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Soft Switched Power Converter for Sonar Transmitter

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ABSTRACT: This project presents a microcontroller based soft switched power converter for active sonar power transmitter. Sonar transmitter consists of underwater electro acoustic transducer elements, power amplifiers and associated electronics. Switch mode power amplifiers (SMPA) are the latest trend in sonar transmitter. Since operating frequency of class D power amplifiers are in the order of kHz, switching losses are very high which a serious concern on efficiency of the system. Soft switched converter as power amplifier is one of the methods to improve the efficiency. Soft switched converters have reduced switching losses, reduced EMI issues, high operating frequency, compact size and high efficiency. A method is proposed in this project for reducing losses in switch mode power amplifiers, in which a full bridge converter is operated in zero voltage switching. The simulation of the proposed system has been carried out using simulation software MULTISIM and the test results are presented.

KEYWORDS: Power Amplifier, Soft switching, transducer, full bridge, sonar, micro controller

I.INTRODUCTION

SONAR is an acronym for Sound Navigation And Ranging. Sonar works with the same principle as that of RADAR but uses acoustic waves instead of electromagnetic waves. Sonar system exploits acoustic energy for detection, localization, tracking & classification of underwater targets. The sonar system generates these acoustic waves using a piezoelectric transducers energized by power amplifiers with powers of the order of kilo-watts [1-2]. Nowadays Linear power amplifiers are replaced by switch mode power amplifiers because of very low efficiency. Under SMPA, class-S PAs got lower switching losses leading to higher efficiency and is chosen over class-D topology. A multilevel staircase output waveform improves quality of the waveform and reduces requirement of higher filter components [3]. However in SMPA at high switching frequency the switching losses are very high. The solution to this problem is implementing soft switching technique in SMPAs. The soft switching technique reduces the switching losses thereby increasing the efficiency. The EMI effects is reduced due to reduction in *di/dt & dv/dt*. The operating frequency of the power amplifier can be increased under soft switching condition thereby reducing overall size of the power amplifier. It offers a great advantage in ships and submarines where space constraints are present. The control signals for the power amplifier switching devices are generated using digital processors/controllers which reduce the overall size and provide advantage of programmability [4-6].

II.SONAR POWER AMPLIFIER

A generalized block diagram of a typical sonar power amplifier is given in Fig.1. A switch mode power amplifier consists of high power/voltage section, low power/voltage control section and data communication section. The high power/voltage section mainly consists of customized high voltage AC/DC converter, Controlled Full Bridge made up of semiconductor switches like MOSFETs & IGBTs, power transformer and power filter. A digital processor or microcontroller with inbuilt PWM modules are used to generate gate signals. These controllers have programmable dead band insertion feature which can be programmed during signal generation.

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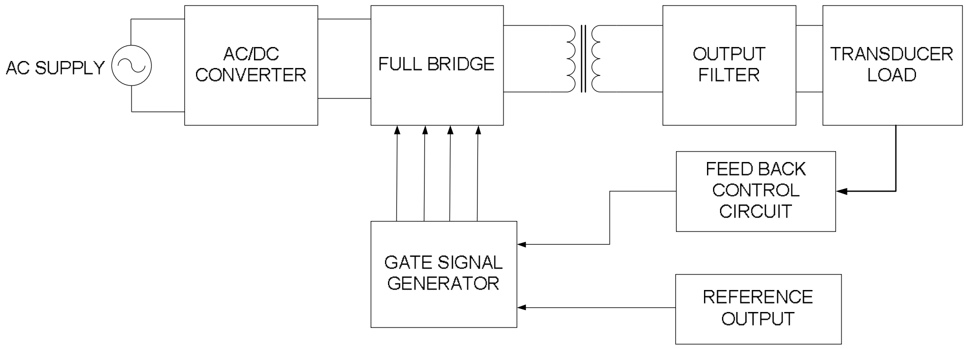

