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Welding invertor using 32-bit microcontroller

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***Abstract* — This paper is a summary of the elaboration of a master's thesis "Welding inverter using 32-bit microcontroller" in the first summer semester. Thesis is a continuation of a bachelor's thesis "Welding inverter" where a welding machine was developed based on 8-bit microcontroller. Finished inverter was capable of welding but the design was not optimal, with multiple bugs. This paper shows further progress of developing welding inverter.**

***Keywords* —microcontroller, STM32, transformer, welding inverter**

I. INTRODUCTION

Welding is a long-established technology for joining metal, arc welding uses heat of an electric arc to locally melt steel or other metals to create a strong bond. Since it takes a lot of heat to melt steel, it also takes a lot of electrical power to generate a welding arc. A machine capable of supplying such a power is called welding machine or welding power supply. Although they existed for a long time, design and capabilities of welding power supplies have changed and continue to change, rapidly. Especially so-called inverter technology-based welding machines [1].

II. WELDING INVERTER

The first generation of welding power supplies have been based on mains transformers. The transformer converted mains 50 Hz voltage to lower voltage and higher current suitable for welding. In order to convert enough power to melt steel, few kW usually, a large transformer is necessary. These welding supplies are notorious for their large dimensions, weight, and inefficiency.

Inverter based welding supplies are also powered by mains 50 Hz voltage, but AC voltage is rectified and filtered into DC bus. The DC voltage is then converted to lower welding voltage using DC/DC converter, which works at high frequencies. Since high frequency transformer can be smaller than mains transformer with respective power rating, welding machines with inverter technology are usually a fraction size and weight of a traditional welding machines [1], [2]. Switching frequency of 20 kHz to 100 kHz is commonly used, that's possible by using modern semiconductors as a power switches. These power switches require a control circuit in order to work properly. The control circuit generates one or multiple pulsed signals depending on the topology. Output power of converter can be controlled by varying duty of control signals or by changing their frequency. Output characteristics of the converter depends on the control circuit, it can be constant current for MMA and TIG welding, or constant voltage for MIG/MAG welding. Regulator with appropriate feedback loop should be also included for maintaining desired value of voltage or amperage while welding. The control circuit that meets these requirements can be made from analog components, dedicated integrated circuits, digital circuits or by using microcontroller [2], [3].

This paper focuses on the full bridge converter-based inverter with constant switching frequency of 100 kHz, controlled by microcontroller implementing peak current mode control resulting in constant current characteristics.

III. CHOOSING MICROCONTROLLER

A 32-bit microcontroller was chosen since the 8-bit ATMega328p was proved insufficient for controlling a such welding inverter. For implementing peak current mode control, it needed external comparator, D/A converter, logic gates and other complementary circuits [3].

Many 32-bit microcontrollers present themselves on the market from many companies such as: Microchip, STMicroelectronics, Texas Instruments, etc. The STM32F303K8 from STMicroelectronics was chosen due to its computing power and available peripherals. Furthermore, the specific microcontroller is available in Nucleo-32 development board with built in programmer, the board is compatible with ATMega328p in Arduino Nano used prior to the STM32.

STM32 family was also desired since the development and debugging software was familiar to the authors and it allowed for use of libraries and drivers. Chosen microcontroller had many useful features but most important for this project were: 72 MHz clock, 6 timers, USART communication, 2 D/A converters, 7 fast comparators and operational amplifier [4].

IV. SETTING UP A MICROCONTROLLER

The full bridge converter requires two PWM control signals both with equal duty to prevent DC magnetisation of the core. The signal should be phase shifted by 180 degrees while maximum duty should be less than 50 %, as a result two signals should not overlap. Overlapping signals would result in cross-firing IGBTs and damaged hardware. Advanced control timer TIM1 is used to generate both PWM signals with channel 1 and channel 4, at pins PA8 and PA11 respectively. To achieve peak current mode control, a signal must be introduced to turn off PWM signal at a specific time when current in primary of the transformer reaches a predetermined threshold. The comparator COMP2 is used to monitor current via current sensor and compare it to DC voltage level which is sourced from DAC1 D/A converter. Since current in the primary of this converter is rising with a slope, the DAC1 value determines time at which comparator forces output high. Output of the COMP2 is then connected to OCREF_Clear input of the advanced timer TIM1, which clears both PWM signals. Thus, a current regulation is achieved. The USART communication was configured to exchange information with Nextion touch screen where a user can change DAC1 value as well as maximum duty cycle of generated PWM signals. Configuration of the microcontroller was done in STM32 CubeMX and Keil µvision according to diagram in Fig. 1 [3], [4].

