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Design and build a Ventalitor Tester with a Peak Inspiratory Pressure Waveform Display as Validation using the MPX5010GP

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ABSTRACT PIP is the highest level of pressure exerted into the lungs during inhalation. Peak inspiratory pressure (PIP) should be kept below 20 to 25 cm H2O whenever positive pressure ventilation is required, especially if a pneumothorax, or new bronchial or lung suture line, is present. The risk of barotrauma increases whenever peak pressure and plateau pressure rise to the same level. In the current situation where checking the ventilator is very important because there are emergency conditions for using and testing the ventilator, the ventilator tester is very often used. Checks are carried out to ensure the output of the ventilator is in accordance with the settings that have been made by the nurse on the ventilator, The purpose of this research is to get the accuracy and precision of the sensor to display the waveform and PIP value of the ventilator output. The contribution to this research is by evaluating the accuracy and precision of the sensor, it can ensure that the measurements obtained from the ventilator output are reliable and trustworthy. This research procedure is to use MPX5010GP to detect the pressure value on the ventilator and then display the value and waveform of the PIP. From this study, the results of the measurement of accuracy and precision from the MPX5010 sensor to detect PIP and display a waveform graph are said to be good. This is because the highest error value is ±6.27% at the 15 CmH20 setting. While the value of the largest standard deviation at the 15 CmH20 setting is 0.837 and the greatest uncertainty value at the 15 CmH20 setting is 0.033. Then, the largest correction value is found in the 25 CmH20 setting, which is 1.56. PIF monitoring is carried out to maximize service to patients and maximize ventilator care. The advantage of this research is the availability of a waveform display as a validation of the ventilator output as a support for calibration on the ventilator device.

INDEX TERMS PIP, MPX5010, Waveform

I. INTRODUCTION

Respiratory activity is an involuntary activity and supports respiratory function in humans[1][2]. Patients will need respiratory support for certain conditions, such as during surgical operations involving general anesthesia or because normal breathing cannot support the body's oxygen needs. In this condition the patient requires ventilator assistance[1][3], There are two types of medical ventilation: such as mechanical ventilators and non-invasive ventilators. For the ventilator is needed. in the case of the covid 19 pandemic[3][4], the virus causes damage to the lungs. And cause a decrease in SpO2[5][6] because the patient is difficult to breathe. During the COVID-19 pandemic, the SARS-CoV-2 virus primarily affects the respiratory system and can lead to lung damage, making it difficult for patients to breathe adequately. One of the critical indicators of respiratory distress is a decrease in SpO2 (oxygen saturation in the blood), which can be life-threatening if not addressed promptly. Ventilators are used in severe COVID-19 cases to help patients breathe by delivering oxygen to their lungs and maintaining adequate oxygen levels in the body. Ventilator is used to help the patient's breathing by pushing air into the lungs with the aim of increasing oxygen levels. Because the ventilator is a very important support for breathing needs, the ventilator must always be in good condition and condition. So there are several parameters that must be monitored specifically, such as the measurement of pressure and flow rate used in the ventilator system, the accuracy of which must be in accordance with the accuracy of the respirator[7][8]. Some parameters that must be considered include Tidal Volume (TV), Respiratory rate (RR), Ratio I: E, peak inspiratory flow (PIF), peak inspiratory pressure (PIP), and Positive end-expiratory pressure (PEEP) etc. PIP is the highest level of pressure exerted into the lungs during inhalation, Peak inspiratory flow (PIP) is the sum of the plateau pressure (Pplat) (the pressure used to keep air in the lungs) and the pressure used to overcome airway resistance (resistance P) to get air into the lungs (elastic backwards from the lungs). lungs and chest wall, friction, etc.). In other words: Peak inspiratory pressure (PIP) = Pplat + P resistance. As a result, Pplat can never be more than the peak inspiratory pressure (PIP), because there will always be an intrinsic resistance that the resistance P must overcome. In mechanical ventilation, this number reflects the positive pressure in centimeters of water pressure (cm H2O)[9][10]. The normal peak inspiratory pressure (PIP) is 25-30 cm H2O. Peak inspiratory pressure (PIP) should be kept below 20 to 25 cm H2O whenever positive pressure ventilation is required, especially if a pneumothorax, or new bronchial or lung suture line, is present. The risk of barotrauma increases whenever peak pressure and plateau pressure rise to the same level. Peak inspiratory pressure (PIP) increases in the presence of airway resistance. Things that can increase Peak inspiratory pressure (PIP) can be increased secretions, bronchospasm, biting ventilation tubes, and decreased lung compliance [8].