Fig. 1 Block schematic of sonar power amplifier for underwater transducer

The Class-D technique is generally used in low frequency underwater applications. However this technique has got limitation at higher operating frequencies. The switches in class-D PA are operated at carrier frequency which is atleast 12 times as that of modulating frequency. Hence the number of switching transitions are very high which produce high switching losses. This becomes significant when the operating frequency is in the order of tens of kilohertz which is close to maximum operating frequency of the devices. This reduces the efficiency of PA significantly. Class-S technique is a solution to above problem at higher frequencies where only two switching transitions are present [3].
The switching losses can be further reduced by implementing soft switching technique in the Sonar Power amplifier [7]. Soft switching offers a number of advantages over hard switched converters. The switch mode converters are subjected to high switching stress and high switching power loss which increase with frequency of the PWM. Another significant draw back of a switch mode operation is EMI produced due to large *di/dt* and *dv/dt* .The switching losses in DC-DC converter can be reduced by soft switching [8]

III.SOFT SWITCHED POWER CONVERTER

In this paper the simulation results of the proposed soft switching power converter for sonar power amplifier is presented. The proposed soft switched power converter improves the efficiency of sonar power amplifier by reducing the switching losses in the semiconductor devices. This topology is a cost effective solution which improves efficiency at higher operating frequency and reduce overall EMI effects. The block schematic diagram of proposed system is shown in Fig. 2.
The output of the full bridge is fed to the tank circuit consisting of a series connected inductor Lr and capacitor Cr. The tank circuit is connected to the primary of the transformer. The sine wave output across the secondary of the transformer is supplied to the piezoelectric transducer.

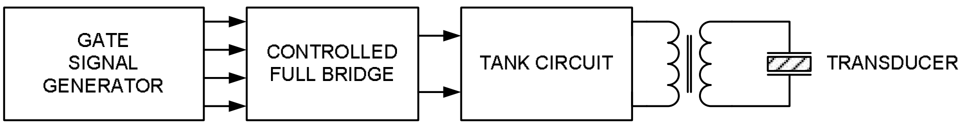

Fig. 2 Proposed soft switching converter

The controlled full bridge circuit is either fabricated using IGBT or MOSFET. MOSFET gain some advantages over IGBT in high frequency sonar power amplifier application. The gating pulse for the MOSFET can be generated using a simple microcontroller. The circuit diagram of the proposed converter is given in Fig.3. The operation of the system can be explained using four modes of operation.

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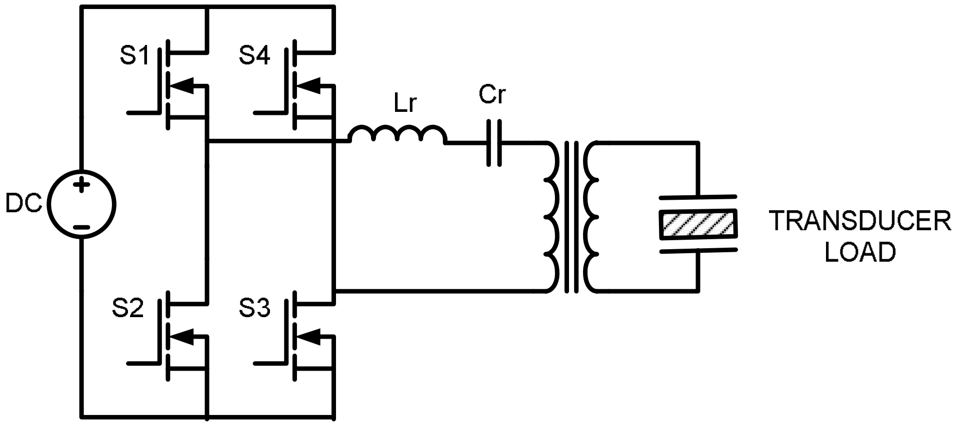

Fig. 3 Circuit Diagram of soft switched power amplifier

1) Modes of operation

The figure below shows the theoretical waveforms of the proposed soft switching converter during its four modes.

