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IMPROVEMENT OF VOLTAGE STRESS ON MOTOR CONTROL HARDWARE VIA OPTIMAL LOCATION OF RC SNUBBER CIRCUIT

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ABSTRACT

While the increase in the customer failure rate in the consumer electronics sector affects the manufacturers negatively in terms of cost. It has also become one of the issues that cause customer loss and customer satisfaction. In addition to the economic losses, during the production and distribution of the spare parts and products that are changed at the customer's home due to the reliability problems experienced in the field, extra carbon emissions are released to the nature for this operation. For these reasons, it has become important to reduce the rate of customer failure.

With the increase in electronic components, the quality and reliability precautions that may occur in the electronic circuits, have become the subject of study today. As in many white goods products, it is advantageous to have variable speed motors in refrigerators due to energy efficiency and energy regulation issues. For this reason, the compressor of refrigerator comes to the forefront as the component that dissipates the highest power proportionally. With the use of variable speed compressors, the need for an electronic board with including power conversion and motor driving capability has arisen.

In this paper, RC Snubber circuits have been studied in order to prevent quality problems that may occur due to high switching frequency in flyback converter topology, which is one of the DC-DC converters that provide isolation. The methods in the literature based on the location of the RC Snubber in the circuit and the determination of its related values were examined and experiments were made on the simulation program. At the same time, a test mechanism was set up on the variable speed compressor motor control card of the refrigerator and measurements were taken with the help of an oscilloscope. The measurements taken in the simulation program and the experimental environment were compared.

Keywords: Refrigerator, Compressor, FlybackConverter, Snubber, Powerquality

1. INTRODUCTION

In recent years, with the growing human need for energy and running out of the natural energy sources, human being should find alternative sources or use the existing ones efficiently. In this way, energy saving practices and precautions will reduce the effects of carbon dioxide emissions and global warming which are serious threat to the future of the world [1]. In case of considering the total energy demand, the energy demand in the residentials (28%) has an important place after transport consumption (32%) in EU. Figure 1 pie chart indicates the energy demand with percentages in EU [2].

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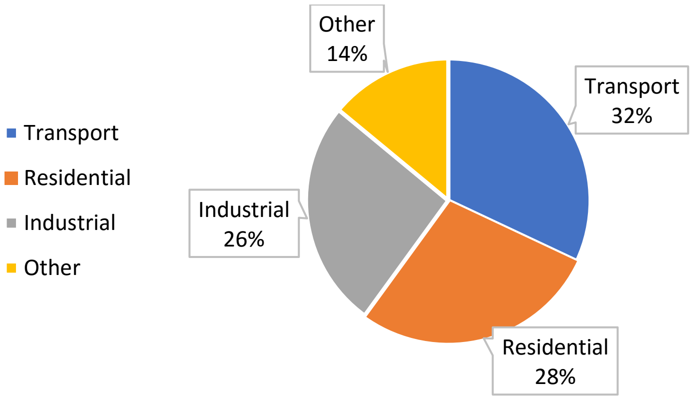


Figure 1. Energy demand percentages in EU

Accordingly, consumer electronics devices tend to consume less energy year by year. Figure 2 shows energy label usage on white goods product from 2015 to 2030 as classified business and low income household [3]. As a result of Figure 2, the number of high energy consumption products tends to decrease and the number of energy efficient product tend to increase by years. One of the providing method of producing energy efficient appliances is that use more electronic boards, components with including smart software.

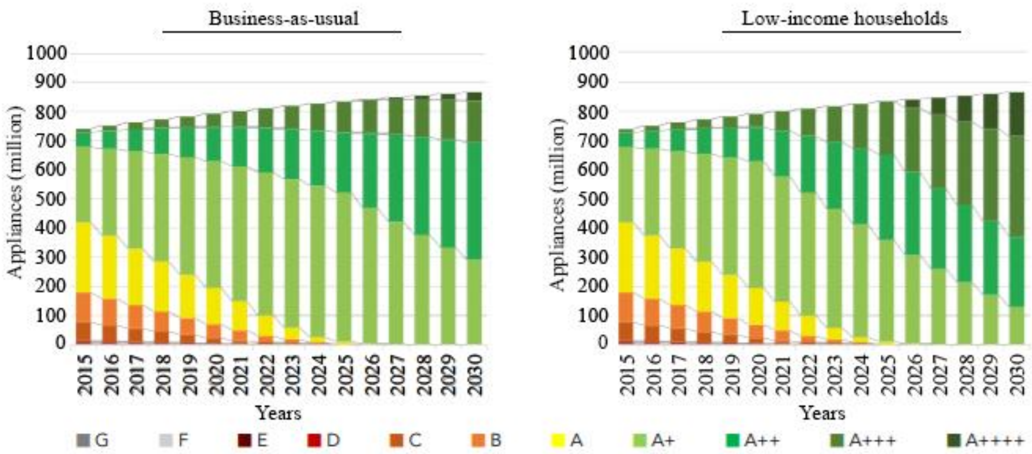


Figure 2. Household appliances energy label variation in case of number of appliances by years for 2015-2030[3]

