

## DEVELOPMENT OF MULTI DUTY CYCLE SEQUENTIAL GATED PULSE FREQUENCY GENERATOR FOR RESONANT ELECTROLYSIS

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### ABSTRACT

For the sustainable future, the potential energy source, transforming method, energy cost per efficiency are inter-related and the development of the future energy plant is a long term research which involve validation of theory, prototyping and etc. No doubt that hydrogen fuel is one of the potential energy carry but the harvesting of hydrogen from water is constraint by the Faraday's law of electrolysis where the efficiency is restricted. Researched found that harvesting hydrogen fuel based on frequency method could achieve higher efficiency than the conventional method. Therefore, a specific frequency generator is proposed to study the effect of various frequency design and voltage input to the hydrogen fracturing process. The designed model is equipped with the pulse, gated pulse and sequential gated pulse features to enhance and optimize the fracturing rate. The detail design and development of the frequency generator is also discussed in the following section.

**Keywords:** Hydrogen fracturing, DC pulsed, diffusion layer, frequency, Timer circuit

### INTRODUCTION

Water electrolysis is considered as one of the promising method in hydrogen generation but the production cost is largely dominated by the DC power supply. In the Faraday of electrolysis, hydrogen is generated as a result of electron transfer on the electrodes surface. The hydrogen is generated when the applied power exceeds the theoretical water decomposition voltage of 1.23V at room temperature [Shaaban, A.H., 1994]. In practical, small overvoltage is use to overcome the practical constraints as the process becomes irreversible, inefficient due to heat loss, electrolyte concentration, electrode material and other factors.

The constant DC power supply to the electrolysis cell creates double layer effect surrounding the electrodes (Shaaban, 1994). As the applied voltage is increased, the applied current and hydrogen generation are increase proportionally. Since the electrode has limited surface area, current increment causes excessive electrons dissipation as heat loss. Meanwhile, higher voltage potential also induces stronger double layer effect which significantly decreases the generation efficiency in heat energy. Research found that constant DC electrolysis is based on electrical double layer formation and is a

diffusion limited process (Shaaban, 1994). It is therefore difficult to increase the input power for a constant volume electrochemical cell without reduction in electrolysis efficiency. Consequently, it is desirable to find a new method of generating hydrogen from water at lower cost.

### **TECHNOLOGY BREAKTHROUGH IN WATER ELECTROLYSIS**

Based on the original working principles, alternative water electrolysis is proposed to maximise the generation rate and minimise the production cost. Some of the technologies including high temperature, high pressure, plasma, DC pulsed and AC electrolysis. The idea of DC pulsed electrolysis was initially reported by Bockris in 1952 [Shaaban, A. H, 1994]. After that, Many researches had been carried out and it shows significant contribution on the relationship between frequency and water electrolysis. The pulsed electrolysis using the electron movement and exchange between molecules/atoms themselves, induced by the high voltage field accumulated between the electrodes, and bringing the water molecules to split rather than electron exchange between molecule and electrodes. The technology has been recently scientifically confirmed in 2006, by Naohiro Shimizu. In his research, DC pulsed electrolysis is based on the strong electric field application and the electron transfer limited process. Pulsed voltage supply prohibits the formation of double layer or diffusion layer. Higher voltage potential is applicable and may open the possibility of high capacity water electrolysis.

Resonant electrolysis or water fracturing process is based on electrical resonant principle which provides distributed capacitance and inductance to the resonant cavity. As it increase the voltage potential between electrodes, it also inhibiting the current flow. The challenge of the integrated hydrogen energy cell is to trigger the sudden catastrophic dielectric breakdown within the resonant cavity with inhibited current leakage while produce instantaneous and adequate fuel for direct combustion. The overall methodology could be divided into several steps and involves a series of important parameters.

### **VARIABLE DC PULSE GENERATION**

In the automobile application, battery is the electric source and it provides constant DC power supply to the car system. In order to adapt the instantaneous hydrogen energy for full scale application, a mechanism is required to transform the constant DC power into DC pulse supply. The basic idea to generate DC pulse voltage potential is illustrated in Figure 1.