In the current situation where checking the ventilator is very important because there are emergency conditions for using and testing the ventilator, the ventilator tester is very often used. Checks are carried out to ensure the output of the ventilator is in accordance with the settings made by the nurse on the ventilator, this check is also known as with calibration [10][11], calibration is carried out using special tools that have been tested by the manufacturer to ensure the calibration tool has high accuracy and precision so that it can be used to determine the feasibility of a medical device to be used on patients[12], this calibration activity it is very important to do especially on tools that are often used so that the use of tools that should be a support for patients does not become a boomerang that worsens the patient's condition. And in the current condition where calibration tools are needed to support checking medical devices, especially calibration tools for ventilators[13][14], where in the last few years they are very often used, but the lack of calibration tools to check ventilators is an obstacle that is of concern, so several studies has been done to make an emergency ventilator calibration tool with the aim of making an emergency calibration tool to check the ventilator output. However, in some of these studies there has been no retrieval and analysis to display the waveform as a parameter to validate the ventilator output[12], with this background the researcher wants to analyze the waveform as a parameter to validate the ventilator output.

In 2014, Fred Duprez et al., conducted a study on the Accuracy of Medical Oxygen using Flowmeters this study aims to determine the accuracy of medical flow to determine the error rate generated from medical flow meters, and obtain conclusion if the number of use of flow meters will affect the accuracy of the output[15][16]. Then, in 2020, Natsumi T. Hamahata et al., conducted a flow curve study when patients received assistance from mechanical ventilation. In this study, the researchers concluded that flow waveform shapes need to be considered when giving mechanical ventilation, giving attention to flow waveforms can to improve the outcome of therapy, researchers hope that further research on flow waveforms when providing mechanical ventilation to patients. Then, in 2021, Tomy Abuzairi et al., conducted a study on the manufacture of an accessible ventilator tester so that ventilator checks can be carried out to maintain the accuracy of the device. Researchers expect further research on certain sensors so that the design of the Low Cost Ventilator Tester can be used accurately[17][18]. All previous studies analyzed the use of PIF on ventilator parameters. from previous studies, no one has used PIF as a validation of the accuracy of the ventilator device output.

PIP is the peak inspiratory Preassure. If the PIP is too low for the patient, the patient may experience dyspnea, patient-ventilator asynchronous, and increased work of breathing. High PIF increases PIF pressure and decreases mean airway pressure[19][20][21], this can lead to decreased oxygenation. the appearance of the PIP parameter has a waveform to determine the timing of respiration on mechanical ventilation, on this waveform the timing of the patient's breathing will be known according to the settings given by the nurse[22][9]. Based on the discussion from previous studies, the authors have not found previous researchers to design a ventilator with a pressure waveform display for validation. So, the authors will make "Design of a Ventilator Tester With PIP and PIF Waveform Displays as Validation (PIP)" which is a development of research that has been done before. This study aims to obtain the accuracy and precision of the sensor to display the ventilator output waveform so that the data obtained can be used to support the manufacture of calibration tools with sensors that have been studied. pressure sensor to measure and display PIP and PIF waveforms. This study aims to analyze the waveform generated from the flow sensor output as a flow sensor and the appearance of the waveform on the Ventilator Tester Design with PIP and PIF Waveform Displays as Validation (PIP)[23][24][25][26].

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II. METHODHOLOGY

Pre-experimental Study: Pre-experimental studies are research designs where the investigator does not have full control over the variables and lacks randomization. These studies are generally used when it is not possible to establish a control group or use random assignment.

