A Study on the Design and Construction of Electronic Apex Locator

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Abstract— **Electronic Apex Locator (EAL) has been developed to determine the true apical foramen location and working length of root canals in endodontic treatment process. It has been long stories of EAL devices since the principle idea was first reported. Since then, many modified ideas and varieties commercial products of electronic apex locators have been studied and introduced in to markets. However, the prices of commercial EAL are mostly expensive which limit the clinical usages in the under-developing or developing countries. From this economic reason, this project was purposed to study on the design and construction of electronic apex locator which has the low-cost price.**

The design and construction of this device based on the principle of clinical utilization, microcontroller and electronics knowledge. The In Vitro test, on functions of the prototype compared to the commercial device, was performed in 20 root canals which embedded in artificial oral condition. We found that the percentage error of our product compared to the commercial device was 1.74%. It showed that the prototype of EAL can correctly identify the apex location and calculate the working length for endodontic treatments with has cheaper price than that of the commercial products and meets the main purpose of project.

Keywords*— *Electronic Apex Locator, root canal measurement, root apex, working length

I. INTRODUCTION

Endodontics is a specialty field in dentistry which diagnoses and treats diseases of dental pulp tissues. When the pulp is infected or becomes abnormalities from various reasons, it must be treated to maintain the tooth in function. This involves the following steps of removing all pulp tissues, microorganisms and necrotic substances from the pulp chamber. Then the root canal will be cleaned, disinfection, enlarging and filled with inert materials such as Gutta-percha rubber.

The pulp removal and enlarging processes are performed by using a required size of Kerr file. During this procedure, a minimal irritation of surrounding tissue is concerned. During the endodontic treatment, the working length has to be performed because the clinician needs to know how deep of root canal should be instrumented. Normally, root canal should not be instrumented over the apical constriction, which is commonly positioned at 0.5 to 0.8 mm. [1-3].

The electronic apex locator (EAL) is a device that has a great deal of attention because it is more accurate than radiographic method in the obscured root canal. The principle idea was first reported in 1942 by Suzuki, who studied the flow of direct current through the teeth of dogs [4]. This idea, however, had limitation in clinical practice. After that, the modified idea had introduced on the basis of the electrical impedance changing across the dentin of canal wall when the instrument reaches the apical constriction in root canal [1, 5-7]. Nowadays, most of the commercial products in market are met in common of this principle.

In Thailand, all of EAL devices are imported and mostly expensive. Moreover, the imported devices may have the difficulties of claiming and maintenance when they have malfunction of usages. From this economic reason, this project was purposed to study on the design and construction of EAL prototype with the low-cost price which may benefit to under-developing or developing countries.

II. DESIGN AND CONSTRUCTION OF EAL

The EAL was designed based on the electronics and microcontroller. The highest impedance is at the apical constriction, where the impedance drastically changes. Therefore, the construction of this device is based on generating the alternating signal into the root canal and measuring the output impedance. This device consists of 3 main parts; part 1 is the signal conditioning, part 2 is the signal processing and the part 3 is the display as shown in Fig.1. The details of each part were briefly explained below.

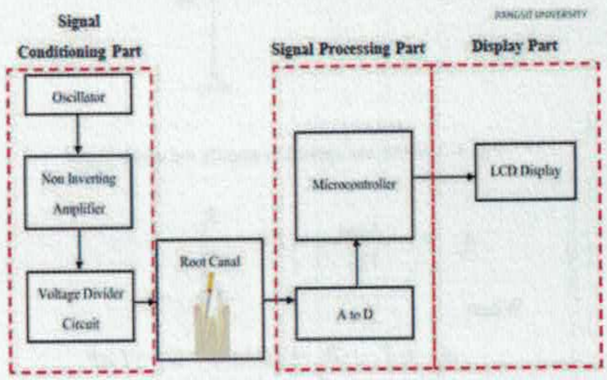

Fig. 1. Blog diagram of the design and construction of EAL device

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A. Signal Conditioning

In this design, the signal conditioner part consists of 3 minor sections; Oscillator circuits, non-inverting amplifier circuit and voltage divider circuit. IC L8038 was employed to generate the output signal which is sine wave, 50 kHz and oscillator circuit was shown in Fig. 2