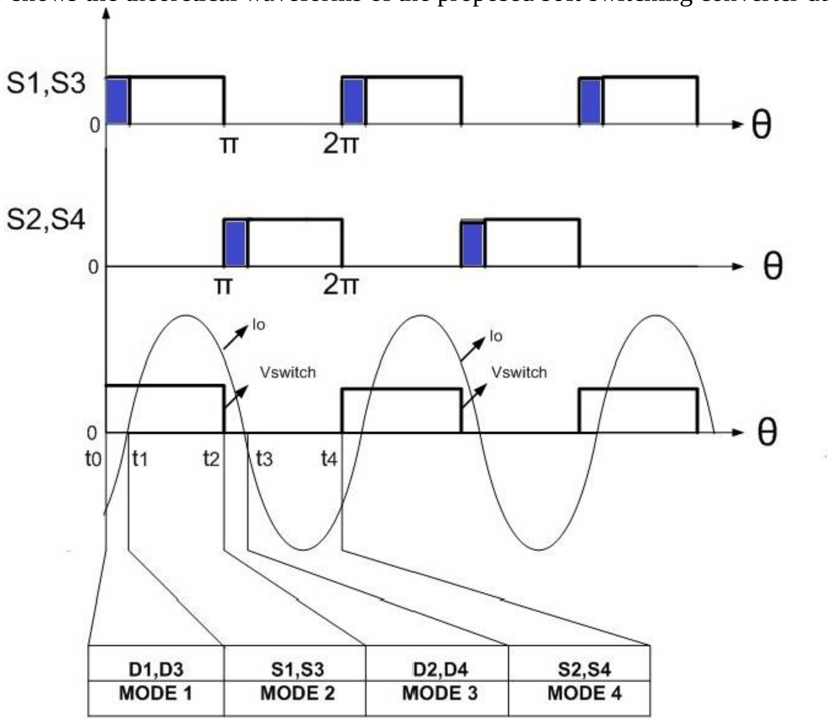

Fig. 4 Theoretical waveforms of the soft switched converter

a. *Mode 1 (t_0-t_1):* The gating pulses for switching devices S2 and S4 are OFF at t=t_0 and devices are OFF. The shaded portion of the pulses is the duration that anti parallel diodes D1 and D3 of switches S1 and S3 starts conducting the negative load (Io) current. The gate pulses for the switches S1 and S3 are OFF and hence the voltage of the switches is zero.

b. *Mode 2 (t_1-t_2):* The anti parallel diodes D1 and D3 are turned off at t=t_1.The switches S1 and S3 are turned on at t_1 under ZVS condition and positive load current I_0 flows to the load through the switches S1 and S3.

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c. *Mode 3 (t_2-t_3):* The switching pulses to S1 and S3 are turned off at t=t_2. The anti parallel diode D2 and D4 of switches S2 and S4 conducts the positive load current. The switches S2 and S4 are now completely OFF and ZVS is obtained.

d. *Mode 4 (t_3-t_4):* The anti-parallel diodes D2 and D4 are turned off at t=t_3.The switches S2 and S4 are turned on under ZVS condition and negative load current Io flows through the load.