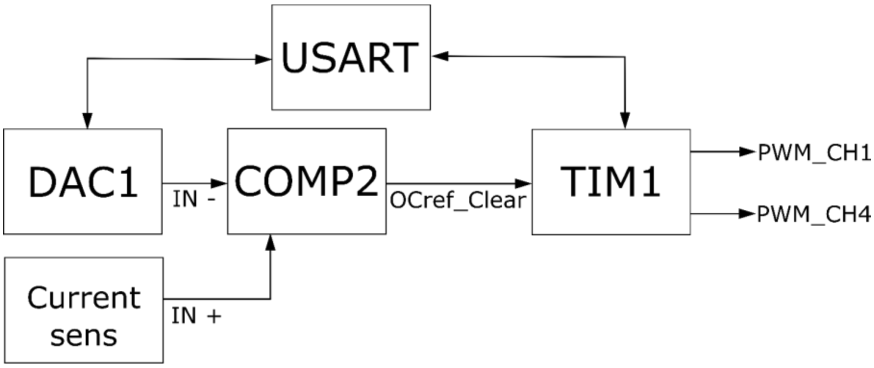
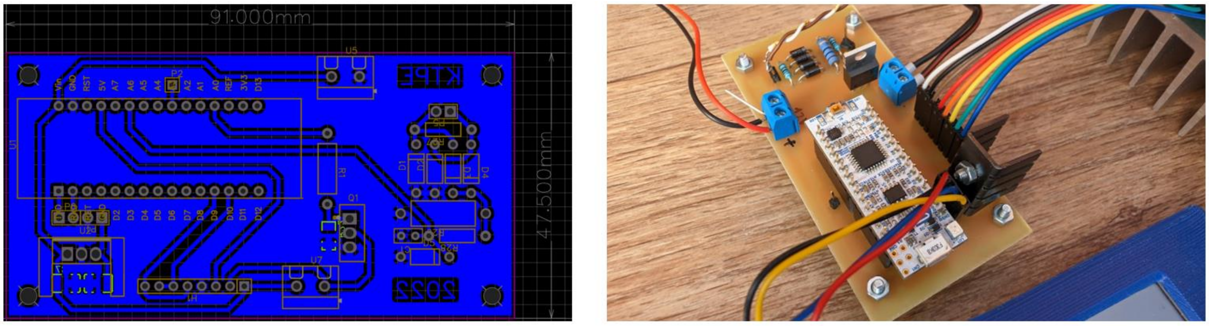


Fig. 1 Diagram of STM32 peripherals

Configured microcontroller was tested on breadboard with oscilloscope, test showed that comparator and timer react within 70 ns – time from comparator match to PWM signal turning off. This time is 30 % improvement over analog components used prior to the STM32 [3].

After successful test on a breadboard, a PCB was designed to minimalize EMI effects when testing welding inverter as a whole. PCB was designed in EasyEDA on a single layer. Emphasis was on maximising area of copper ground plane. Fig. 2 a) shows final design with Nucleo32 board with external voltage regulator, power transistor for switching 12 V power to gate drivers and complementary components for current sensing. Fig. 2 b) shows etched PCB with all the components mounted and connected to the inverter. The control board was powered by external 12 V switched mode power supply by Meanwell. The PCB was tested and made sure all the peripherals of the microcontroller work as expected.