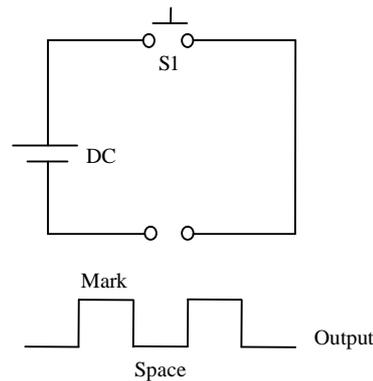


Figure 1: Basic Concept of generate DC pulsed voltage potential

As the switch button S1 is pull and push repetitively, the output will be spitted into Mark (high potential) and Space (low potential) form. For the consistent control of Mark time and Space time, a control mechanism is required to replace S1. In the Stanley Meyer original patent, he used a semiconductor called thyristor or SCRs (silicon controlled rectifier) to switch the DC signal into pulsed signal [Stanley M., 1992]. One major problem associated with SCRs is that they are not fully controllable switches. In high frequency applications, thyristor are poor candidates due to large switching times arising from bipolar conductor. As the invention of MOSFET (metal oxide semiconductor FET), SCRs have almost been replaced. MOSFETs have much faster switching capability because of their unipolar conduction. In recent development, Naohiro Shimizu makes some improvement by using static induction thyristor (SIThy) with FET (field effect transistor) to introduce ultra-short pulse for water electrolysis (Naohiro, 2006).

A DC pulsed electrolysis experiment had been carried out by Aly H. Shaaban in 1995 and result found that the hydrogen production rate is closed related with voltage amplitude, duty cycle and frequency [Shaaban, A. H, 1994]. Water with different mass and contaminant level will also influent the frequency range and consequently production efficiency. Therefore, a variable DC pulsed generator was designed and developed using Timer IC rather than thyristor since it allow fine tuning on various aspects. By referred to the instantaneous water fracturing process states and limitation, the capability of the variable DC pulsed generator is designed for the following purposes:

- a. Adjustable constant voltage
- b. DC pulsed
- c. Gated Pulsed
- d. Sequential Gated Pulsed

### ADJUSTABLE CONSTANT VOLTAGE

In the Faraday of electrolysis, minimum voltage potential will initiate the process while the increment of voltage potential will increase production rate of hydrogen production. The performance data of the conventional electrolysis is the original reference for the development of water fracturing methodology. Considering the application of the energy cell in automobile, 12V DC power supply is regulated using LM338T 5 Amp Adjustable regulator IC. The detail of the circuit diagram is shows in Figure 2.

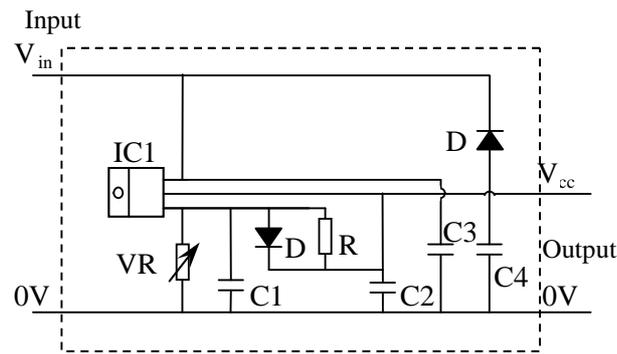


Figure 2: Circuit diagram for constant voltage regulation

In the circuit diagram, VR (Variable resistor) play the main role to tune the output voltage to the desired value while the diode D is serves as the protecting component from any short circuiting. Although the DC power supply from battery can be direct switched into DC pulse shape, the function of circuit diagram in Figure 2 is used to dampen the voltage variation from battery or alternator meanwhile control the hydrogen production rate during the fracturing process.

### DC PULSED

Instead of using thyristor, SCRs or MOSFET, Timer IC would produce a much precise DC pulsed voltage potential. By different combination of resistance and capacitance value, the Mark time and Space time for the input voltage is controlled. Combined with the LM338T, voltage amplitude is adjusted accordingly. Some of the important characteristic of the Timer IC is listed in Table 1.

Table 1: Specification of Timer IC [555\_timer\_IC, 2010]

Supply voltage ( $V_{CC}$ )	4.5 to 15 V
Supply current ( $V_{CC} = +5$ V)	3 to 6 mA
Supply current ( $V_{CC} = +15$ V)	10 to 15 mA
Output current (maximum)	200 mA
Power dissipation	600 mW
Operating temperature	0 to 70 °C

Basically, the Timer IC could be grouped into three operating modes which are monostable, astable and bistable or Schmitt trigger. In astable mode, the Timer IC outputs a continuous stream of rectangular pulses having a specific frequency which operate as an oscillator. The proposed astable circuit diagram for the DC pulsed voltage supply is indicated in Figure 3.

