

Ultrasound Driving Application of a Universal Waveform Generator Derived from Displaying Driving System

Chang Ge¹, Jihui Wu², Yongming Tang²

¹Department of Electrical and Computer Engineering, University of Alberta, Edmonton, Canada

²School of Electronic Science and Engineering, Southeast University, Nanjing, China

Email: cge@ualberta.ca

Received 9 August 2014

Abstract

The design of a universal waveform generator derived from displaying driving applications using floating power and Miller integrator circuit is introduced first. Then, the feasibility of driving ultrasound transducers is verified by the test of the circuit and compared with other specific design of pulse generator for ultrasound driving purpose.

Keywords

Universal Waveform Generator, Ultrasound, Pulse, Miller Integrator Circuit

1. Introduction

Piezoelectric ultrasound transducers are used for a various kinds of applications. The popularity of piezoelectric ultrasound transducer comes from its high controllability. In general, piezoelectric ultrasound transducer has a structure like the one shown in **Figure 1** [1]. To get expected ultrasound output frequency ranging from 60 KHz to as high as 60 MHz, only the thickness of piezoelectric layer and matching layer need adjustment. For ultrasound transducer driving, an alternative power supply need is generally applied on the electrodes.

The effective driving of piezoelectric ultrasound transducers depends on the high amplitude pulse. In common applications like ultrasound detection, surgical ultrasound and ultrasound chemistry, the requirement for high amplitude is due to the fact that attenuation of ultrasound will cause loss of information contained in the reflection wave in a pulse-echo detection system or reduce the power of ultrasound induced effect. In practical circuits, the high amplitude ultrasound pulses can be implemented either in unipolar form or in bipolar form [2]-[5]. Unipolar form has the advantage of shorter wave length, *i.e.* higher frequency. Bipolar form can get to the high amplitude with lower unwanted DC current and leakage.

Regardless of the type of pulse wave generated, different kinds of ultrasound driving pulse generator circuit have many characters in common, with the biggest one being the using of high speed high voltage MOSFET and corresponding driving structure at gate electrode. At present days, the research works about the ultrasound pulse generators focus on three aspects, they are the pulse generator for higher frequency [3]-[5], pulse generator for lower cost [2], multifunction and reconfigurable pulse generators [5], respectively.

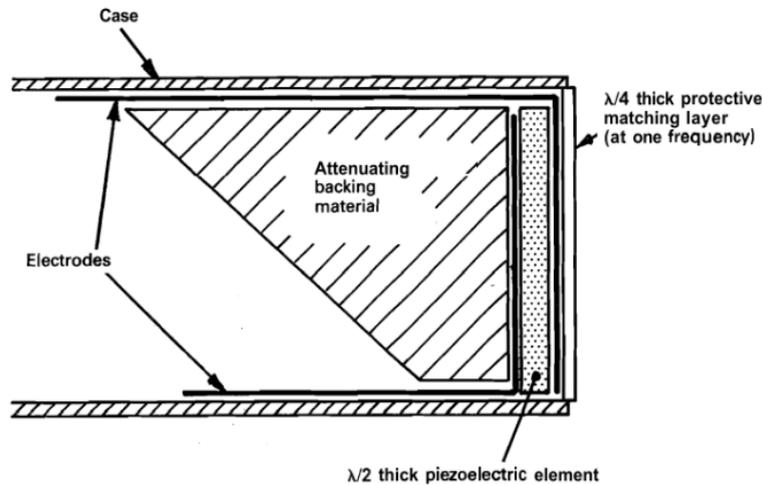


Figure 1. Generic structure of a piezoelectric ultrasound transducer [1].

As we know, many other electrical devices need high voltage pulses for controllable driving, such as displaying device. Similar to the driving circuit of an ultrasound transducer, the displaying driving circuit also depends on the MOSFETs for pulse generation. The frequency for displaying and ultrasound driving overlaps a lot as well. Moreover, as the scale of displaying devices significantly reducing, the difference of circuit size between displaying and ultrasound driving is becoming smaller. There is also a trend of low cost, versatile design in the displaying driving applications. Therefore, it is possible for the displaying driving circuit being applied to ultrasound driving directly or after tiny modification.