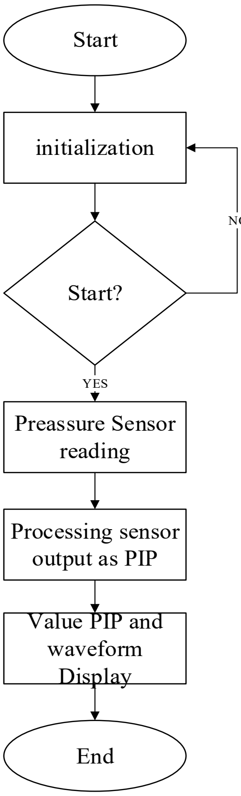

FIGURE 2. . The flowcart system in research design of ventilator tester using MPX5010GP sensor

After Only Design: The After Only Design is a specific type of pre-experimental design. In this design, the researcher only measures the dependent variable (in this case, data retrieval on the Ventilator Tester module) after the experimental treatment or intervention has been applied. There is no pre-test measurement, and no control group is used for comparison. Single Group: In this research, only one group of subjects (presumably patients or participants) is involved. The intervention, which is the use of the Ventilator Tester module, is applied to this single group. No Pre-test Measurement: As mentioned earlier, there is no measurement of the dependent variable (data retrieval on the Ventilator Tester module) before the intervention is applied. The researchers directly observe and measure the outcomes after the use of the Ventilator Tester on Ventilator 1 at Lumajang Hospital. Comparison Group: While the research design does not include a comparison group, it is possible that there is a comparison being made with previous or historical data, or data from other ventilators, to understand the impact of using the Ventilator Tester module on the accuracy or performance of Ventilator 1.

The independent variable in this study is the PIP module used. the dependent variable is the flow sensor used, namely MPX5010GP[27][28]. And the controlled variable is the microcontroller board used, namely Arduino. This study uses the MPX5010GP pressure sensor as a flow input, then the data flow will be processed using an Arduino microcontroller, and the flow results will be displayed on the LCD Display[29]. The block diagram in **FIGURE 1** has 3 main parts, namely process input and output, the input consists of the MPX5010GP pressure sensor which is the source of input data on the microcontroller, the process section consists of a microcontroller which functions to receive data from the sensor, the microcontroller will process the output from the sensor into PIP, so that the sensor value can be displayed as PIP on the display, in the output process there is a display that serves to display data that has been processed by the microcontroller.

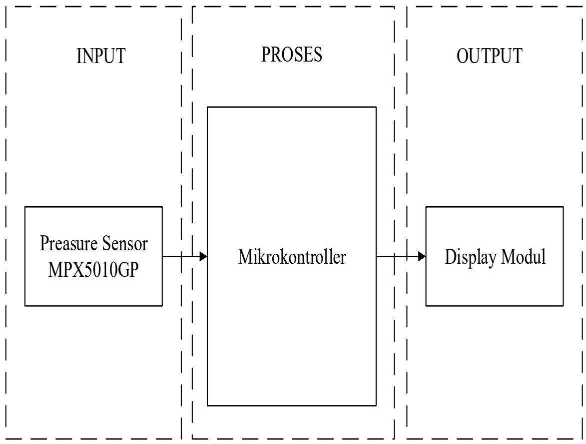

FIGURE 1. The diagram block of the system in research design of ventilator tester using MPX5010GP sensor

Based on FIGURE 1 it is explained that there are 3 parts namely. Input: The input to the system is data from the MPX5010GP pressure sensor. This sensor likely measures pressure and provides corresponding data to the microcontroller. Process: The process section consists of a microcontroller, which receives data from the pressure sensor. The microcontroller then processes this data, likely converting it into a meaningful value, such as Peak Inspiratory Pressure (PIP), which is commonly used in medical settings to measure the maximum pressure applied to the lungs during inhalation. Output: The output process involves a display that shows the processed data (in this case, the PIP value). The display allows users or medical personnel to visualize the information and monitor the pressure.

This paragraph can explain **FIGURE 2** turn on the ON button after the module turns on then the process will initialize after the initialization process is complete it will continue in the next section, namely the selection of starting conditions, when the condition starts to value false then the process will return to initialization and if the condition starts to be true then the process will continue on sensor readings

Pressure and continues on processing the pressure sensor value to get PIP after data processing is complete then the process will continue on the appearance of data that has been processed by the microcontroller.