While the number of electronic components and boards have been increasing day by day, their sustainability and repair costs are another rising issue for each consumer electronics manufacturer. A recent Eurobarometer survey indicated that the most common reason for purchasing a new digital device was the breakdown of the old product [4]. Also, according to conducted survey by Kantar TNS on behalf of Oslo Metropolitan University between 2018 and 2019, the electrical appliances that had broken down over the past two years are asked. Figure 3 indicates that respond of participants on survey. White goods appliances breaking down percentage takes a really important place like mobile phones. According to these results, while total white goods failures are 48%, mobile phone failures are 29%.

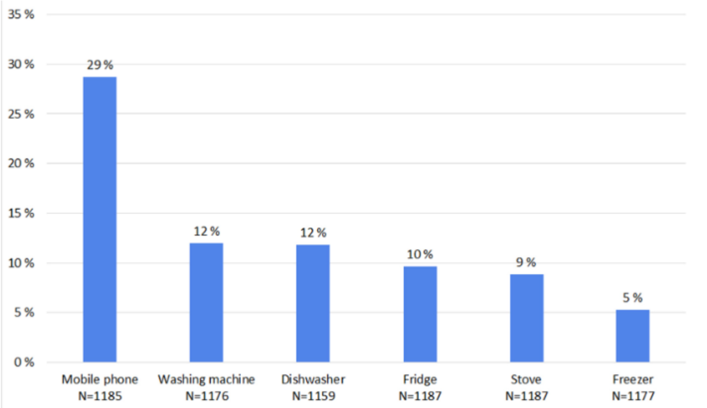


Figure 3. Proportional indication of the devices that have failed in the last two years of the survey participants (N: represents count of participant)[4]

In the view of such information, concentrate of decreasing repair quantities has been become as inevitable issue. In this study, one of the voltage stress decreasing circuit that is RC Snubber circuits on refrigerator compressor motor control board are examined. RC snubber location on circuit and RC value determination issue is examined with integrated of flyback converter circuit on refrigerator compressor motor control board.

Basically, the gas compression cycle refrigeration system is the heat transfer phenomena which provides to keep desired temperature in enclosed area, although outside of enclosed area temperature is varying. There are fundamentally four components of modern refrigeration systems which are compressor, condenser, expansion valve and evaporator. If it is wanted to be controlled more sensible in case of temperature and efficiency, more components could be added on refrigeration cycle such as sensors, actuators, electronic boards, smart cooling algorithms etc.

When it is considered about power or energy consumption perspective, the largest component of refrigerator is the compressor which is located back side of refrigerator. Also, refrigerator has auxiliary components which consume less power when it is compared to refrigerator compressor. These components could be defined as evaporator fans, condenser fan etc. Gas compression refrigeration cycle system flowchart is indicated in Figure 1.3 with the main lines [5].

In addition to four fundamental components of refrigerator, there is special refrigerant cooling liquid inside refrigerator system. This liquid swings round the refrigerator system cycle. The refrigerant cooling liquid may be fluid or gas form based on its characteristic inside refrigerator system. Also, it has a characteristic which transfers heat to the environment [6].

One of the extensive ways of DC-DC converter is flyback converter in terms of from high voltage to low voltage as providing isolation of SMPS topologies. Good measure of voltage and current stress are taken place on flyback circuit in case of relatively high frequencies. Due to natural characteristics of transformer, it stores related energy in case of switch on. Then, releases the energy to the output side of transformer during switch off time. Naturally, the windings of transformer are not distributed in case of coupling to the core. Because windings are isolated physically from each other. Therefore, there are energy stored between isolated windings which causes to occur leakage inductance [7].

Switching frequency increasing operation brings some drawbacks which could be defined as inefficiency, reliability problems and high EMI level. Also, voltage or current spikes, high dv/dt, di/dt or ringing signals could be occurred on implemented circuits. Particular snubber circuits are designed in order to take precautions to the unconformities which are mentioned above sentences. These unconformities create the aim of snubber circuits existence [8].