In this paper, the design of a universal waveform generator derived from displaying driving system is described, followed by corresponding test, with a result showing that the generator is capable of generating waveform satisfying requirement of ultrasound driving on amplitudes. Then comparisons with typical ultrasound driving pulse generators are carried out in order to verify the possibility of using the universal waveform generator for ultrasound driving. Last but not least, a conclusion based on comparisons is provided in together with brief description of future work.

2. Design of Universal Waveform Generating Circuit

2.1. Circuit Function

The circuit designed here has put an emphasis on generating multiple kinds of waves that can fulfill the requirement of multiple applications. Thus, the high-voltage driving circuit should be able to generate integral wave, triangle wave, square wave, positive and negative pulses and achieve rapid transitions and slope changes between different voltage within a wide range of input signal frequency. Since different displaying driving systems also have different requirement on pulse amplitude, in some cases, multiple positive and negative voltage levels are expected. The universal waveform generator should be able to reach at least five different voltage level, an analog zero, two positive level and two negative level.

Therefore, seven modules should be included in the driving system, respectively, to achieve rapid transitions and changes with slope between positive and negative voltage levels as well as the analog zero, *i.e.* the function to ramp down to $-VSUS$, jump down to $-VSUS$, ramp down to $-VPP$, jump down to $-VPP$, jump to GND, jump to $+VSUS$, and ramps up to $+VSETUP$. Here, the voltage levels involved has a relationship in size as:

$$+VSETUP > +VSUS > 0 > -VPP > -VSUS$$

The schematic block diagram is shown as **Figure 2**. In order to implement certain waveforms, taking a unipolar negative pulse ramping down with slope to $-VSUS$ as an example, first the RAMP_DN_ $-VSUS$ module works, to pull the voltage of the output line from zero to $-VSUS$ with a slope. Then the GND module works to lift the voltage of output line back to zero. As a result, a negative pulse to $-VSUS$ with a slope is generated. For other pulse, the generation is similar to the negative pulse. The frequency of the pulse depends on the control signal frequency and the frequency limitation of devices.

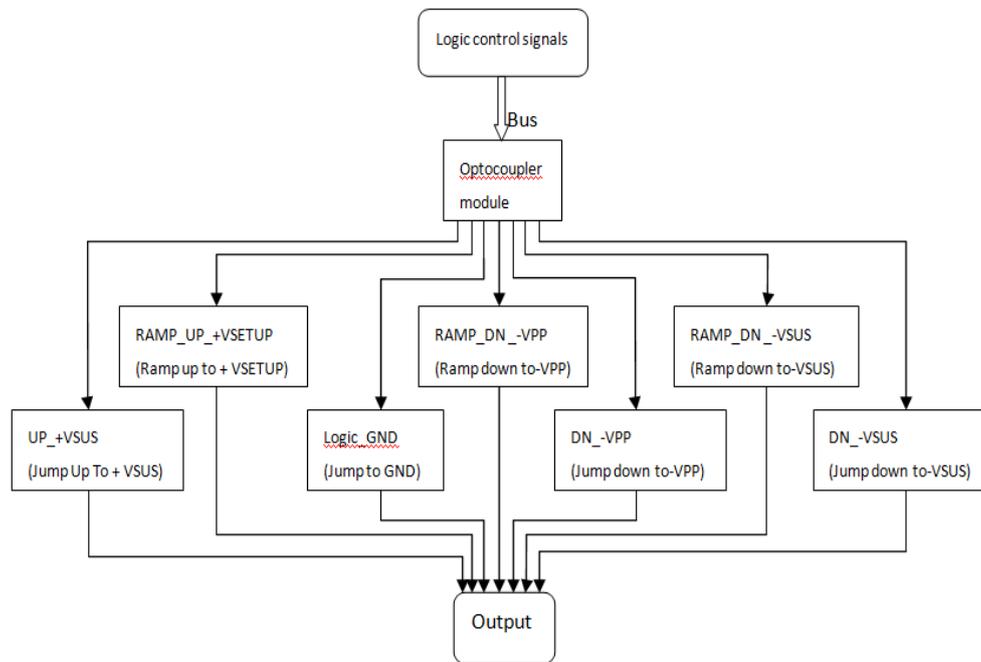


Figure 2. The schematic block diagram of the circuit design.

As for the logic control signals, since the seven modules are in parallel, the control signal is at least 7-bit-long signal with each bit control one module. Assume that the left most controls the Ramp_Dn_-VSUS module and the right most controls the GND module. Then, to implement the waveform mentioned in previous Section 2.1, a series of “1000000” and “0000001” is required.