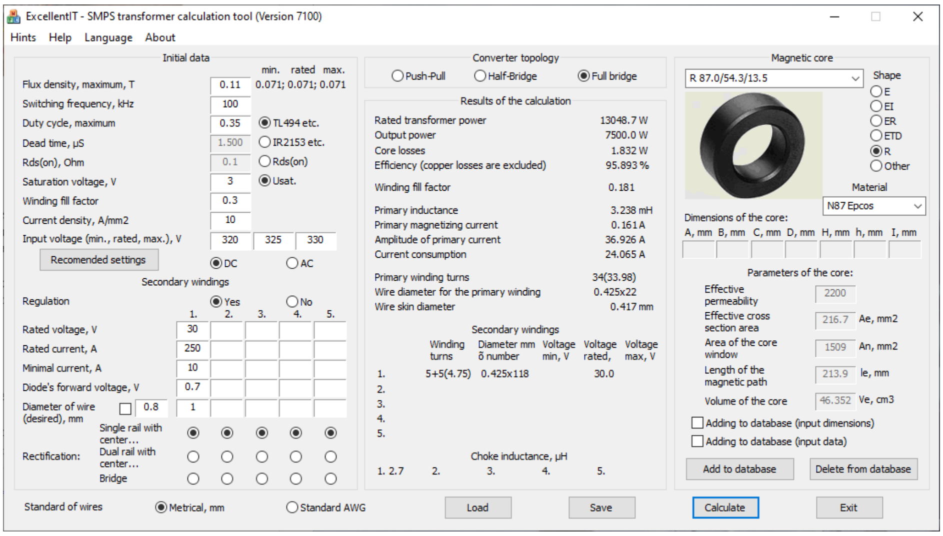


a) b)

Fig. 2 Microcontroller PCB

V. HIGH FREQUENCY TRANSFORMER

In the next phase, attention was shifted to the high frequency transformer. In the previous experiments with welding, it was discovered that output voltage of the inverter is too high. This was not surprising, since primary to secondary turns ration was chosen rather arbitrary [3]. To resolve this issue, a new transformer had to be wound. ExcellentIT transformer calculation tool was utilized for the necessary computations. Input parameters were core size and material, switching frequency, input voltage, maximum duty cycle, desired output voltage, output current, wire thickness and converter topology. As a result, primary and secondary winding turns, number of parallel wires, primary and secondary inductances, secondary choke inductance, rated transformer power and core losses were displayed, according to Fig. 3.



Initial data

		min.	rated	max.
Flux density, maximum, T	0.11	0.071;	0.071;	0.071
Switching frequency, kHz	100			
Duty cycle, maximum	0.35	● TL494 etc.		
Dead time, µS	1.500	○ IR2153 etc.		
Rds(on), Ohm	0.1	○ Rds(on)		
Saturation voltage, V	3	● Usat.		
Winding fill factor	0.3			
Current density, A/mm2	10			
Input voltage (min., rated, max.), V	320	325	330	

● DC ○ AC

Secondary windings

Regulation ● Yes ○ No

	1.	2.	3.	4.	5.
Rated voltage, V	30				
Rated current, A	250				
Minimal current, A	10				
Diode's forward voltage, V	0.7				
Diameter of wire (desired), mm ☐ 0.8	1				
Rectification: Single rail with center...	●	●	●	●	●
Dual rail with center...	○	○	○	○	○
Bridge	○	○	○	○	○

Standard of wires ● Metrical, mm ○ Standard AWG

Converter topology

○ Push-Pull ○ Half-Bridge ● Full bridge

Results of the calculation

Rated transformer power	13048.7 W
Output power	7500.0 W
Core losses	1.832 W
Efficiency (copper losses are excluded)	95.893 %
Winding fill factor	0.181
Primary inductance	3.238 mH
Primary magnetizing current	0.161 A
Amplitude of primary current	36.926 A
Current consumption	24.065 A
Primary winding turns	34(33.98)
Wire diameter for the primary winding	0.425x22
Wire skin diameter	0.417 mm

Secondary windings

	Winding turns	Diameter mm ŏ number	Voltage min, V	Voltage rated,	Voltage max, V
1.	5+5(4.75)	0.425x118		30.0	
2.					
3.					
4.					
5.					

Choke inductance, µH

1. 2.7 2. 3. 4. 5.