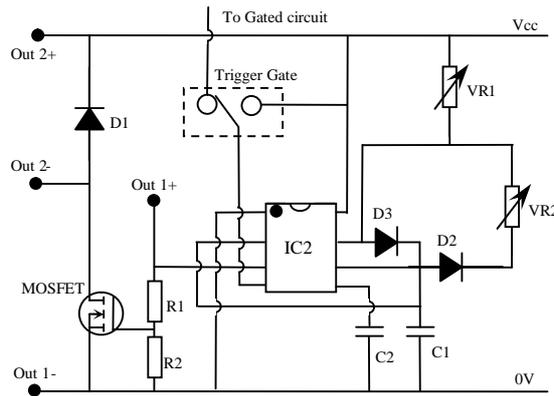


Figure 3: DC Pulsed voltage supply circuit

Refer to the circuit diagram, VR1 and VR2 is variable resistor used to control the Mark time,  $T_m$  and Space time,  $T_s$  of a pulse which will determine the duty cycle, % of the voltage pulse. The Time period of the pulse is the time for one complete cycle, but it is usually better to consider as frequency  $f$  which is the number of cycles per second. In this circuit, the output voltage frequency range,  $f$  is set by capacitor C1. Trigger gate is a selection switch between Gated pulse and Pulsed voltage output depends on the output requirement. The output from the IC2 could be used directly as Out 1 or rectify by MOSFET as Out 2. The control parameters and related calculation is listed as follow:

$$\text{Mark time, } T_m = \ln(2)VR_1C_1 \quad (1)$$

$$\text{Space time, } T_s = \ln(2)VR_2C_1 \quad (2)$$

$$\text{Duty cycle} = \frac{T_m}{T_m + T_s} = \frac{VR_1}{VR_1 + VR_2} \% \quad (3)$$

$$\text{Pulse time, } T_P = T_m + T_s$$

$$T_P = \ln(2)(VR_1 + VR_2)C_1 \quad (4)$$

$$\text{Pulsed frequency, } f_P = \frac{1}{T_P} = \frac{1}{\ln(2)(VR_1 + VR_2)C_1} \quad (5)$$

The main different between Out 1 and Out 2 would be the current supply at Out 2 capable to withstand higher current limit than Out 1. Although Timer IC shows significant advantage compare to SCRs, the main constraint of the Timer IC would be the current limit. In order to use Out 1 directly in hydrogen fracturing process without broken the IC2, a precision current limiter is installed between power supply and Vcc as illustrated in Figure 4.

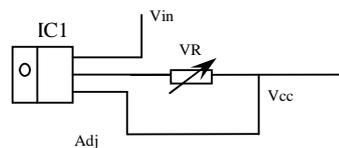


Figure 4: Precision current limiter for circuit IC2.

The output current to the circuit in Figure 4 is calculated as follow:

$$I_{out} = \frac{V_{ref}}{VR} \tag{6}$$

### GATED PULSED

In the next level, gated pulsed voltage supply will further limit the current limit and enhance the performance of the hydrogen production rate. The concept of gated pulsed voltage supply generation could be illustrated in Figure 5.

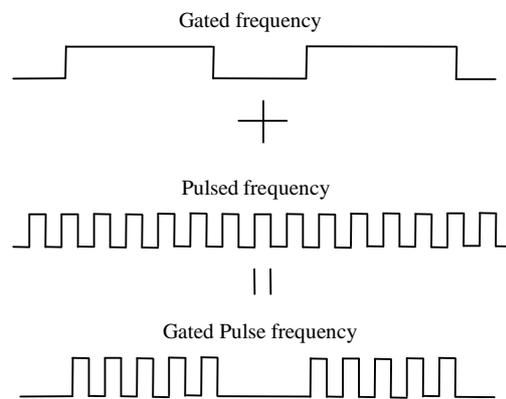


Figure 5: Methodology to generate Gated Pulse frequency

The output frequency shape is achieved by using gated circuit to control the generation of pulsed frequency. In order to do that, the gated Mark time and Space time must be several times the pulsed frequency. As the gated circuit output turn to  $V_{cc}$ , pulsed circuit is activated to generate higher frequency. As the gated circuit output turn to  $0V$ , pulsed circuit is deactivated and will not generate any output frequency. The proposed gated circuit diagram is illustrated in Figure 6.