2.2. Circuit Design

The seven modules in the universal waveform generator are implemented using similar structure. Take the RAMP_DN_-VSUS module as an example, which is shown in **Figure 3**. Besides the logic control modules and output line, an optocoupler module, a push-pull circuit driving the pulse generator circuit and an isolation module is included. For the pulse generating circuit, here a Miller integrating circuit with MOSFET is used for voltage level ramping down with slope. The miller integrator circuit has a potentiometer at the gate electrode of MOSFET. The slope of the waveform when ramping down to -VSUS can be adjusted by adjusting the potentiometer.

The circuit implementation of the Miller integrating circuit is shown in **Figure 4(a)**. For voltage ‘jumping’ part in every module, a common MOSFET driving structure is used, like those in [2]-[5]. All pulse generating modules use the same type of N-MOSFET.

Another unique character of the universal waveform generator designed here is the usage of a floating power supply implemented by an ASIC chip DMCD 15S15-200. By using the floating power to drive related chips, the waveform generator can implement bipolar waveforms using only N-MOSFET, each of which is responsible for one kind of voltage change. This design strategy contributes greatly to making the pulse generated more symmetric in rising and falling time. A peripheral design for DMCD 15S15-200 is shown in **Figure 4(b)**. Each of the seven modules mentioned has a similar DMCD 15S15-200 circuit like **Figure 4(b)** to provide power supply.

Figure 5 is the picture of the PCB circuit board for the universal waveform generator. Here a two-layer PCB board is fabricated.

3. Testing Results

Test results of the circuit are shown in **Figure 6**. In the tests, the output of the universal waveform generator is directly connected to Angilent DSO7034B oscilloscope. Clearly, the result shows that the universal waveform generator can generate ramping up and ramping down waves with the amplitude of 300 V and bipolar pulse

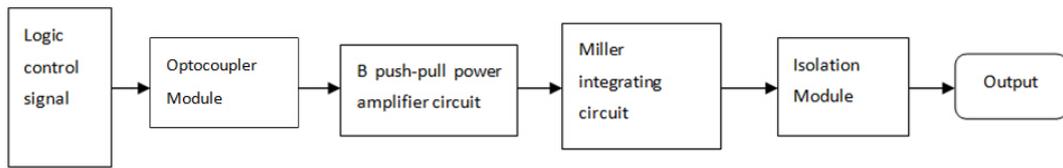


Figure 3. The block diagram of ramp_DN_VSUS module.

