ANALOG CONTROL CIRCUITS FOR SEPIC CONVERTER

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Abstract: *Control switching circuits play a major role in power electronics converter circuits. In this paper, three different simple cost effective analog control circuits have been developed using three different analog ICs for dc-dc SEPIC converter and their performances are tested. These IC's does not require any interface with the computers, hence no programming is required. They are suitable for small scale systems. The converter is tested in laboratory using the developed control circuits on various duty cycles ranging from 10 % to 90 % with fixed frequency. The performances of the control circuits are compared based on the components requirements, simplicity and duty ratio.*

Key words: *dc-dc power conversion, pulse circuits, SEPIC converter, switching circuits.*

1. Introduction

For operating the power electronic MOSFET switches employed in dc-dc converters and dc-ac converters, an appropriate gate voltage must be applied to drive the device into conduction mode for low on-state voltage [1]. The control voltage should be applied between the gate and the source terminals. The control or the switching signals are generated by different pulse generation circuits. A power MOSFET switch requires a variable duty cycle, fixed frequency control signal to get a variable dc voltage from a fixed dc input. A Pulse width modulation (PWM) scheme with fixed frequency is preferred because of inductor designing factor. The control and the firing circuit should have the following properties:

- Fixed switching frequency
- Min and max duty cycle = 10% - 90%
- Pulse amplitude >3V
- Constant rectangular gate pulses
- Lesser external components
- Simple to control and vary

The advanced dc-dc converter topologies such as SEPIC converter [2]-[7], Cuk converter [8], Luo converter [9], Zeta converter [10], KY converter [11] etc. were discussed in literatures. A sinusoidal pulse width modulation (SPWM) control circuit was adopted using a Field Programmable Gate Array (FPGA) digital control for a 1-phase cascaded multilevel inverter fed induction motor drive [12]. Similarly, a delta PWM technique for ac-ac converters was implemented using FPGA [13]. A DSP 1104 board was used for power factor correction in a boost converter with predictive control [14]. The control algorithm for a modified SEPIC converter was developed using TMS320F2812 DSP with a sampling rate of 30 kHz [15]. In digital control, the existing analog control law was implemented using FPGA, DSP processor or microcontroller to generate the pulse pattern for the given dc-dc converter circuit. Recently, new control boards such as arduino kit, PIC kit and Raspberry pi controller kit are available to control and trigger a power semiconductor switch. These digital controllers require interface with the computers, hence programming is required which increases the system complexity and total cost. They are especially undesirable in small-scale systems. To overcome such difficulties, several analog circuits are presented.

A PWM controller IC KA7552 was preferred for boost SEPIC converter with reduced switch voltage stress and zero ripple input current [16]. It can be operated from 5 kHz to 600 kHz with a maximum duty ratio of 70%. A LM3478 controller was used to control the pulse width in a SEPIC converter [17]. The major limitation is LM3478 can be operated at frequencies above 100 kHz [18]. A L6599 high voltage resonant controller IC was used for LED lighting applications with a duty cycle of 50 % [19]-[20]. In this paper, LM555, TL494 and 74HC14 ICs are employed for a duty cycle range from 10 % to 90% to drive a power MOSFET in a SEPIC converter. The control circuits are fabricated on a printed circuit board (PCB) with minimum number of components. The desired characteristic such as wide duty ratio is being performed by these analog ICs.

2. Control circuits using analog IC's

A SEPIC converter is capable of performing both buck as well as boost operation from a fixed input dc source. The converter works on a fixed frequency and a variable duty cycle ranging from 10% to 90% for its buck and boost operation. The pulse width which is actually the turn on time of the switch, should be variable from minimum to maximum duty ratio to deliver ideal buck and boost results. There are three different pulse generating circuits consisting of three different ICs such as 555 timer, TL494CN and 74HC14P are developed. In each circuit, a variable resistor is used whose ohmic drop decides the pulse duration. The three different ICs are explained in detail as follows:

A. IC555 Timer

The circuit diagram shown in Fig. 1 has been used to generate pulses for SEPIC converter using IC 555 and the components used are listed in table 1. It produces a variable PWM by varying the potentiometer. This IC can be used over a wide range without affecting the frequency. To get a variable duty cycle, a timing capacitor is fixed. A positive 12 V input supply is given at 4^{th} and 8^{th} pin of IC 555 and also at 7^{th} pin through a resistor in astable mode, PWM pulses are captured at pin 3.