2. METHODS

It is really helpful to be able to observe the set up circuit on the simulation programs before putting it into practice. There is possible to manage recursive actions without using simulation programs in project. At the same time, simulation works could be used as pathfinder. Also, the results on simulation program gives clue about specific research issue.

On the other hand, there could be diversity between simulation program results and real experimental results. Rate of diversities depends on how real life parameters and dynamics are inserted on simulation programs. Sometimes, the ability of simulation programs can not enough to simulate real life variables with all parameters. One of the important things the difference between simulation and real life results is that interpret or estimate which parameters could cause the variation.

In this simulation work, behavior of flyback converter switching signal is examined. The mentioned circuit is used on refrigerator motor control board. The refrigerator motor control board input is chosen as 230Volt AC which is possible to represent house grid in European Region. Later on, AC house grid is rectified to DC supply signal. After rectification, this signal is forwarded to flyback converter as an input. Psim simulation circuit includes flyback converter which has a input of rectified house AC power supply and generates 15Volt output. Different types of RC circuits are applied to the flyback converter circuit on simulation program.

Before starting on experimental works on refrigerator compressor motor board, the simulation works are executed on Psim program. The signal between Drain and Source of flyback MOSFET are examined on simulation program. This signal characteristic is one of the important reasons of MOSFET failure issues in the long term at customers houses. The signal is aimed to examined about three criteria which is overshoot value, settling time and peak value. The fundamental definitions of these terms are explained in next paragraph.

Peak value could be defined as the maximum value of electrical signal or waveform in negative or positive side. Overshoot is the occurrence of a signal or function exceeding its target value. Undershoot is the same phenomenon in the opposite direction. Settling time is the time required for an output to reach and remain within a given error band following some input stimulus. Another useful definition is about ringing. Ringing is an unwanted oscillation on signal which could be voltage or current. If it is possible to obtain frequency of oscillation, it is called ringing frequency. Ringing frequency is assigned on oscillation part of signal. All related definitions are indicated on Figure 4 in order to visualize the used terms.

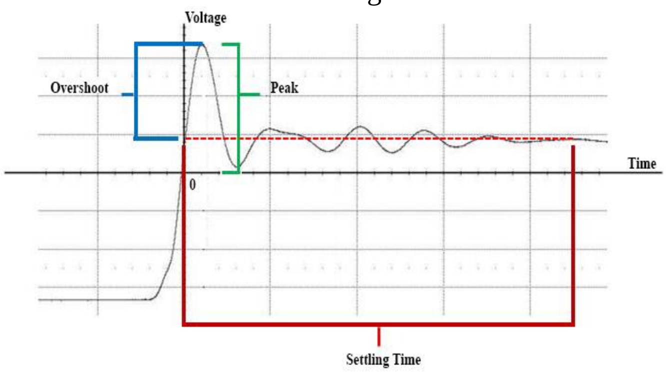


Figure 4. Explanation of Peak, Overshoot and Settling Time terms on sample signal

First of all, there is no snubber or additional circuit is used on flyback converter circuit in order to observe current status between drain and source pins of flyback converter MOSFET. Installed circuit on Psim simulation program is indicated with details in Figure 5.

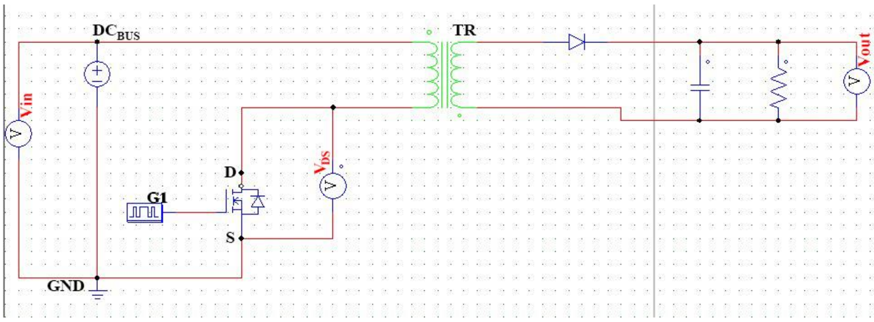
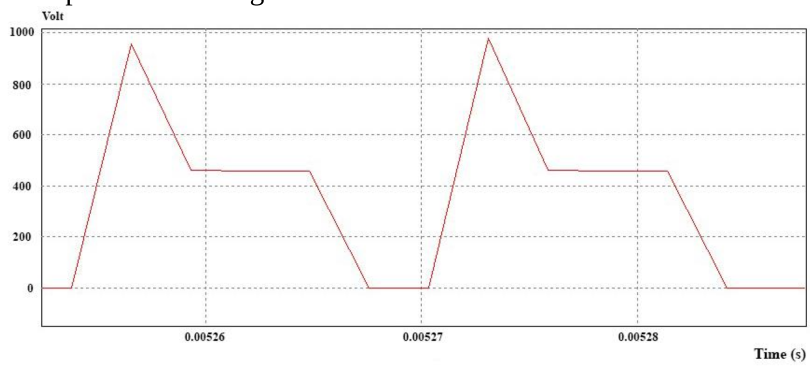