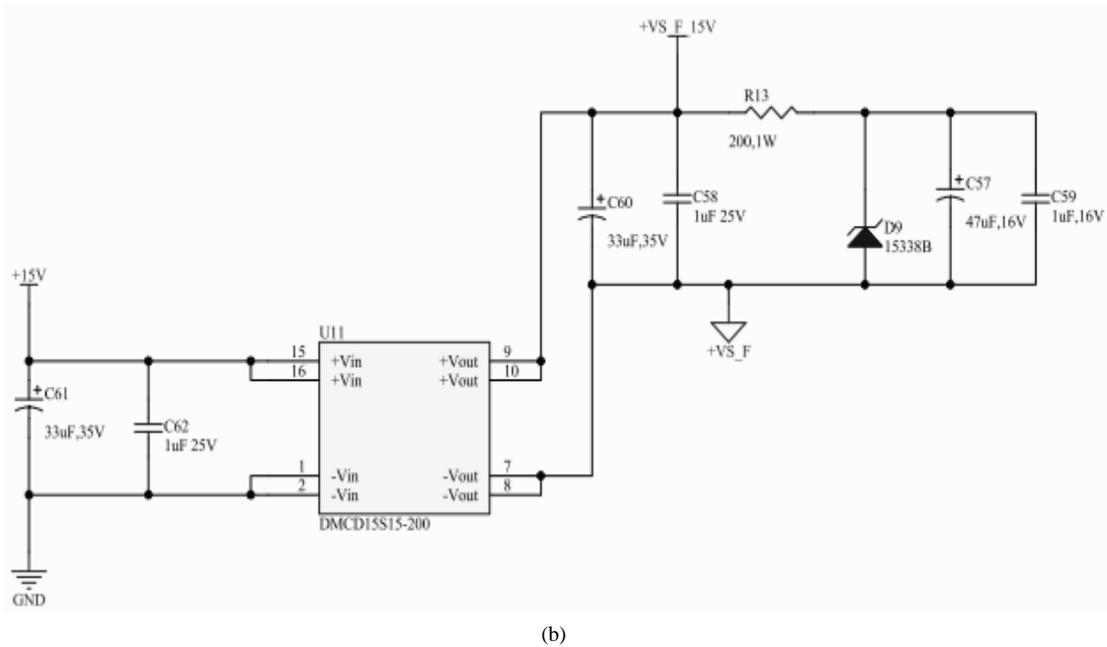
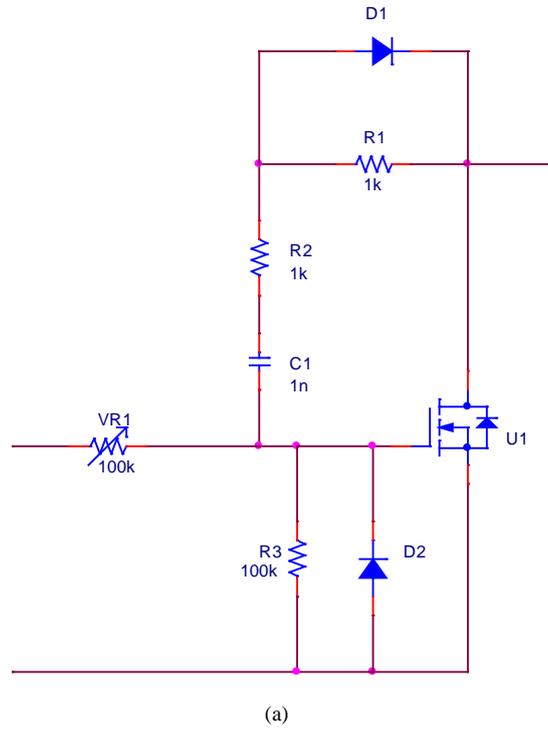


Figure 4. Characteristic structure of the waveform generator designed: (a) The Miller integrating circuit; (b) The floating power supply using DMCD15S15-200.



Figure 5. PCB board fabricated of designed circuit.