A. DATA ANALYSIS

The PIP (Peak Inspiratory Pressure) measurement is carried out by setting 15 CMH20, 20 CMH20, and 25 CMH20 in Pressure Mode 5 times. The average value of the measurement is obtained by using the mean or the average by applying equation (1). The average is the number obtained by dividing the number of values by the number of data in the set:

$$\overline{x} = \frac{x1+x2 \ldots +xn}{n} \tag{1}$$

where x denotes the mean (mean) for the n-measurements, x1 denotes the first measurement, x2 denotes the second measurement, and xn denotes n measurements. Standard deviation is a value that indicates the degree (degree) of variation in a data set or a measure of the standard deviation of the mean. The standard deviation (SD) formula can be shown in equation (2):

$$\mathrm{SD} = \sqrt{\frac{\Sigma(xi-\overline{x})^2}{(n-1)}} \tag{2}$$

where xi indicates the number of desired values, x indicates the average of the measurement results, n indicates the number of measurements. Uncertainty (UA) is a doubt that appears in each measurement result. The uncertainty formula is shown in equation (3):

$$UA = \frac{SD}{\sqrt{n}} \tag{3}$$

where UA indicates the uncertainty value of the total measurement, SD indicates the resulting standard deviation, and n indicates the number of measurements. %error indicates a system error. The lower Error value is the average difference of each data. Errors can indicate deviations between the standard and the design or model. The error formula is shown in equation (4).

$$\%\mathrm{ERROR} = \frac{(x_n - \mathrm{x})}{x_n} \times 100\% \tag{4}$$

where xn is the measured value of the machine calibrator. X is the measured value of the design.

III. RESULT

In this study, the module has been tested using a calibrator, namely the Ventilator. Designs featured in **FIGURE 3.**

FIGURE 3 . Ventilator Tester Display Ventilation Tester display with two PIP and PIF waveforms for validation

The digital part consists of the arduino microcontroller[30] which is the main board of the device and the MPX5010GP pressure sensor[20][31] like in the **FIGURE 4**.

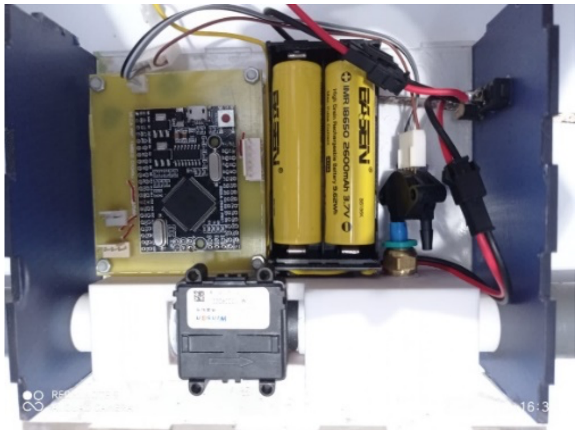

FIGURE 4 . overall circuit ventilator tester using sensor MPX5010GP

Data retrieval on the Ventilator Tester module was carried out using Ventilator 1 which was carried out at Lumajang Hospital. Error indicates the difference between the actual value coming out of the Ventilator and the measured value from the Ventilator Tester module, with the CMH20 pressure for PIP measurements. It can be seen in the table below that the smallest error value from the measurement of the Ventilator Tester module with Pressure mode on Ventilator 1 is in the PIF 15 CMH20 setting, while the smallest error value for Ventilator 2 is in the PIP 25 CMH20 setting.

TABLE 1
Comparison Value of Module Measurement Error on Ventilator 1 and Ventilator 2

Setting Pressure	Ventilator 1(%)	Ventilator 2(%)
15 CMH20	±0.27%	±6.27%
20 CMH20	±3.92%	±4.63%
25 CMH20	±6.20%	±1.59%
Rata-rata $(\overline{X})$	±3.46%	±3.11%

From the measurement results in TABLE 1, the overall error value obtained from the Ventilator Tester module can be said to be good with the highest error of ±6.20% on Ventilator 1, namely at 25 CMH20 settings, while in Ventilator 2, ± 6.27% at 15 CMH20 settings. And for the smallest error value in the measurement of Ventilator 1, which is ±0.27% at 15 CMH20 settings, while in Ventilator 2 it is ± 1.59% at 25 CMH20 settings.