Figure 5: Flyback Converter circuit diagram without snubber on simulation program

The set up circuit includes DC voltage source(rectified from 230V AC power supply) as input, switching MOSFET, transformer and output passive components. The output of flyback converter is 15Volt which is necessary to supply other components of refrigerator motor control board.

As a first step, the signal between drain and source of MOSFET is observed on simulation circuit. In this circuit, existing component values of refrigerator compressor motor control board are used to simulate current situation. According to simulation program result, peak value, settling time and overshoot values are processed on Figure 6.



Peak (Voltage)	Settling Time (uS)	Overshoot (Voltage)
951	5	494

Figure 6. Obtained signal waveform which is measured between drain and source pins of MOSFET on simulation program in case of no snubber. Also, Peak, Overshoot and Settling time values are indicated

In this paperwork, two method of calculation RC values is examined about assigning appropriate RC values on refrigerator compressor motor control circuit flyback converter MOSFET. One of them is about assigning RC values on Buck converter [9]. Another one is related to obtain RC values on Flyback Converter [10]. The RC values are tried to assign on refrigerator compressor motor control board circuit. Below section includes about implementation of Ridley's method (2005) in case of RC values calculation.

The RC snubber circuit values should be designed based on used circuit type.

- As a first step, there are two measurements are needed to proceed next steps of calculations. One of them is total effective capacitance or the other one is leakage inductance. Capacitance is hard to define and measure when it compared to measure leakage inductance. It is a combination of nonlinear semiconductor junction capacitances, transformer winding capacitance, and any other stray capacitances such as heatsinks. In this case, measure leakage inductance is more useful with frequency response analyzer or LCR meter. LCR meter was used in order to measure leakage inductance on refrigerator compressor motor control hardware.

- A short circuit is implemented to secondary part of flyback transformer. Then, impedance of primary part of flyback transformer is measured. As expected, impedance value is varying depends on applied frequency. According to the method, ringing frequency of snubber signal was taken as reference. So, 6 micro Henry was measured, in case of refrigerator compressor motor control board ringing frequency(6.4Mhz) which is shown in Figure 7 as red dashed borders. Figure 9.4 indicates the signal between drain and source of MOSFET which is located on refrigerator compressor motor control board flyback converter as it could be seen zoomed format.

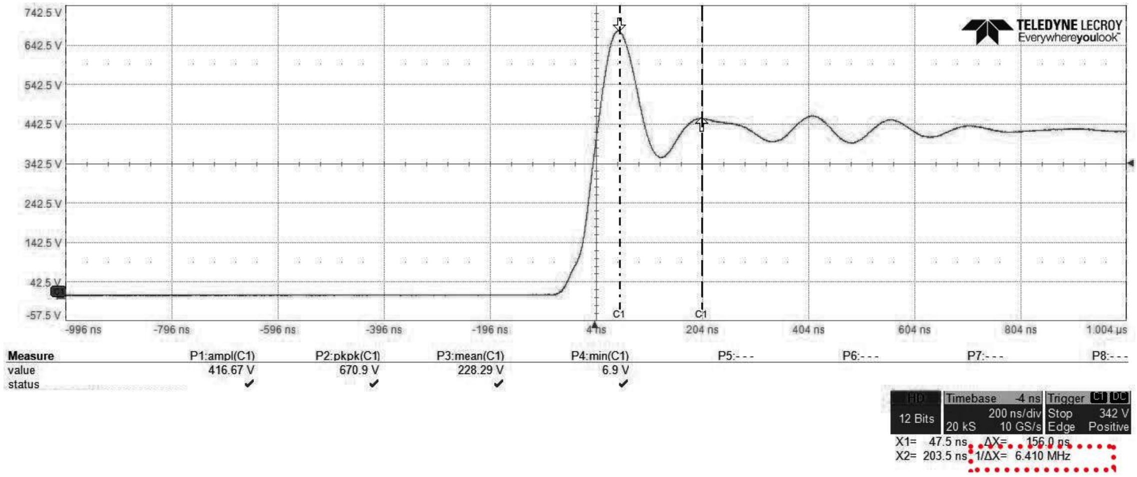


Figure 7. Obtained signal from oscilloscope which has ringing frequency 6.4 Mhz as it could be seen red dashed border