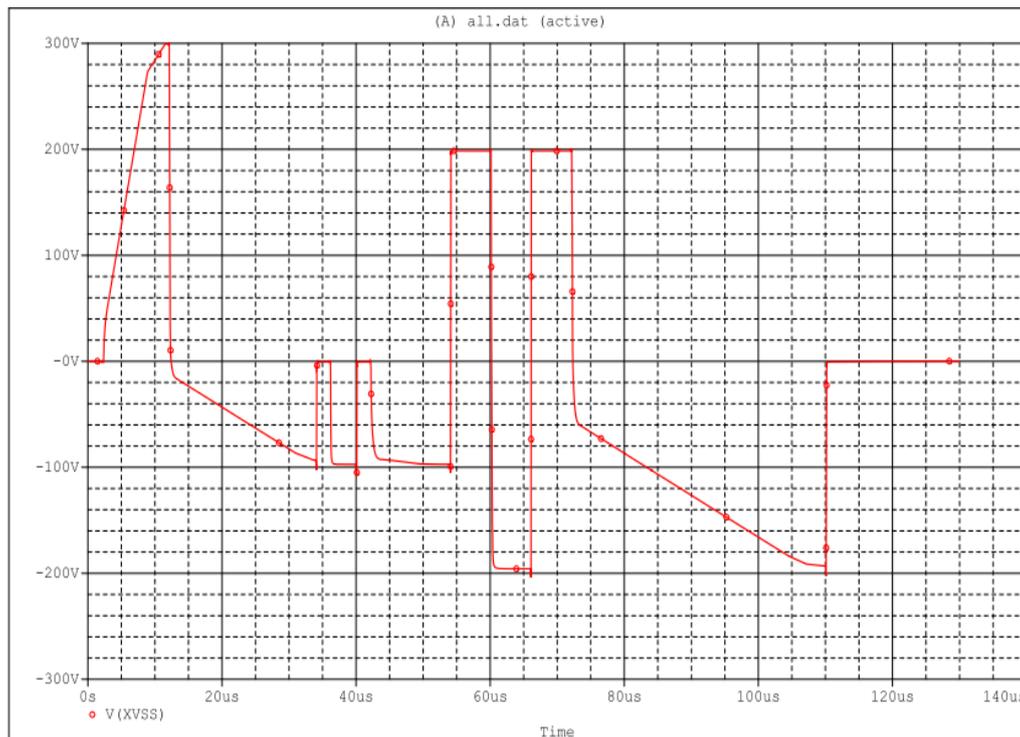


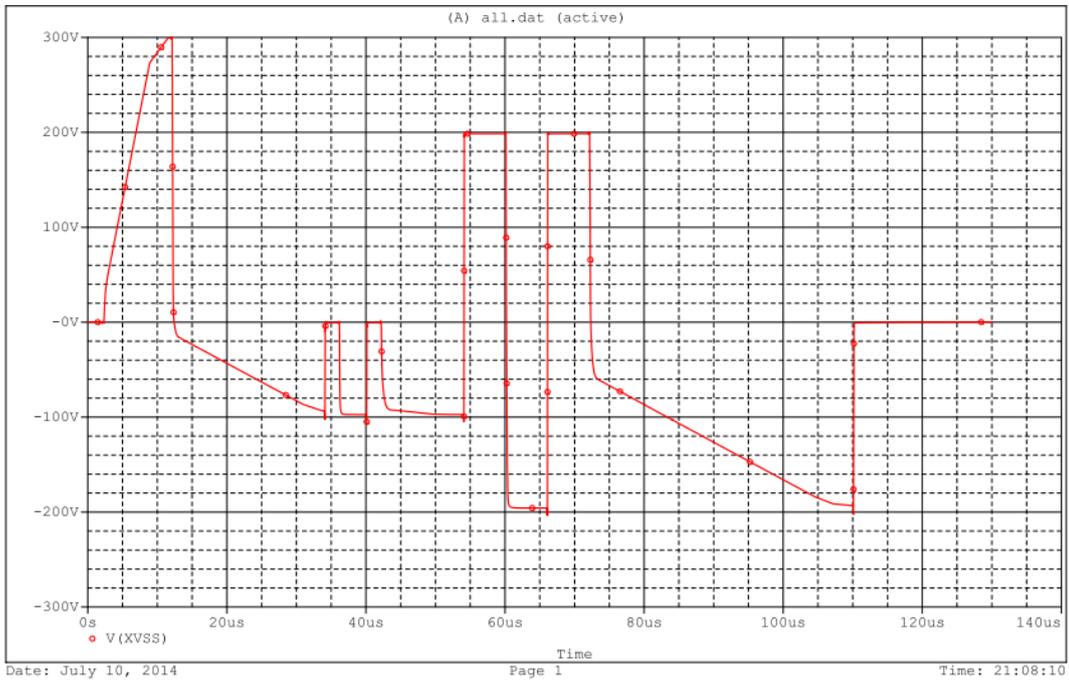
Figure 6. Testing wave of the designed circuit.

with a peak-to-peak voltage of 400 V. For the frequency, the test frequency is 100 KHz for both the bipolar pulse and ramping pulse. The maximum frequency for the prototype can be 330 KHz.

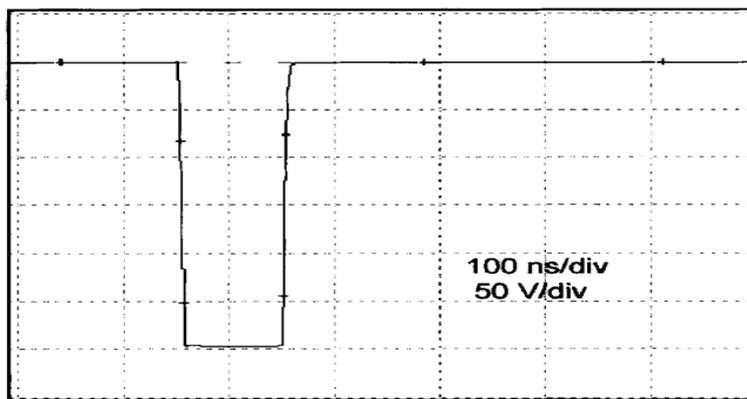
Figure 7 provides a comparison of waveforms generated by the universal waveform generator, and circuit specifically designed for ultrasound driving in [2]-[5]. Through the comparison, the amplitude of waveform, both unipolar and bipolar, generated by the universal waveform generator is proved to satisfy the requirement for ultrasound transducer driving.