From the overall error value and the average error value on the two ventilators used, it can be seen if it does not exceed the tolerance range so that the Ventilator Tester module is fairly accurate for detecting the PIP value on the Ventilator. TABLE 1 is the error value obtained by the actual value compared to the value that beats the Ventilator Tester. TABLE 2 is the standard deviation value obtained from measurements with the ventilator tester module. It is said to be good, because the results of the standard deviation value do not exceed the average value of the ventilator tester module measurement. TABLE 3 is the uncertainty value (UA) which is used to see how much deviation (accuracy) is from the ventilator tester module in reading the flow value. TABLE 4 is the correction value in this study proving that there is still an error or insecurity between setting the value and the average.

TABLE 2
Comparison Value of Standard Deviation Measurement Module on Ventilator 1 and Ventilator 2

Setting Pressure	Ventilator 1(%)	Ventilator 2(%)
15 CMH20	0.837	0.548
20 CMH20	0.548	0.548
25 CMH20	0.548	0.837
Rata-rata ($\overline{X}$)	0.644	0.644

Based on TABLE 2, it can be said that the standard deviation value of the Ventilator Tester module measurement results is good, this is because the standard deviation value does not exceed the average value of the Ventilator Tester module measurement results. Thus, the average value of the Ventilator Tester module measurements can be used as a data representation of the entire measurement. The standard deviation value indicates that there is an oscillation or standard deviation in the measurement. From all measurements, the largest standard deviation value on Ventilator 1 is at setting 15 CMH20, which is 0.837, while on Ventilator 2 is at setting 25 CMH20, which is 0.837. The standard deviation value is said to be quite good, which means that the data distribution or deviation is not too large, so it can still be said that the Ventilator Tester module measurement results are quite precise.

TABLE 3
Comparative Value of Uncertainty (UA) of Module Measurements on Ventilator 1 and Ventilator 2

Setting Pressure	Ventilator 1	Ventilator 2
15 CMH20	0.033	0.022
20 CMH20	0.022	0.022
25 CMH20	0.022	0.033
Rata-rata ($\overline{X}$)	0.026	0.026

Based on **TABLE 3**, we can see the uncertainty value of the measurement results of the Ventilator tester module which is used to see how close the measured value is to the actual value. This uncertainty is also used to see how much accuracy the Ventilator Tester module is, it can be stated that the smaller the uncertainty, the higher the accuracy. In this study, the greatest uncertainty value in the measurement of Ventilator 1 was found in the 15 CMH20 setting, which was 0.033, while the Ventilator 2 was in the 25 CMH20 setting, which was 0.033. The results of this uncertainty can still be said to be good, so the accuracy of the Ventilator Tester module is also said to be good. Measurement results or readings that have random results are said to have no good stability. If it is associated with data reading, it does not change during the measurement, the graphic measurement does not change up or down and the values that appear do not change continuously.

Based on this, we can see the uncertainty value from the measurement results of the Ventilator tester module which is used to see how close the measured value is to the actual value. This uncertainty is also used to see how much accuracy the Ventilator Tester module is, it can be stated that the smaller the uncertainty, the higher the accuracy. In this study, the greatest uncertainty value in the measurement of Ventilator 1 is found at the 30 LPM setting, which is 0.061, while in the Ventilator 2 there is a 30 LPM setting, which is 0.054. The results of this uncertainty can still be said to be good, so the accuracy of the Ventilator Tester module is also said to be good. Measurement results or readings that have random results are said to have no good stability. If it is associated with data reading, it does not change during the measurement, the graphic measurement does not change up or down and the values that appear do not change continuously.

TABLE 4
Comparative Value of Module Measurement Correction on Ventilator 1 and Ventilator 2

Setting Pressure	Ventilator 1	Ventilator 2
15 CMH20	0.04	0.92
20 CMH20	0.8	1
25 CMH20	1.56	0.4
Rata-rata ($\overline{X}$)	0.8	0.773

The correction value is an additional value given to compensate for the addition of errors systematically. The correction value in this study proves that there are still errors or inequalities between the setting value and the average. From the table above, it can be seen that the correction value indicates an error in the system from the module. If the correction value is smaller, the better the performance of the module will be. Based on TABLE 4, it can be seen that the largest correction value in the measurement results of the Ventilator Tester module on Ventilator 1 at 25 CMH20 is 1.56. Meanwhile, in the Ventilator 2 measurement, the largest correction value is found in the 20 CMH20 setting, namely 1. When viewed from the largest correction value and the average correction value from the module, it can be said that the error caused by the module is relatively small. Therefore, the system module performance is considered good. Measuring instrument can be said to be good if it has high accuracy and precision. Not all measuring instruments that have good precision also have good accuracy. In addition, the measurement also requires good sensitivity or good response to small changes in the input signal.