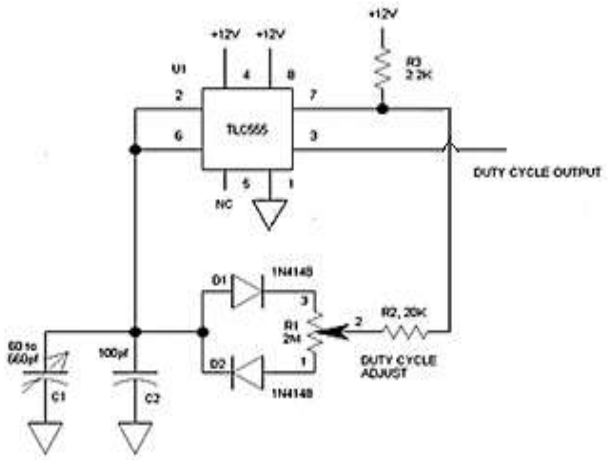


Fig. 1. Duty cycle control circuit using 555 timer

Table 1
Components used in 555 timer circuit

Component	Part No.	Value
Timer IC	NE555	N/A
Capacitors C_1, C_2	472, ceramic	47 nF
Diodes D_1, D_2	1N4148	N/A
Variable resistor R_1	N/A	2 MΩ
Resistors R_2 and R_3	N/A	20 kΩ, 2.2 kΩ

B. PWM Control IC TL494

It is a fixed frequency 16 pin IC. It has two internal op-amps which generate saw tooth wave and control signals. It consists of a comparator which compares both signals to produce a variable PWM. A dead time control pin generates the modulated pulse depending upon the voltage across the dead time control (DTC) pin. The supply voltage ($+V_{cc}$) must be between +7 V and +15 V. The TL494 device incorporates all the functions required in the construction of a PWM control circuit on a single chip [21]. In this IC, a timing capacitor C_T and a resistor R_T determine the oscillatory frequency f_{osc}. Assuming C_T=1μF, R_T can be calculated from the following equation for the given switching frequency:

$$f_{osc}=\frac{1}{R_T*C_T} \quad (1)$$

For f_{osc}=10 kHz and C_T=1μF, R_T value is 100 Ω.

The circuit diagram of a TL494CN PWM IC is shown in Fig. 2. The voltage at DTC terminal (pin 4) should be varied from 0-2 V to get PWM signal output at pin 8. By giving V_{cc}= +15V at pin 12, PWM output signal at pin 8 is captured. It has minimum number of components with 4 external resistors and a capacitor.

