DESIGN AND CHARACTERISTICS OF NANOSECOND PULSE GENERATOR FOR VISIBLE LIGHT APPLICATION

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To my family, especially my mother, father and wıfe

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In the name of Allah The Most Gracious, The Most Merciful

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ABSTRACT

Application of visible lights in sensing and medical systems is gaining interest in research. The systems used for the said purposes usually consist of a pulse generator, a visible light source and an optical fiber as the sensor. Light employed in the system is typically in short pulses rather than continuous waves. Nanosecond pulse generator is needed for those applications. This research aims to develop a nanosecond pulse generator for visible light applications. In this study, a nanosecond pulse generator based on LT1720 comparator was developed to be used with light-emitting diode (LED) as light source and its performance through optical fiber was tested. A simulation of the circuit was performed use Multisim to compare the pulse width of output pulses from simulation and the actual circuit. Six LEDs that emit lights of different wavelengths were tested to determine their output power. The optical pulse emitted by LED through a plastic optical fiber with various fiber lengths was then received by a photodetector PDA55 which demodulated the optical pulse into electrical signal. The data obtained shows that the pulse generator was able to produce square pulses with pulse width as small as 30.70 ns. Mean relative error of the pulse width between pulses generated by simulation and those from the actual pulse generator was 3.88%. LED that emits lights at 621 nm wavelength was found to produce the highest output power. The LED was also able to emit optical pulses that follow closely the electrical pulses in term of shape, although a bit of dispersion occurs resulting in longer pulses. Mean relative difference of the pulse width between electrical pulses and optical pulses was recorded at 4.40%. However, the output power of the LED was very low, restricting its use from high power visible light application. The system was able to work with optical fiber as long as 5 meters. For a system use an optical fiber longer than 10 meters, the output power is undetectable by the photodetector.

ABSTRAK

Penggunaan cahaya boleh nampak dalam sistem pengesanan dan perubatan semakin menarik minat dalam penyelidikan. Sistem yang digunakan untuk tujuan tersebut biasanya terdiri daripada penjana denyut, sumber cahaya boleh nampak dan gentian optik sebagai pengesan. Cahaya yang digunakan dalam sistem tersebut biasanya di dalam bentuk denyutan pendek berbanding gelombang berterusan. Penjana denyut nanosaat adalah diperlukan untuk penggunaan tersebut. Penyelidikan ini bertujuan untuk membangun penjana denyut nanosaat untuk penggunaan cahaya boleh nampak. Dalam kajian ini, penjana denyut nanosaat berdasarkan comparator LT1720 telah dibangunkan untuk digunakan bersama diod pemancar cahaya (LED) sebagai sumber cahaya dan prestasinya melalui gentian optik telah diuji. Simulasi litar telah dilaksana menggunakan Multisim untuk membandingkan lebar denyut luaran daripada simulasi dan litar yang sebenar. Enam LED yang memancarkan cahaya dengan panjang gelombang berbeza diuji untuk menentukan kuasa luarannya. Denyut optik yang dipancarkan oleh LED melalui gentian optik plastik pelbagai panjang yang kemudiannya diterima oleh pengesan cahaya PDA55 yang menukarkan denyut optik kepada isyarat elektrik. Data yang diperolehi menunjukkan penjana denyut dapat menghasilkan denyutan berbentuk segi empat dengan lebar denyut sekecil 30.70 ns. Ralat relatif purata lebar denyut di antara denyutan yang dihasilkan dari simulasi dan penjana denyut sebenar adalah 3.88%. LED yang memancarkan cahaya dengan panjang gelombang 621 nm didapati menghasilkan kuasa optik tertinggi. LED itu juga dapat memancarkan denyutan optik yang mengikut denyut elektrik dari segi bentuk, walaupun sedikit penyebaran berlaku menyebabkan denyut menjadi lebih panjang. Perbezaan relatif purata lebar denyut di antara denyut elektrik dan denyut optik dicatatkan pada 4.40%. Namun, kuasa luaran yang dihasilkan LED adalah sangat rendah, menghadkan penggunaannya daripada penggunaan cahaya boleh nampak berkuasa tinggi. Sistem ini dapat berfungsi dengan gentian optik sepanjang 5 meter. Bagi sistem yang menggunakan gentian optik yang panjangnya melebihi 10 meter, kuasa luaran yang dihasilkan tidak dapat dikesan oleh pengesan cahaya.