IV. DISCUSSION

After testing the Ventilator Tester module, data collection and analysis of the results are carried out to determine the performance of the module manufacture. This research also aims to obtain the accuracy and precision of the sensor to display the waveform of the ventilator output. Then the results obtained on the ventilator are as follows:

In reading the PIF value on the Ventilator Tester module in volume mode, the error value obtained from the Ventilator Tester module can be said to be good with the highest error of ±6.20% on Ventilator 1, namely at setting 25 CMH20, while on Ventilator 2, ±6.27% at setting 15 CMH20. And for the smallest error value in the measurement of Ventilator 1, which is ±0.27% at 15 CMH20 settings, while in Ventilator 2 it is ± 1.59% at 25 CMH20 settings.

The largest standard deviation value on Ventilator 1 is at setting 15 CMH20, which is 0.837, while on Ventilator 2 it is at setting 25 CMH20, which is 0.837. The standard deviation value is said to be quite good, which means that the data distribution or deviation is not too large, so it can still be said that the Ventilator Tester module measurement results are quite precise. Meanwhile, the greatest uncertainty value in the measurement of Ventilator 1 is in the 15 CMH20 setting, which is 0.033, while in Ventilator 2 there is a 25 CMH20 setting, which is 0.033. The results of this uncertainty can still be said to be good, so the accuracy of the Ventilator Tester module is also said to be good.

For the largest correction value in the measurement results of the Ventilator Tester module on Ventilator 1 at 25 CMH20 settings, namely 1.56. Meanwhile, in the Ventilator 2 measurement, the largest correction value is found in the 20 CMH20 setting, namely 1. When viewed from the largest correction value and the average correction value from the module, it can be said that the error caused by the module is relatively small. Therefore, the system module performance is considered good.

All previous studies analyzed the use of PIF on ventilator parameters. from previous studies, no one has used PIF as a validation of the accuracy of the ventilator device output. then there is a weakness from this research, the value of the tool's output cannot be saved. then the battery capacity tends to be small so it takes several charging times. then a display that is not equipped with graphics. Tomy Abuzairi et al., conducted a study on the manufacture of an accessible ventilator tester so that ventilator checks can be carried out to maintain the accuracy of the device. Researchers expect further research on certain sensors so that the design of the Low Cost Ventilator Tester can be used accurately[17][18]. The weakness of the research lies in the fact that previous studies did not analyze the use of Peak Inspiratory Flow (PIF) as a validation parameter for the accuracy of ventilator devices. This suggests that there may be a gap in the existing literature in terms of using PIF as a performance measure for ventilators.

Due to various factors, the module made by the author is still far from perfect, both in terms of planning, manufacturing, and how the module works. So that there are several shortcomings that have been analyzed from the tool that the author made. The first is that the display on the hardware can use other applications or interfaces so that it can be clearer and the value of the results from the module can be stored. Then it is necessary to discuss the MPX5010 sensor and its effect using 1 input or 2 inputs to identify the suitability of the conversion value.

IV. CONCLUSION

The purpose of this research is to test and prove the accuracy and precision of the sensor to display the waveform of the ventilator output. The measurement accuracy and precision of the MPX5010 sensor for detecting PIP and generating waveform graphs is said to be good. This is because the highest error value is ±6.27% at setting 15 CMH20. Meanwhile, the largest standard deviation value is at setting 15 CMH20, which is 0.837 and the greatest uncertainty value is at setting 15 CMH20, which is 0.033. Then, the biggest correction value is in the 25 CMH20 setting, which is 1.56. Furthermore, the MPX5010GP sensor reading program and conversion to PIP values are designed using the Arduino IDE Application, as well as delivery to the TFT LCD to display graphs and read PIP values. Based on the testing of the ventilator tester module that has been carried out by comparing the measurement results with a calibrated ventilator device and the results obtained are said to be good and can carry out their work functions. The future development of research that can be done in the future will be found adding an SD Card for storing values and waveforms. then the addition of a battery so that the tool can be used longer, and also the addition of a web display to display graphic so that the results obtained are more accurate.

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