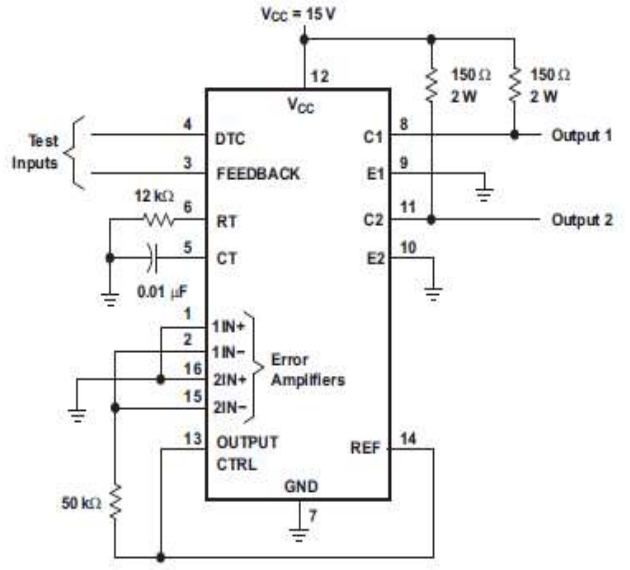


Fig. 2. TL494CN PWM circuit diagram

C. Analog IC 74HC14

The circuit diagram of IC74HC14 for pulse generation is shown in Fig. 3. By giving +10V supply to the pin 14, the output pulse is obtained at pin 4 as desired. The number of components used in TL494CN PWM circuit is less than the remaining pulse generation circuits and is very simple. A single capacitor is required for generating the pulse to trigger the power MOSFET used in a SEPIC converter.

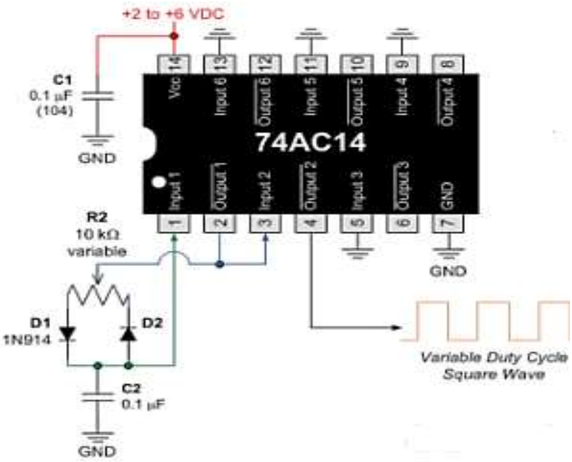


Fig. 3. Analog IC 74HC14 circuit diagram

3. Experimental results

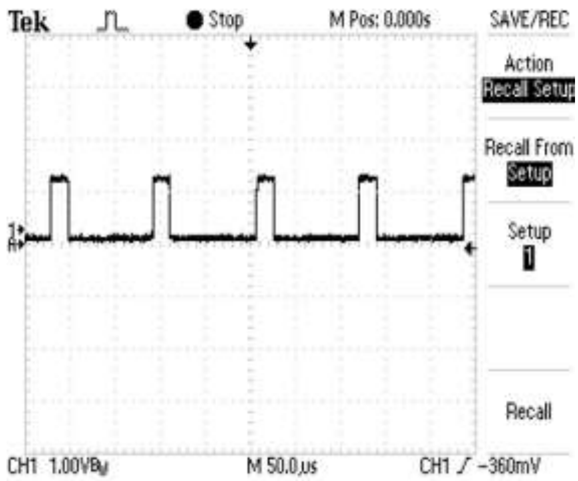
All the analog control ICs and their pulse generating circuits have experimentally tested to generate variable rectangular pulse width ranging from 10% to 90% which are ideal for to trigger the power MOSFET of a SEPIC converter. The power circuit is supplied by an input voltage of 10 V as per specifications given in Table 2 and the experimental set up is depicted in Fig. 4.

Table 2
Specifications of a SEPIC converter

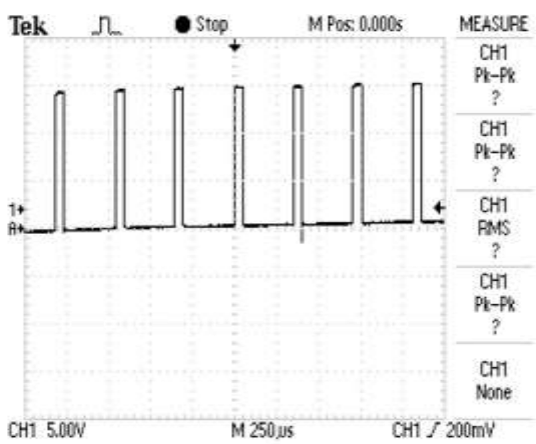
Parameters	Values
Input voltage	10 V
Switching frequency	10 kHz
Maximum duty cycle	90 %
Output current (max)	2A
Output load	15 Ω, 3A
Inductor L_1, current rating i_{L_1}	178µH, 12A
Inductor L_2, current rating i_{L_2}	178µH, 5A
Capacitor C_1, voltage rating V_{C_1}	10µF, 50V
Diode forward current, blocking voltage	15A, 60V
MOSFET switch	IRFP250
Diode	MBR30100CT
Power rating	50 W