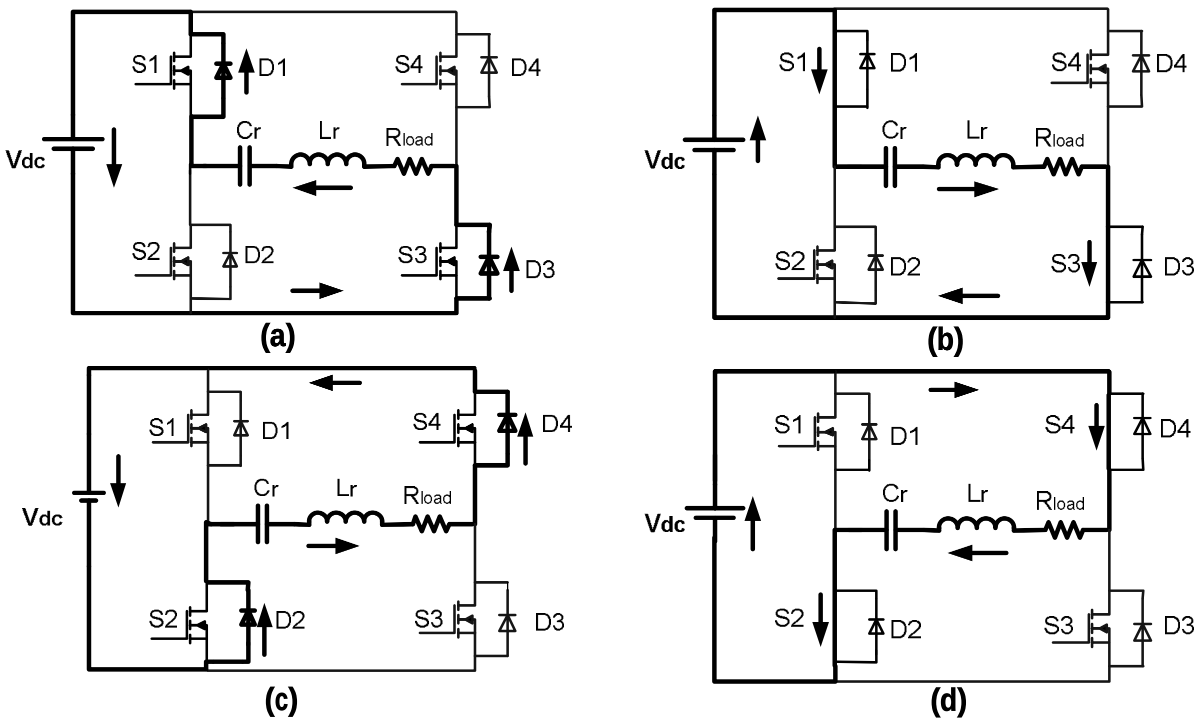

Fig. 5 Modes of operation. (a) Mode 1. (b). Mode 2. (c) Mode 3. (d) Mode 4.

2) Design of tank circuit

The resonant frequency (fr) of passive elements inductor Lr and a capacitor Cr can be written as

$$f_r = \frac{1}{2\pi\sqrt{L_r C_r}} \qquad (1)$$

This series tank circuit is connected in the primary of the transformer as shown in Fig.2. The tank circuit resonates the output voltage waveform across the secondary of the transformer. For achieving soft switching for a given switching frequency fs the resonant frequency should be less than or equal to the switching frequency. For a typical switching frequency of 35 kHz the tank circuit elements can be designed as follows.

Given fs = 35 kHz, Select Cr = 1µF
Solving the equation (1) for resonant frequency of 35 kHz we get Lr = 20µH

IV.SIMULATION RESULTS

A simulation study has been carried out using simulation software MULTISIM. The control signals for the MOSFETS in the full bridge converters are generated by a pulse generator which results in the switching of devices at desired frequency. The gate control signals is supplied to the full bridge converters are shown in fig 6. The switching frequency is 35kHz.The switches S1 and S3 are given square pulse with 50% duty ratio. Similarly to form negative half cycle of

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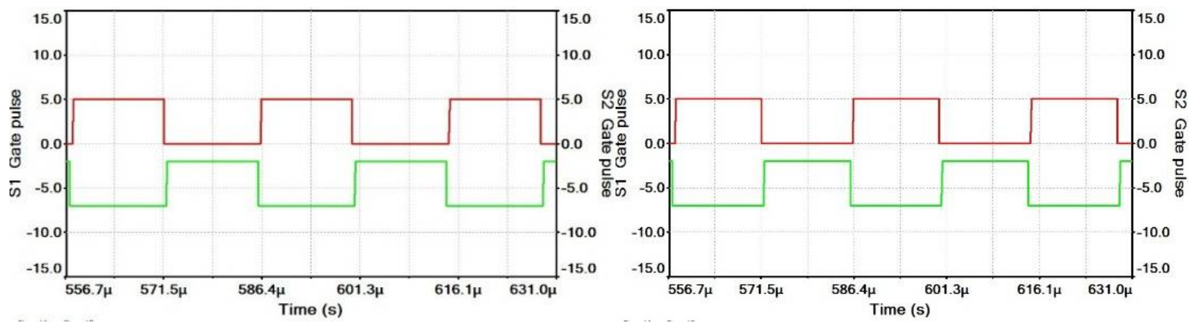
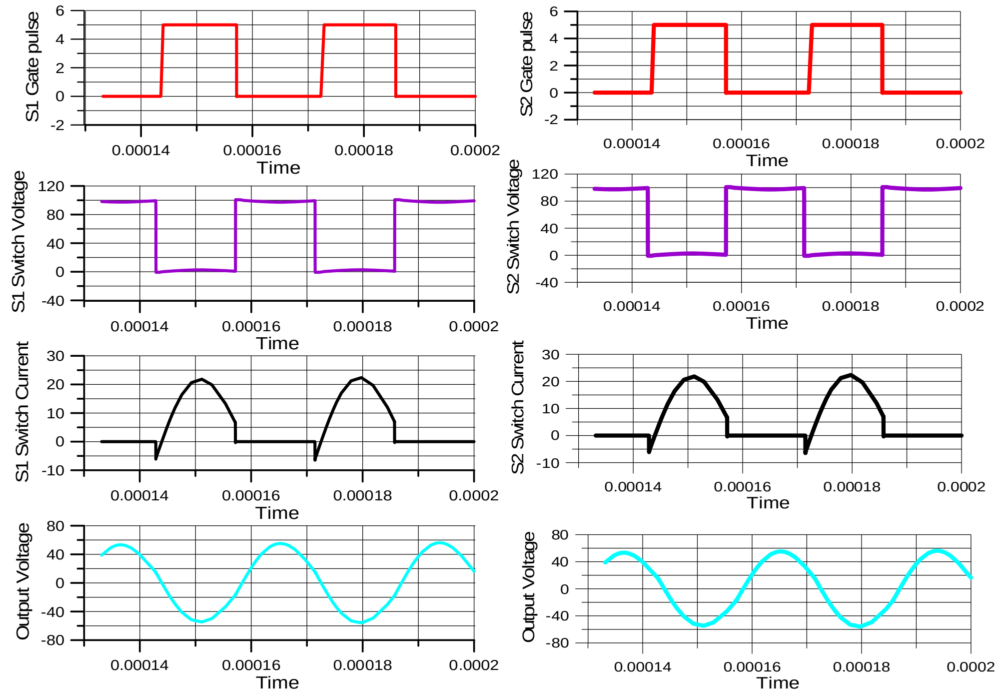
the output waveform switches S2 and S4 are given inverted square pulse of S1 and S3 with suitable dead band to avoid cross conduction of the switches of same leg.