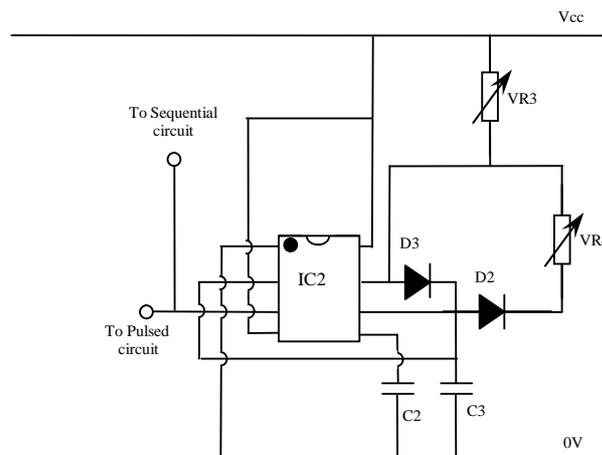


Figure 6: Proposed Gated circuit diagram

The control parameters and related calculation is listed as follow:

$$\text{Mark time, } T_m = \ln(2)VR_3C_3 \quad (7)$$

$$\text{Space time, } T_s = \ln(2)VR_4C_3 \quad (8)$$

$$\text{Duty cycle} = \frac{T_m}{T_m + T_s} = \frac{VR_3}{VR_3 + VR_4} \% \quad (9)$$

$$\text{Gate time, } T_G = T_m + T_s$$

$$T_G = \ln(2) (VR_3 + VR_4)C_3 \quad (10)$$

$$\text{Gated frequency, } f_G = n f_P$$

$$f_G = \frac{1}{nT_P} = \frac{1}{n \ln(2)(VR_3 + VR_4)C_3} \quad (11)$$

$$f_G = \frac{1}{\ln(2)(VR_3 + VR_4)C_3} \quad (12)$$

Similarly, a precision current limiter is proposed between power input and Vcc to protect the IC2 from overload or damage (Refer to Figure 4).

### SEQUENTIAL GATED PULSES

When the gated pulse voltage potential is integrated with voltage intensifier circuit, resonant electrolysis could achieve its maximum efficiency. Pulsed frequency is important to eliminate the double layer or diffusion layer around electrode. In the VIC circuit, the charge – discharge between inductor charging choke and water capacitor introduce unipolar voltage potential. Meanwhile, the gated frequency will temporary switch off the voltage supply to the cell so that unipolar voltage potential could turn into step charging effect pattern and allow catastrophic effect between water molecules. In contrast, the gated pulse DC voltage input supply less energy to the hydrogen cell compare with Faraday of electrolysis. Instead of maximise the water fracturing efficiency, a special design of Sequential fracturing process is proposed. In order to do that, the input power to the cell could be optimise by generating sequential gated pulsed frequency which illustrated in Figure 7.

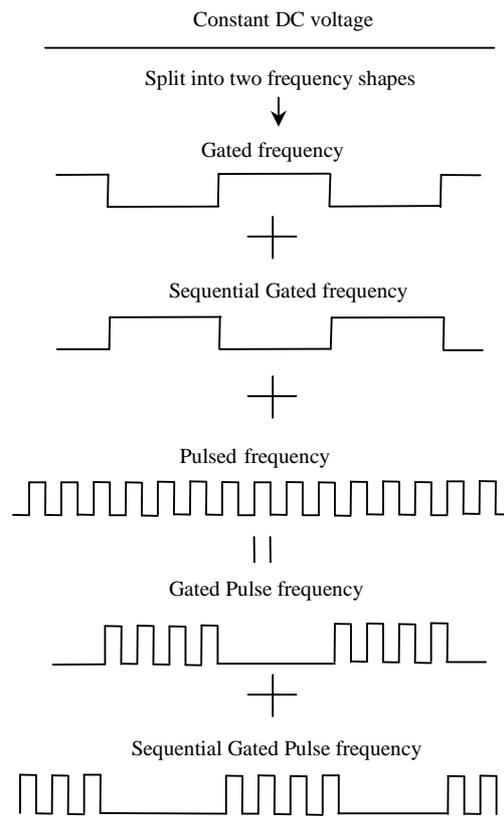


Figure 7: Methodology to maximise input voltage to electrolysis cell

Using two units of Gated IC2 circuit board, constant DC voltage input is split into two gated frequency shape with 180° offset (second output is called sequential gated frequency). By integrate with pulsed IC2 circuit, gated pulse and sequential gated pulse frequency is generated. In order to do that, two gated circuit diagram and two pulsed circuit diagram is combined as shows in schematic diagram in Figure 8.