The pulse waveforms are observed for a minimum duty cycle of 10 %, 50 % and a maximum duty cycle of 90% using IC 555, TL494CN and 74HC14P. They are illustrated in Fig. 5 to Fig. 7 for a load of 15 Ω which are ideal to trigger the MOSFET in a SEPIC converter for its respective buck and boost operation. The circuit is tested for various duty cycles with variable resistive load. The magnitude of the pulse is based on the supply voltage (+V_{cc}).

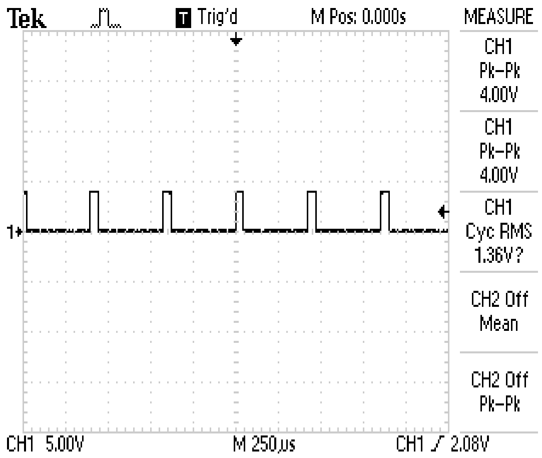
Fig. 4. SEPIC converter experimental set up



(a) 555 timer PWM pulses

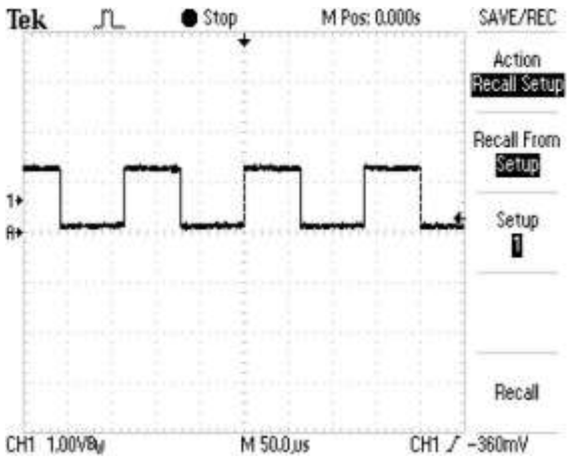


(b) TL494CN PWM pulses

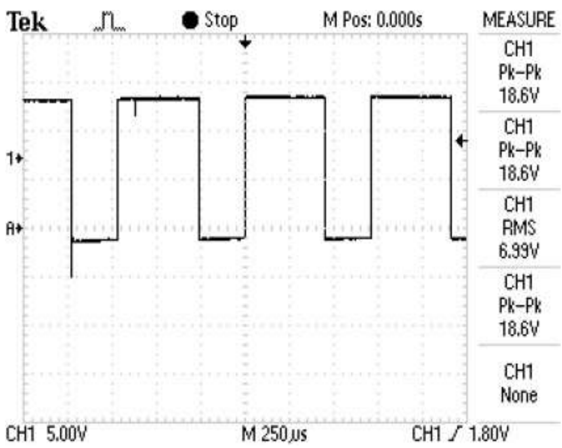


(c) Analog IC 74HC14 PWM pulses

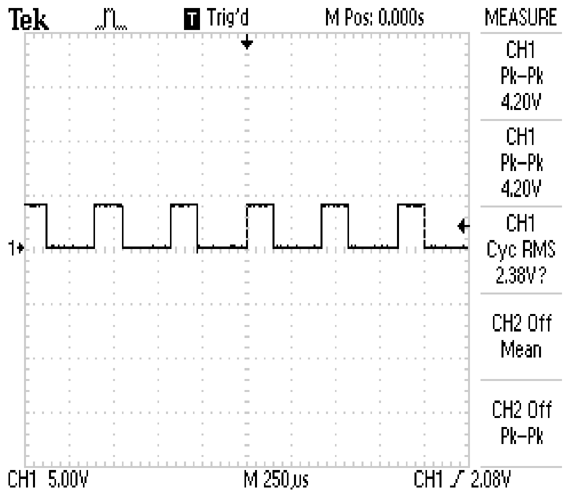
Fig. 5. PWM pulse waveforms for 10% duty cycle