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LIST OF ABBREVIATIONS

BSL	-	Backscattered Light
C	-	Capacitance
dB	-	Decibel
FWHM	-	Full width at half maximum
LED	-	Light Emitting Diode
EMI	-	electromagnetic interference
IOR	-	Index of Refraction
MMOF	-	Multi mode optical fiber
OFS	-	Optical fiber sensor
ORL	-	Optical return loss
OTDR	-	Optical Time Domain Reflectometer
R	-	Resistance
SMOF	-	Single Mode Optical Fibre

LIST OF SYMBOLS

α	-	Attenuation coefficient
Bns	-	Backscatter factor
c_o	-	Coupling efficiency
c_{vacuum}	-	Speed of light in vacuum
c_{medium}	-	Speed of light in a medium
H	-	Reflection height
L	-	Fibre length
n_1	-	Refractive index of medium 1
n_2	-	Refractive index of medium 2
n_{eff}	-	Effective index of the SMF
$n_{material}$	-	Refractive index of the material (liquids)
$P_{backscattering}$	-	Backscattered and reflected optical power
Pin	-	Power launched into the coupler
$Pout$	-	Power output
P_{OTDR}	-	OTDR's received power
$P(0)$	-	Optical power at the end of fiber
R	-	Reflectance
S_{fiber}	-	Coefficient of fiber
S_{int}	-	Coefficient of internal OTDR
T	-	Pulse width
T	-	Charge time of capacitor
w	-	Pulse width
v	-	Pulse group velocity
x	-	Position relative to the input end of the fiber

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Pulse generation is an important part of much electronic equipment in operation today. Many circuit applications require the generation of fast rising variable-width pulses. Such applications include computer circuitry, radar, television, sampling oscillography, and the use as test pulses in the evaluation of high speed circuits (Upadhyay *et al.*, 2014). Typically, rise times of the order of a few nanoseconds or even fractional nanoseconds are the requirements. A system may contain several wave form generators, and it is usually necessary to incorporate some timing signal so that these waveforms will have some common time reference. Also a pulse generator may be used to trigger circuits, such as switching a binary counter (Karatasos *et al.*, 2004).

Pulsed light systems have found many applications and areas of research in recent decades. Visible light pulses have recently been used in the biological and medical field to study subcellular effects caused by nanopulses (Zhang *et al.*, 2013). Light is one of the medium for communication transmission that human beings used since the ancient times until today. Ancient mankind used fire to sends message to another distant place and construct lighthouse to guide the ships around the shore. Over the times, mankind always find a way to utilize the light in more elaborate way. For example, light can be seen used in early warning systems during the war by pointing the light into the sky in case of enemy attacks. Machineries usually have light indicators on them. In modern ages, we can see the light is used as the traffic signs, or commercial displays. The discovery of optical fiber enables mankind to utilize light for transmitting data in a very long distance.

Before the existence of optical fibre, data transmission in telecommunication field depends mainly on signal carried by electromagnetic field using highly conductive media such as copper. However, conductivity of the material will eventually limit it transmission characteristics. To fulfil the demands of higher speed and capacity in data transmission, optical fibre was utilized and in the past decades, it has emerged as one of the vital component in the telecommunication field, slowly replacing copper cables as the common medium for data transmission. This is because light wave can travel in a remarkable high speed, able to carry much more information than electric signal, and have low losses over long distances. Other advantage of optical fiber-based communication are immune to electromagnetic field interference, corrosion free and safe to be operated in hazardous environments (Yeh *et al.,* 2012).

1.2 Research Background

In nanosecond circuitry, it is sometimes necessary for the output pulse to occur upon triggering with minimum delay. A way of doing this is described with repeatability of pulse width still intact.

Width of the optical pulse is one of the influencing factors to the visible light application such as sensing and measurement. Shorter pulse width can only travel in a short distance as its carries less energy as compared to longer pulse width. However, short pulse width also has its advantages in form of able to provide a more precise reading, hence increasing the resolution. This make optical pulse with long pulse width is suitable for long distance telecommunication and transferring a bulk of data while optical pulse width shorter pulse width suitable for transmitting data between and within building or Local Area Network (LAN) and short-distance sensing.

Due to its various advantages, optical fiber has a huge potential to be used in sensing applications. Optical fiber sensing is capable to perform distributed measurements, which allow several measurements in the same time. In recent years, several techniques involving optical fiber has been developed for distance measurements which in turn can be used to measure derived quantities such as refractive index, displacement and velocity. Civil engineering is one of the field that benefitted massively from this discovery, as optical fiber sensors has been used to monitor water pressure and vibrational frequencies induced by water loads in a dam (Henault *et al.*, 2010).