Most of the output in **Figure 7** has a specific frequency response spectrum. This is not reflected in the test of the universal waveform generator. The explanation for this is provided later.

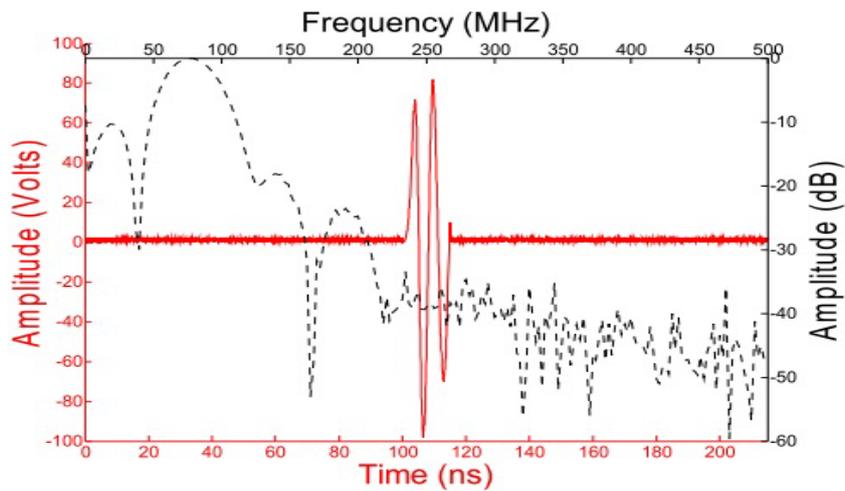
Also, the frequency of the waveform in [2]-[5] is higher. This is because they aim at high frequency ultrasound (HFUS) applications, which is an emerging application of ultrasound over 20 MHz. Besides these high frequency applications, there are still many commercial ultrasound applications at much lower frequency, such as some of the B-mode scanning and non-destructive detection transducers [6]. Regardless of the frequency, as mentioned previously, to ensure certain resolution or power of the effect induced, pulse with the relatively high amplitude of over 100 V is always expected. The frequency is of great importance, the amplitude plays a more significant role in verification of feasibility to drive ultrasound transducers for a given circuit.



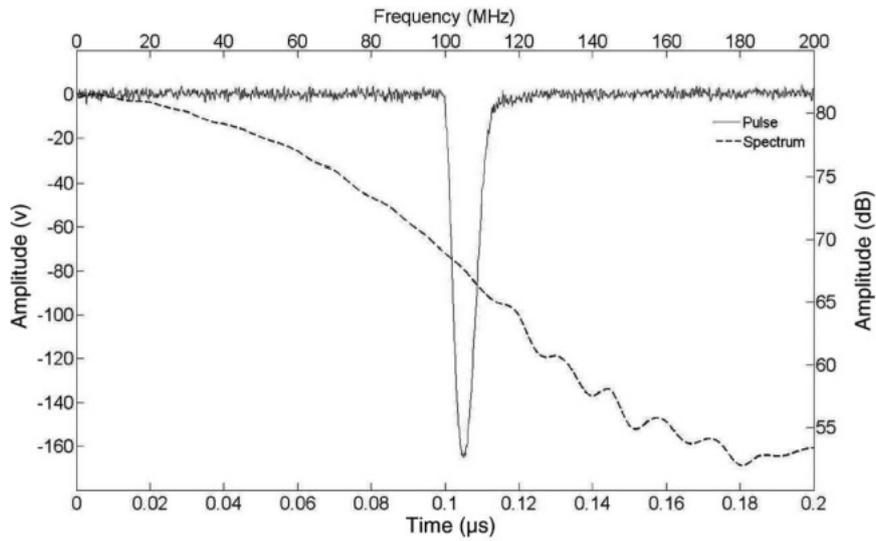
(a)