(a) 555 timer PWM pulses

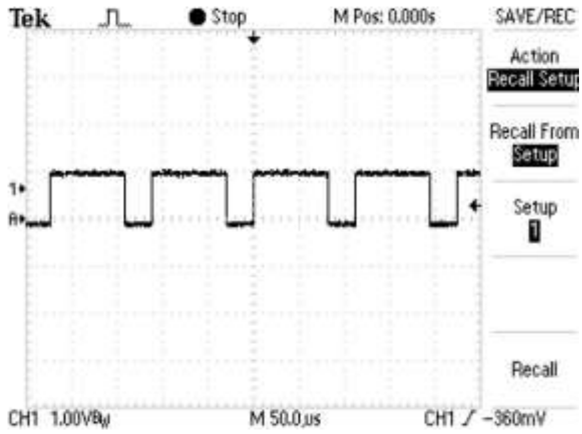


(b) TL494CN PWM pulses

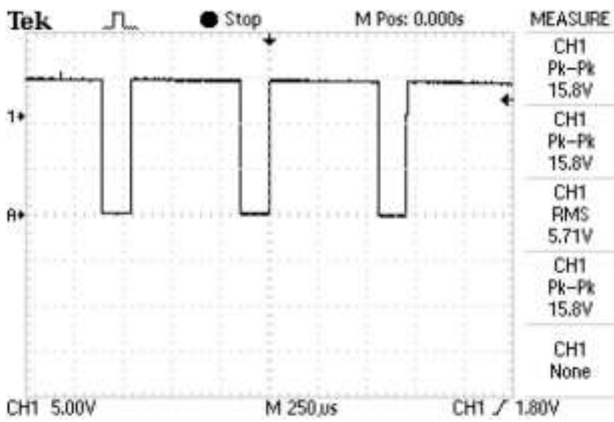


(c) Analog IC 74HC14 PWM pulses

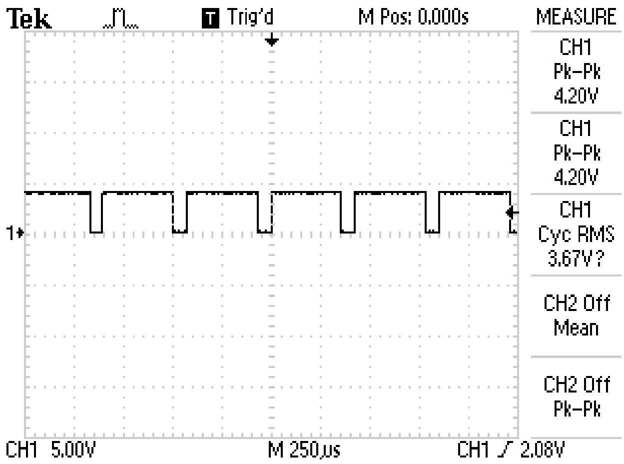
Fig. 6. PWM pulse waveforms for 50% duty cycle