Optical fiber sensor still has a lot of potential to be discovered. Most research focuses on designing optical fiber sensor system that is cheaper and less complex by reducing the quantities of components involved (Younis, 2012). Many research on optical fiber sensing also focuses mainly on measuring linear displacement in a small range.

The emergent of optical fibre as sensing medium means a standard of quality for it needs to be established. Some of the parameters that can be manipulated for optical fiber sensing are the length of optical fiber and attenuation. These parameters can be measured through optical time domain reflectometry method. Optical time-domain reflectometer (OTDR) is an instrument to characterize optical fiber and also can be used for optical fiber sensing. It works by injecting a series of short optical pulses into the optical fiber, and measure the attenuation of the optical link by extracting the backscattered pulse (Martinez-Pinon *et al.*, 2008). It measures the strength of backscattered pulses and integrating it as a function of distance *(Žgalj et al.*, 2011). It also able to locate breaks on the optical fiber by measuring the loss of optical energy at certain points.

In this research, we suggest the development of nanosecond pulse generator for visible light application. We are using light in the visible range wavelength, which is from 400 to 700nm. Visible light exhibits low loss inside the plastic optical fiber, which are more commonly used for short distance application in recent time.

1.3 Problem Statement

Most of visible light applications employs light in pulsed form rather than in continuous wave for either transmitting data or making a measurement as a sensor. As visible light application in optical fiber is usually limited by distance, a short pulse is needed to prevent overlapping of pulses due to the effect of dispersion. This is especially true for plastic optical fiber, common transmission medium for visible light, which can usually operate up to distance of 100 meters only. This leads to the need of a pulse generator that able to generate pulse of nanosecond width especially for short distance application. Nanosecond pulses are usually generated by using avalanche transistor technique, which needs a high input power. This makes the circuit usually complex and unsuitable to be used with light source other than laser. A pulse generator that operates in low power and has a simple operation is needed for some cases of visible light application. In this study pulse generator for visible light application was developed by exploiting the output race condition. Width of the visible optical pulse in the nanosecond range as this transmitter is intended to be used only in short range distance. The pulse generator circuit developed is able to produce nanosecond width pulses to modulate the optical signal.

1.4 Research Objectives

The main aim of this research is to develop a nanosecond pulse generator for visible light application. To achieve that, a set of objectives are planned as follows:

1) Design and develop a nanosecond-width square pulse generator to trigger the light source and modulate the optical pulse
2) Evaluate the parameter of pulse generator by comparing it to circuit simulation such as pulse width, rise time, and fall time
3) Determine the most suitable wavelength of LED that produce the highest optical power output to be used in the system
4) Evaluate the difference between electrical pulse and optical pulse after light transmitted through the plastic optical fiber.

1.5 Scope of the Study

This research focus in developing the nanosecond pulse generator that is able to be used for visible light application. This research starts by developing a pulse generator circuit to produce nanosecond-width electrical pulse or modulation pulse. The LED is chosen to be used as the light source for this study as for visible range. Six LEDs were used in this research, with different wavelength of 465 nm, 470 nm, 520 nm, 570 nm, 620 nm and 621 nm. The optical pulses injected into plastic optical fiber that acts as the transmission medium. Photodetector are used to detect the optical signal and the signal can be observed in an oscilloscope. From that observation, many parameter of the visible light transmitter can be measured and concluded

1.6 Significant of the Study

As visible light communication and sensing gaining more interest, a low cost and simple method for producing short light pulses is needed. A low voltage, low power short light pulse technique might be needed for some application, such as determination of refractive index by optical fiber.

In a recent development in medical field, photodynamic therapy uses optical fiber to deliver light to treatment area (Meserol, 1996). The visible light transmitter circuit can be used for that purpose in case a short pulse of light is needed to be injected to the treatment area.

1.7 Outline of Thesis

In the first chapter, we discussed the problem statement, objectives of the research, scope of the study and significant of the study.

In Chapter 2, literature review regarding pulse generation techniques, light-emitting diode properties, plastic optical fiber properties, principle of light in optical fiber, attenuation and dispersion in fiber were discussed.

In Chapter 3, research methodology is explained. Pulse generator circuit is designed and tested, examination of LED with various wavelength and the experimental procedures are discussed in this chapter.

In Chapter 4, data obtained from experiment are collected and discussed. A comparison between the electrical and optical pulse are presented. The justification of LED used in the experiment is also explained in this chapter.

Finally in Chapter 5, conclusions made from the discussion are presented and recommendations of further study are stated.

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