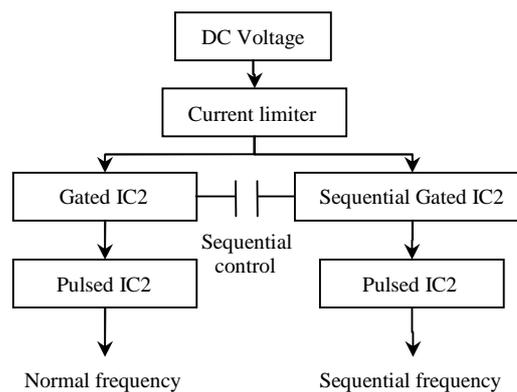


Figure 8: Algorithm for the generation of sequential output frequency

The combined frequency circuit consists of four main Timer ICs. For the testing and tuning purposes, low, medium and high frequency range is allocated by three capacitance values. A selection switch is designed to tune the desired frequency range. Generally, gated IC is equipped with higher capacitance value than the pulsed IC since the pulse frequency must be higher than the gated frequency. With two variable resistors

incorporate with diodes, Mark time, Space time and duty cycle is adjustable from 10% to 90% accordingly. The combination allows variable control in frequency range, Mark time, Space time, duty cycle and voltage amplitude. All four Timer IC circuit is assemble parallel to the input power from the voltage regulation and current limiter circuit so that each IC receive equal voltage supply. First gated IC is direct drive by input voltage while its output also used to trigger the sequential gated IC and pulsed ICs based on requirement.

In the proposed control algorithm, gated IC2 is the main circuit. The output of this circuit is used to control the activation of pulsed IC2 and at the same time, it connects parallel to the sequential gated IC2's trigger pin via a sequential control capacitor. As the gated IC2 generate positive output, the capacitor is charged. As the gated IC2 switch to deactivation mode, capacitor discharge and trigger the sequential gated IC2 to generate a positive pulse. In this mechanism, constant DC voltage supply could be split into two gated frequency which is  $180^\circ$  offset.

### **DEVELOPMENT OF WORKING PROTOTYPE MODEL**

In the prototyping stage, various circuit board is use to separate the power regulation circuit, current limiter circuit, gated IC circuit, pulsed IC circuit and frequency selection circuit. Two gated IC circuit is soldered in one board while two pulsed IC circuit on another board as shown in Figure 9.

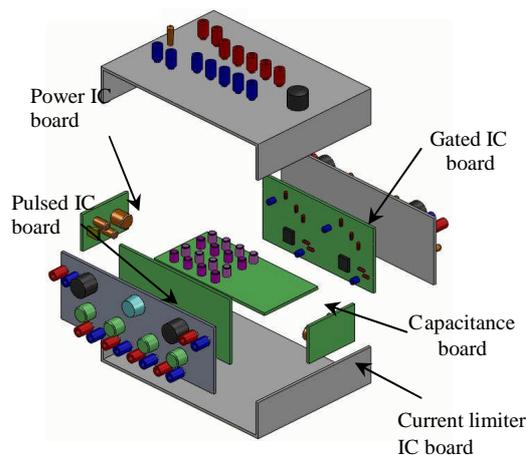
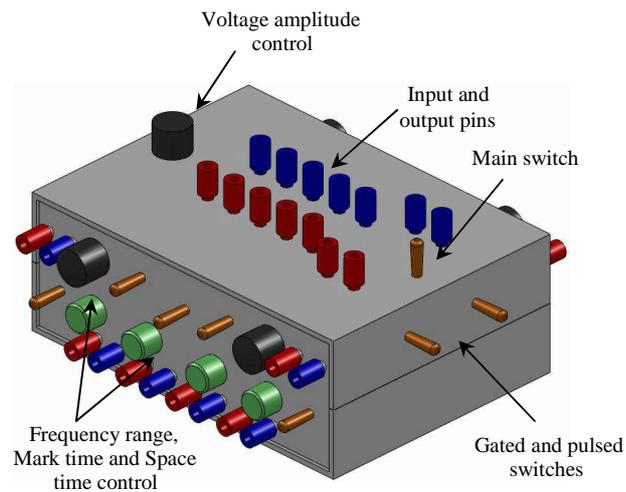