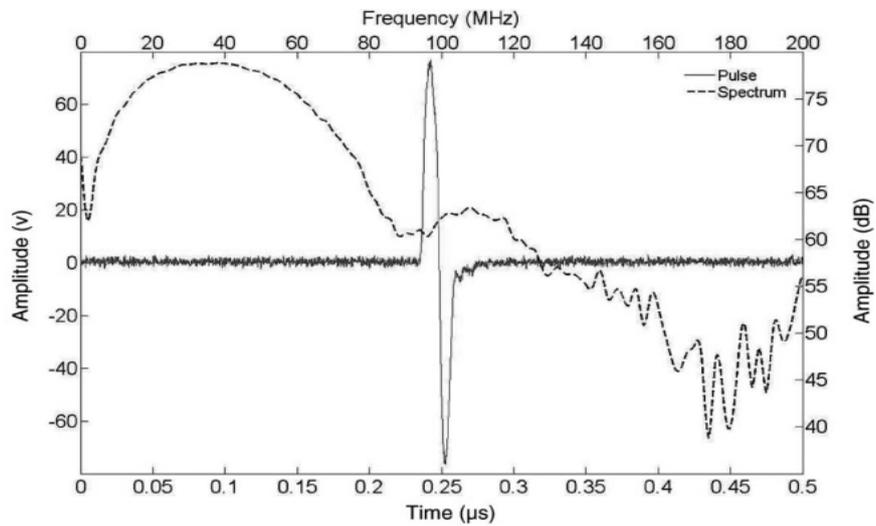
(b)



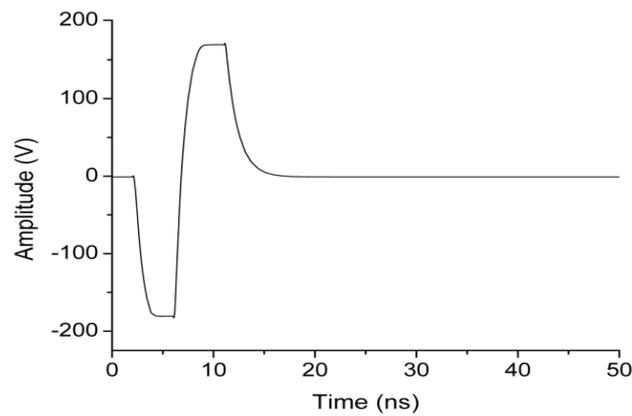
(c)



(d)



(e)



(f)

Figure 7. Outputs of pulse generators involved in this Paper: (a) Circuit designed in this paper; (b) Output in [2]; (c) Output in [3]; ((d), (e)) Unipolar and bipolar output in [4]; (f) Bipolar output in [5].

4. Comparison with Circuit Designed for Ultrasound Driving

The comparison of amplitude and discussions for frequency of waveform generated has been provided in previous part. Here the discussion mainly focuses on the comparison of other factors. As for the controlling digital signals, compared with [5], which implements bipolar pulses generation, the universal waveform generator designed here doesn't need the complicated controlling signals as the one in [5]. The design in [5] uses a PMOS and NMOS pair. Due to the difference in mobility of holes and electrons, switching time of the PMOS and NMOS is not different, therefore, control signal for NMOS and PMOS need to be designed respectively. The difference also leads to asymmetry in rising and falling times [5]. For the waveform generator designed in this paper, there are no such problems since the ASIC chip DMCD15S15-200 is used to provide floating power and only N-MOSFETs of same type are used.

A multifunction and reconfigurable pulse generator for ultrasound driving was introduced in [4]. It can generate unipolar waves, bipolar waves as well as arbitrary waves. The unipolar wave has the higher amplitude, similar result is got in the waveform generator designed here. However, the unipolar and bipolar pulse generator part are separated part as shown in **Figure 8** [4]. For the universal waveform generator designed in this paper, unipolar pulse generation only uses part of the bipolar pulse generation circuit. The only difference is in the control signals. This reduction on circuit complexity make the circuit designed in this paper easier to maintain and debug, while provides similar waveform output.

Generally, in the ultrasound driving system, the matching network is used for damping unwanted waveforms at other frequencies and maximizing the power efficiency. In the references [2]-[5], the matching network leads to the damping curves shown in **Figure 7**. Since its origin is displaying driving circuit, the universal waveform generator designed in this paper doesn't have such a matching network. However, the network is between the pulse generator and transducer, *i.e.* a component outside the driving pulse generator. So, the missing of matching network in the universal waveform generator doesn't affect its application in ultrasound transducer driving.