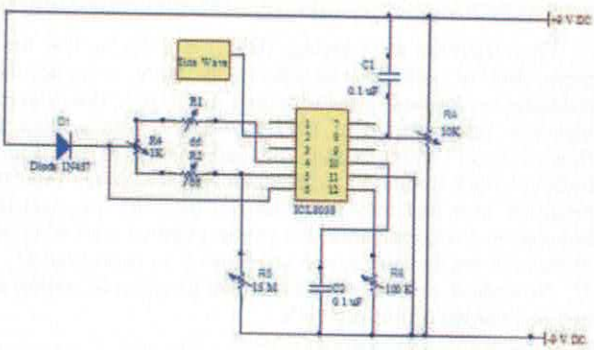

Fig. 2. Oscillator circuit

The non-inverting amplifier circuit was used in this design because the output signal from oscillator circuit was only 1.9 V, which below the expectancy of voltage at 4 V. Then, LM358 was applied to amplify the output signal as shown in fig 3. And R_8 was calculated in the equation below.

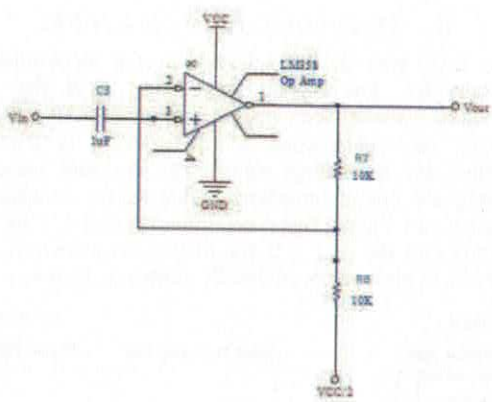

Fig. 3. LM358 was applied to amplify the output signal

$$A_v = \frac{V_{out}}{V_{in}} = 1 + \frac{R_7}{R_8}$$

When

$$A_v = 2 \,,\; R_7 = 10\,k\Omega \,,\; C_3 = 1\,\mu F$$

$$\therefore R_8 = 10\,k\Omega$$

Due to the impedance in root canal cannot be directly measured, the voltage divider circuit was applied for indirect evaluation. In this case, the resistor (R_9), which is 10 kΩ, was selected because the impedance inside the root canal is approximately 6.5 kΩ. The voltage divider circuit can be shown as Fig. 4

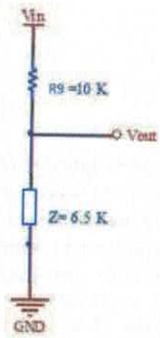

Fig. 4. Voltage divider circuit which designed in signal conditioning part

B. Signal Processing

In this section, it consists with 2 parts; the microcontroller and A to D part. Input signal was processed from A to D and then Arduino (AVR; UNO R3) was programmed to control input and output signals. The main signal processing algorithm was shown Fig 5, when "Drawscale" is the depth of root canal whereas "Batscale" demonstrates the battery. The results from oscillator circuit were set as the references for the calculation program in minor programs.

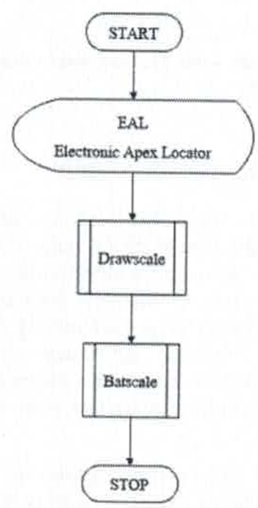

Fig. 5. The algorithm of main signal processing part

C. Display

Graphic LCD (tsm256128c, 256x128 pixels) was employed for the display part. Each scale which shown on screen was in mm. and the moving scales demonstrated the position of file tip in root canal as shown in Fig. 6

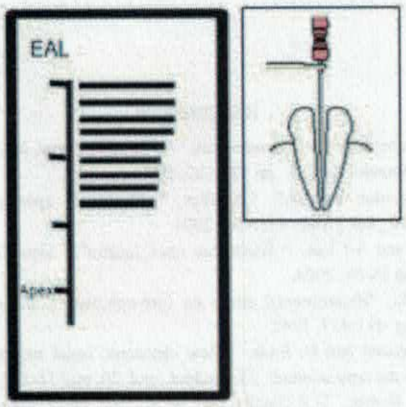

Fig. 6. The display of the EAL device demonstrates position of file tip in root canal

III. Functional and Application Tests

To test the function of oscillator circuit, the output signal was measured by oscilloscope. The application tests were evaluated by root canals measurement. 20 teeth were applied in the artificial mandible and measured their canal lengths by inserting the endodontic file in the root canal as shown in Fig.7. When the file reached at the position of clinical working length (0.5mm. above the root apex), the device was alarmed. Then the rubber stop was fixed at the tooth crown and the length of root canal was measured from the file tip to the rubber stop by standard ruler. The same procedure was applied for both prototype and commercial EAL (Root ZX mini, USA). The average of the data was calculated for the efficiency comparison between the prototype and the commercial device.