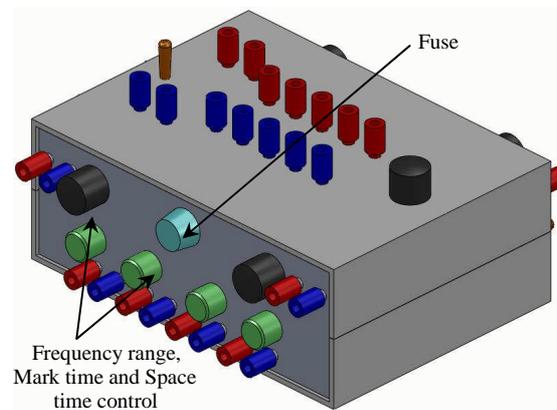
Figure 9: Exploded view of the frequency generator Prototype model

On the external view of the prototype model, rotary switches, plugging pins, knobs, toggle switches are integrated with the circuit boards to provide flexible control and various frequency pattern output for testing and tuning application. In Figure 10a, Top panel of the prototype model consist of main power switch between frequency model and power source, voltage amplitude control to modify the hydrogen production rate, input pins, output pins, voltage and current monitoring pins.

On the gated panel, it consist of Gated IC frequency range selection switches, Mark time, Space time tuning knobs, monitoring pins, gated frequency and gated pulse frequency switches and sequential gated switches. In Figure 10b, pulse panel consist of pulse IC frequency range selection switches, Mark time, Space time tuning knobs and current limiter control knob.



a. Gated frequency control panel



b. Pulsed frequency control panel

Figure 10: Assembly view of the gated pulse frequency generator control, input and output panels

With the design of the top, gated and pulse panel, the proposed prototype model able to provide the following operating modes:

- a. Variable voltage amplitude constant DC voltage output without pulse transformation.
- b. Variable voltage amplitude, double low frequency DC pulse voltage output with low, medium and high ranges in 10% to 90% duty cycle.
- c. Variable voltage amplitude, double high frequency DC pulse voltage output with low, medium and high ranges in 10% to 90% duty cycle.
- d. Variable voltage amplitude, double DC gated pulse frequency voltage output with low medium and high ranges in 10% to 90% duty cycle.
- e. Variable voltage amplitude, DC gated pulse frequency and DC sequential gated pulse frequency voltage output with low, medium and high ranges in 10% to 90% duty cycle.

- f. Variable voltage amplitude, MOSFET control double DC gated frequency voltage output with low, medium and high ranges in 10% to 90% duty cycle.
- g. Variable voltage amplitude, MOSFET control double DC gated pulse frequency voltage output with low, medium and high ranges in 10% to 90% duty cycle.
- h. Variable voltage amplitude, MOSFET control DC gated pulse and DC sequential gated pulse frequency voltage output with low, medium and high ranges in 10% to 90% duty cycle.

The capability of the prototype model allow the detail performance analysis and comparison between Faraday of electrolysis and water fracturing process in low frequency pulse, high frequency pulse, gated pulse, sequential gated pulse and switch-over pulse conditions.

## **CONCLUSION**

A low cost adjustable multi output frequency is proposed and serves as an important equipment to further validate the theory in water fracturing process compared to Faraday's Law of Electrolysis. The benefit from the research is not to solve or isolate the consequences from global emission issue but to provide a future platform for the sustainable energy plant as one of the potential renewable energy option.

## **FUTURE WORK**

The development of the working model is continue with the prototyping process where all the proposed circuit diagram and the integrated model will be transform into actual model. The finished model will conduct series of test using specific equipment. For the actual application and performance test, special water fracturing process test equipment is designed and under development stage. The test rig is important to gather the performance data of the frequency generator itself as well as the methodology for the sequential hydrogen fracturing process.

## **ACKNOWLEDGEMENTS**

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### **Nomenclature**

$T_m$	mark time in s
$T_s$	space time in s
$T$	cycle time in s
$f_p$	pulsed frequency in Hz
$f_G$	gated frequency in Hz
$VR_1$	resistance in $\Omega$ with minimum $100\Omega$
$VR_2$	resistance in $\Omega$ with minimum $100\Omega$
$VR_3$	resistance in $\Omega$ with minimum $100\Omega$
$VR_4$	resistance in $\Omega$ with minimum $100\Omega$
$C_1$	capacitance in $F$ with variable range
$C_3$	capacitance in $F$ with variable range
$V_{ref}$	reference voltage in V
$VR$	resistance in $\Omega$
$I_{out}$	Output current in A