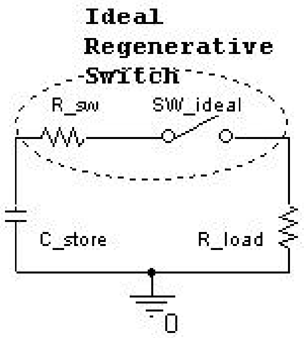

Figure 3. – Simplified representation of the complementary pair regenerative switch system

V. RESULTS

The methods described above have the aim of producing faster optical pulses. A blue LED with a peak emission at 472 nm is used as an optical source. The electrical pulses are measured at the output from the regenerative switch and across the LED (Fig. 4). The rise time of the LED voltage pulse is 1.7 ns and its pulse width at the 50% of its peak value (FWHM) is 2.9 ns. The optical pulses are detected by a photomultipleir tube with the rise time of 3.5 ns. Though the existence of optical pulse with a rise time of less than 3.5 ns is apparent, the limitation of the optical equipment has prevented

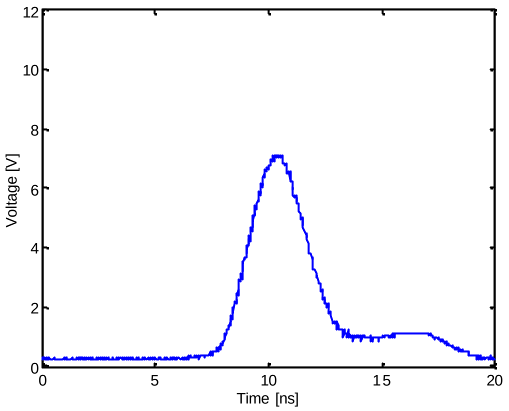

Figure 4. – Regenerative switch output pulse (···) and Voltage across LED (---)

the accurate measurement of the optical pulse. Further improvements are being performed on the electronic circuit. Adequate optical signal measurements will be taken once the LED driver circuit is optimised in terms of electric signal.

VI. CONCLUSION

The physical limitations and characteristics of the LEDs used in the pulsing circuits are described. Some of the standard LED pulsing circuits are reviewed. The resulting waveforms from the experimental development of the LED pulse driver are presented. We expect to continue with the optimisation of the driver that we developed.

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