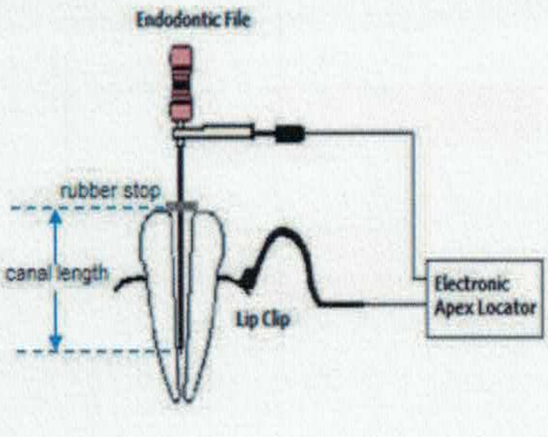

Fig. 7. The measurement of root canal length which demonstrated the apex location

IV. Results and Discussions

EAL prototype was shown in fig.8. The cable which connected to the device was clipped to the endodontic file. The screen shows the depth of the endodontic file in root canal. Each level strip demonstrates the movement of the file in 0.5 mm.

Fig. 8. Electronic Apex Locator; a. the whole device and b. the screen showed the depth of the file tip when it reached to the apex

When the endodontic file, which connected to the EAL prototype, was inserted in root canals, the alarm was starting to beep when the screen showed the tip was close to the apex. The beeping was higher frequent when the tip went closer. After the tip went over the apex, the continuous sound was detected. This function is similar to the commercial device that the alarm noise gives more effective in notification than that of the picture shown on screen.

The efficiency testing of the prototype device was performed by the method as previously mentioned and the results were shown in TABLE I

The average of measured length by the commercial and prototype device were 19.07 ± 1.13 mm. and 19.06 ± 1.13 mm. (n=20), respectively. The absolute percentage error was calculated and showed 1.74%, which represents the accuracy of our prototype device. In this study, however, was performed in the normal single root canal teeth. In realistic of endodontic treatment, somehow, the complex shape of root canals always reported. Therefore, complex shape and various canals teeth should be randomly tested for general usages in clinics. On the other hand, this prototype was programed and displayed the depth of every 0.5 mm.. Therefore, less distance should be performed for more accuracy.

TABLE I. THE LENGTH MEASUREMENT OF 20 ROOT CANALS BY THE PROTOTYPE COMPARED TO THE COMMERCIAL PRODUCTS

No. of root canals	The length of root canals (mm.)		Error (%)
	Commercial product	*Prototype device*	
1	19.19	19.38	0.99
2	20.93	20.37	2.68
3	19.89	20.77	4.42
4	20.05	19.74	1.55
5	20.31	20.26	0.25
6	19.42	19.11	1.60
7	19.07	18.57	2.62
8	19.11	19.95	4.40
9	19.44	19.69	1.29
10	16.21	16.55	2.10
11	19.00	18.73	1.42
12	18.40	18.69	1.58
13	18.37	18.02	1.91
14	19.54	19.09	2.30
15	19.51	19.62	0.56
16	19.23	18.93	1.56
17	16.33	16.20	0.80
18	18.99	19.25	1.37
19	19.49	19.29	1.03
20	18.98	19.05	0.37
	Absolute percentage error		**1.74**

V. CONCLUSION

In this research, we design and construct the low coast electronic apex locator which utilized as a diagnostic device in endodontic dentistry. Generally, the commercial price of electronic apex locator is variety from ten thousands to thirty thousand baths which limits the clinical usages in under-developing or developing countries. Moreover, all of the devices were imported from aboard that may create the difficulties of claiming and maintenance when they has malfunction at works. The device we developed, the price was reduced to 5000 bath and the accuracy is close to the commercial device. To confirm the efficiency of this device, however, the clinical trial should be performed. Afterward, we expect to improve the better quality and purpose to produce the commercialized product in under-developed or developing country for substitution of imported medical devices.

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