(a) 555 timer PWM pulses



(b) TL494CN PWM pulses



(c) Analog IC 74HC14 PWM pulses

Fig. 7. PWM pulse waveforms for 90% duty cycle

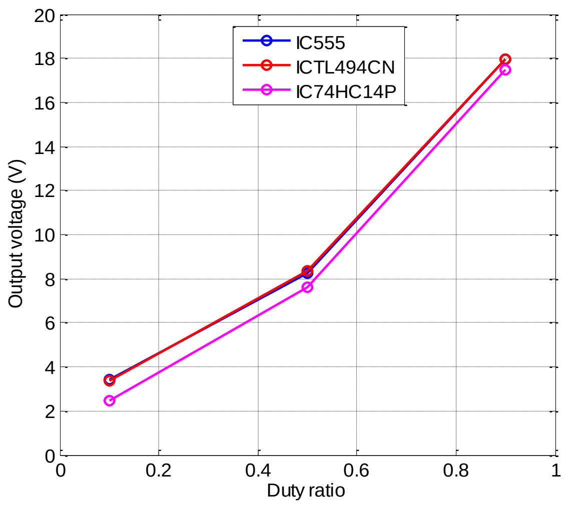


Fig. 8. Output voltage of a SEPIC converter

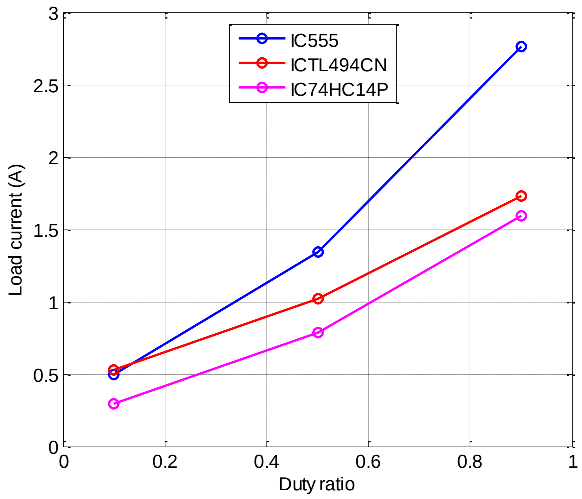


Fig. 9. Output load current of SEPIC converter

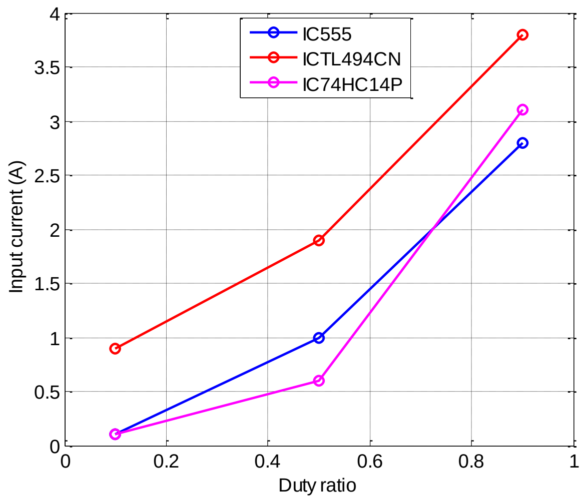


Fig. 10. Input current of a SEPIC converter

Fig. 8 shows the output voltage obtained by the control circuits using analog ICs specified for 10% (min), 50% and 90% (max) duty cycles. It is proved that the output voltage obtained by IC 555 and TL494CN remains same and the output voltage obtained by 74HC14 is less than the other two ICs for same duty cycles. The load current and the input current characteristics obtained from a SEPIC converter by the control circuits are illustrated in Fig. 9 and Fig. 10 respectively to prove the effectiveness of the control circuits. The TL494CN driver circuit gives additional loading effect to the SEPIC converter which makes to draw higher input current.

4. Conclusion

In this work, the performances of analog control ICs used for the control of a SEPIC converter are presented. Based on the experimental results, it is concluded that the SEPIC converter works desirably well as per the specifications in the experimental domain. All the three control circuits support the SEPIC converter to perform well in both buck and boost mode with a maximum duty of 90%. The number of external components is less in TL494CN PWM circuit than IC 555 and IC74HC14P pulse generation circuits. Analog control ICs minimizes the cost and size of the board and decreases the system complexity. They are especially desirable in small-scale systems. These simple control circuits can also be employed for Cuk converter and Zeta converter to test their performances experimentally with minimum cost.

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