Magnetic core

R 87.0/54.3/13.5

Shape ○ E ○ EI ○ ER ○ ETD ● R ○ Other

Material N87 Epcos

Dimensions of the core:

A, mm	B, mm	C, mm	D, mm	H, mm	h, mm	I, mm

Parameters of the core:

Effective permeability	2200	
Effective cross section area	216.7	Ae, mm2
Area of the core window	1509	An, mm2
Length of the magnetic path	213.9	le, mm
Volume of the core	46.352	Ve, cm3

☐ Adding to database (input dimensions)
☐ Adding to database (input data)

Fig. 3 ExcellentIT transformer calculation tool

A new transformer was then wound with these specs. In addition to Kapton tape and wire ties, a winding holding insert was designed. Its purpose is to prevent winding from moving while conducting pulsed currents. Insert was designed in Fusion360, and 3D printed from ASA plastic material for its stability at elevated temperatures. Fig. 4 a) shows insert design, b) shows finished high frequency transformer.

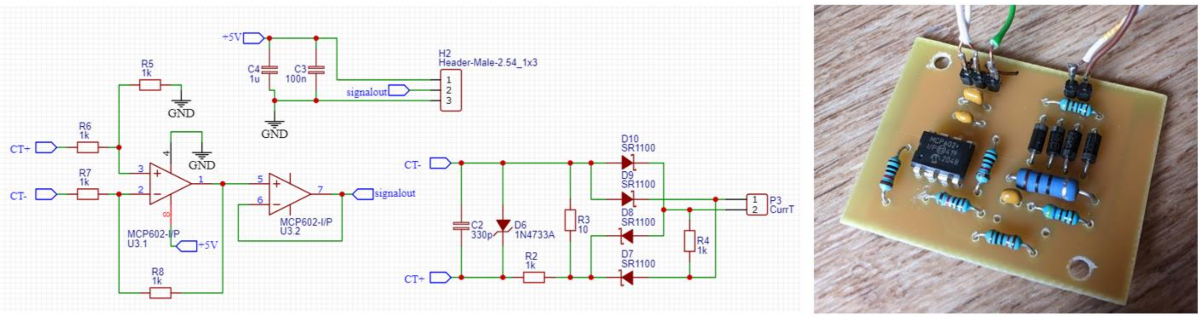
a) b)

Fig. 4 Transformer winding holder

VI. EMI PROBLEMS

Soon enough after testing the inverter with a small load (around 500 W), a voltage spiking was noticed at the gates of the power IGBTs while they were supposed to be turned off and another transistor was turning on. The spiking reached peak to peak voltage of 5 V, it was caused by high *di/dt* and *du/dt* in the power module. Since gate-emitter threshold voltage of used FGH40N60SMD transistor is 4,5 V, spikes could provoke unwanted turning on of the transistor – thus short circuit of the DC bus through another transistor [5]. To resolve this issue transistor’s gate pins was retrofitted with a small EMI suppression ferrite bead. Later testing showed suppressed U_{GE} spikes of less than 1 V, thus mitigating risk of accidental cross firing IGBTs.

Similarly, to transistor’s gate, the switching noise was also picked up by current sensing circuit, thus feeding incorrect data to the microcontroller’s comparator, causing premature OCref_Clear signals to the TIM1 timer. After identifying noise to be common mode, a common mode choke was used for suppression. To get the most precise signal from the sensor and to remove rest of the common mode noise, a differential amplifier was suggested, as per Fig. 5 a). The theory was simulated using Proteus tool, common mode noise from the current sensor would show on the inverting, as well as non-inverting input of the operational amplifier and only the differential signal would be on its output. This clean differential signal could then be sent to the microcontroller. After simulation, the circuit was laid out onto a PCB, which was then manufactured Fig. 5 b). Operational amplifier MCP602 was chosen for its bandwidth of 2,8 MHz and Rail-to-Rail capable inputs and output and ability to be powered from single 5 V supply [6]. Addition of this circuit removed most of the common mode noise while the inverter was tested with a 500 W load.



a) b)

Fig. 5 Differential amplifier

VII. CONCLUSION

32-bit STM32 microcontroller was proven to be more capable than 8-bit ATMega328p with additional circuitry. Built in peripherals of the STM32 sped up development since they could be configured by software and minimal external components were needed. The welding inverter can now be tested and debugged with higher loads or perhaps welding.

ACKNOWLEDGEMENT

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