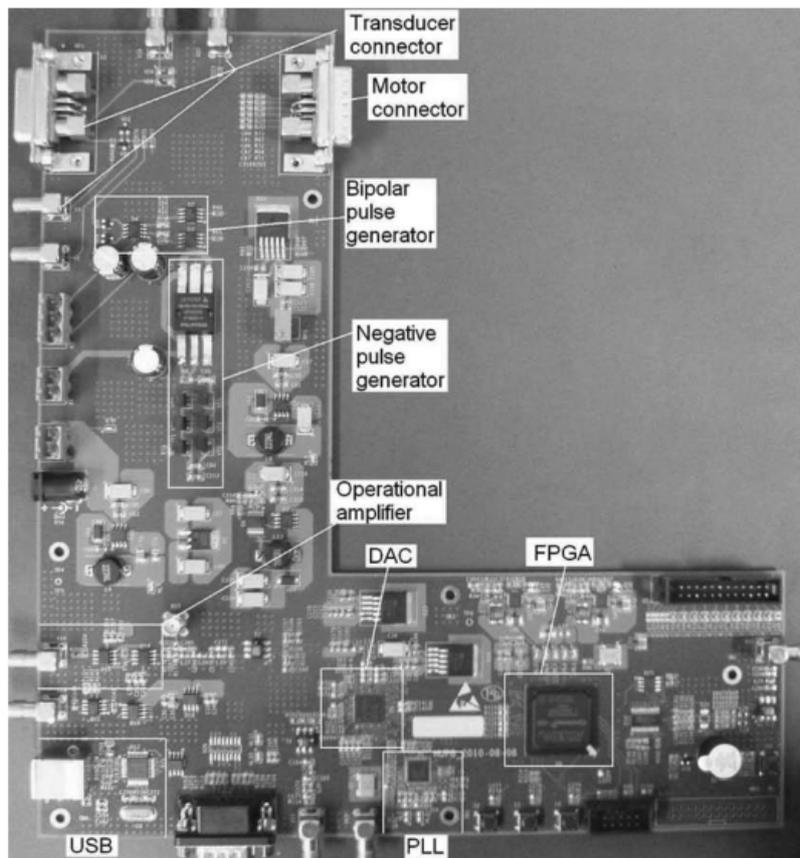


Figure 8. PCB board provided in [4].

5. Summary

Through test and comparison, it can be found that the universal waveform generator designed in this paper has an output amplitude similar or even larger to the ultrasound driving pulse generators [2]-[5]. Using N-MOSFET for pulse generation only, the circuit alleviates the problem of asymmetry in bipolar waveforms. Together with a driving ability designed for displaying applications, which is powerful enough to drive ultrasound transducers, the waveform generator designed in this paper is believed to be able to driving ultrasound transducer and generate ultrasound wave with expected intensity for various applications. In detail, the waveform generator can be used as a reconfigurable pulse generator. To fully put the universal waveform generator into ultrasound driving application, further work includes the supplement of matching network and removal of some modules unrelated to ultrasound driving as a consideration of cost. Moreover, as high frequency ultrasound applications are becoming more and more popular, substitution of some devices to faster ones is expected in order to implement high frequency applications.

References

- [1] Preston, R.C. (1991) Output Measurements for Medical Ultrasound. Springer, Berlin.
<http://dx.doi.org/10.1007/978-1-4471-1883-1>
- [2] Brown, J.A. and Lockwood, G.R. (2002) A Low-Cost, High-Performance Pulse Generator for Ultrasound Imaging. *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, **49**, 848-851.
<http://dx.doi.org/10.1109/TUFFC.2002.1009345>
- [3] Wu, J.-X., Du, Y.-C., Lin, C.-H., Chen, P.-J. and Chen, T.S. (2013) A Novel Bipolar Pulse Generator for High-Frequency Ultrasound System. 2013 *IEEE International Ultrasonics Symposium (IUS)* [Serial Online], 1571.
<http://dx.doi.org/10.1109/ULTSYM.2013.0400>
- [4] Qiu, W.B., Yu, Y.Y., Tsang, F.K. and Sun, L. (2012) A Multifunctional, Reconfigurable Pulse Generator for High-Frequency Ultrasound Imaging. *IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control*, **59**, 1558-1567. <http://dx.doi.org/10.1109/TUFFC.2012.2355>
- [5] Xu, X.C., Yen, J.T. and Shung, K.K. (2007) A Low-Cost Bipolar Pulse Generator for High-Frequency Ultrasound Applications. *IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control*, **54**, 443-447.
<http://dx.doi.org/10.1109/TUFFC.2007.259>
- [6] Cheeke, J.D.N. (2012) Fundamentals and Applications of Ultrasonic Waves. CRC Press, Boca Raton.
<http://dx.doi.org/10.1201/b12260>