(a) (b)

Fig. 6 Gate control signals for the MOSFETs at 35 kHz. (a) Gate signal for S1 and S2. (b) Gate signal for S3 and S4

The simulation is carried out different operating frequency and output power. Fig 7 shows the gate pulse, voltage, current and output voltage waveforms for switch S1 and S2 at 35 kHz switching frequency. From this it is understood that when the switch is turned ON there is a reverse current flowing through the antiparallel diode. Thus the switch is turned ON only after the switch voltage is reduced to zero. This ensures the ZVS turn on condition for the switches S1 and S2. Zero voltage switching reduces the switching losses thereby increasing the efficiency. The voltage and current transients are reduced at the switching instant. This reduces the EMI effect. Sinusoidal output voltage is obtained across the transducer load.



(a) (b)

Fig. 7 Switch Gate pulse, voltage, current, output voltage. (a) Switch S1. (b) Switch S2

The FFT analysis for the output voltage at 1 kW power output is shown in Fig 8. It shows that the 3rd harmonics is 73 dB below the fundamental.

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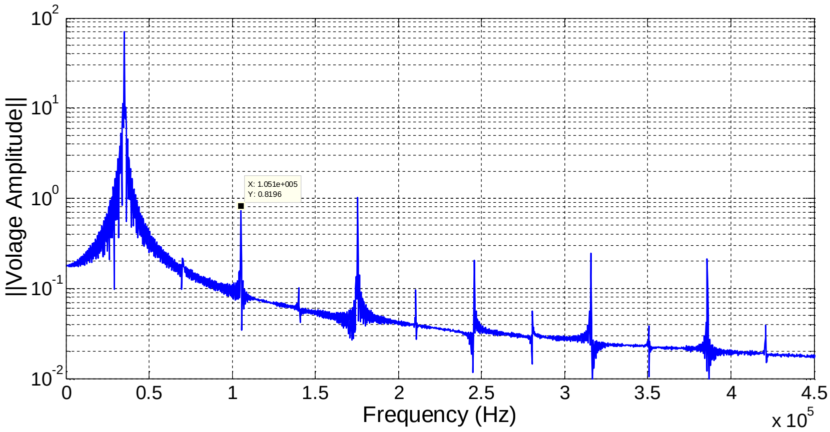

Fig. 8 FFT analysis of output Voltage at 1kW output power

VI.CONCLUSION

A Soft Switched power converter for sonar power amplifier is presented. The system gives many advantages like reduced switching losses, less EMI effects, increased operating frequency, reduced overall size and high efficiency. The system comprises of a soft switching technique which reduces the switching losses of the high power semiconductor devices of a full bridge topology compared to conventional full bridge converters. The use of a microcontroller dsPIC30F2010 which is a 16 bit digital controller for the generation of the control signal makes the system versatile with software updates. The proposed system is an apt solution as far as commercial competency and performance is concerned.

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