- Next step is that find characteristic impedance of flyback circuit. Below formula was used in order to calculate characteristic impedance. Z=R equalities is used when select resistor value. Also, characteristic impedance formula is indicated as below. According to below equation, appropriate resistor value is found as 200 Ohm.

$$Z = 2\ \pi\ L\ f_r$$

- After obtain resistor value, capacitor value should be calculated. According to method of Ridley (2005), below formula is used to find capacitance value of RC snubber circuit. In this case, 2nF capacitance value is founded.

$$C\ =\ \frac{1}{2\,\pi\ f_r\ \ R}$$

The resistor and capacitor values which are founded with Ridley's method (2005), are applied on simulation program based on refrigerator compressor motor control board flyback circuit. Also, the location of RC circuit is another critical working point. RC circuit could be connected to circuit as below combinations. Below combinations of RC circuit location on flyback converter is realized on simulation program with using RC values which is determined by the help of Ridley method (2005).

- Parallel connection of RC which is paralleled between drain and source pin of MOSFET
- Serial connection of RC which is paralleled between drain and source pin of MOSFET
- Parallel connection of RC which is paralleled between positive side of DC BUS signal and Drain pin of MOSFET
- Serial connection of RC which is paralleled between positive side of DC BUS signal and Drain pin of MOSFET

As a second step, a simulation circuit is set up as parallel connection of RC which is paralleled between drain and source pin of MOSFET. Figure 8 is indicated setting up circuit configuration on simulation program.

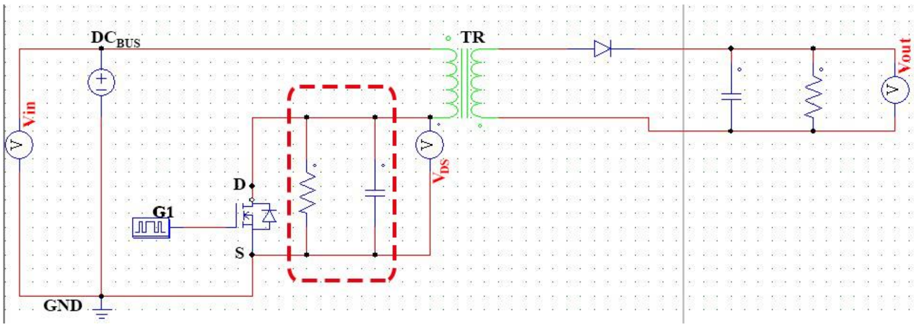
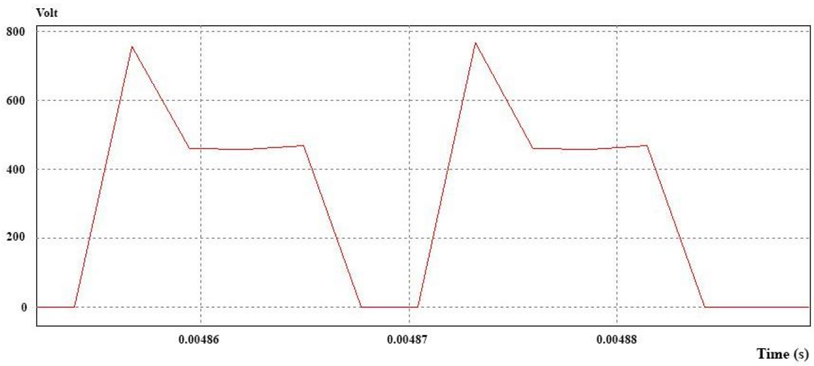


Figure 8. Flyback Converter circuit diagram, parallel connection of RC which is paralleled between drain and source pin of MOSFET on simulation program

When the circuit structure in Figure 8 is set up, the following signal is obtained which is shown on Figure 9. In this case, the signal between drain and source of MOSFET are acquired once again. The output of simulation program is shown on Figure 9.6. Also, peak value, settling time and overshoot values are processed on Figure 9. On the graph, the horizontal axis represents the time, the vertical axis the voltage.



Peak (Voltage)	Settling Time (uS)	Overshoot (Voltage)
767	6	308

Figure 9. Measured signal between drain and source pins of mosfet on simulation program in case of parallel connection of RC which is paralleled between drain and source pin of mosfet. Also, Peak, Overshoot and Settling time values are indicated

In third phase of simulation work, serial connection of RC which is paralleled between drain and source pin of MOSFET. The setup circuit is close to conventional RC snubber circuits. Figure 10 shows the schematic of circuit that is realized on simulation program.

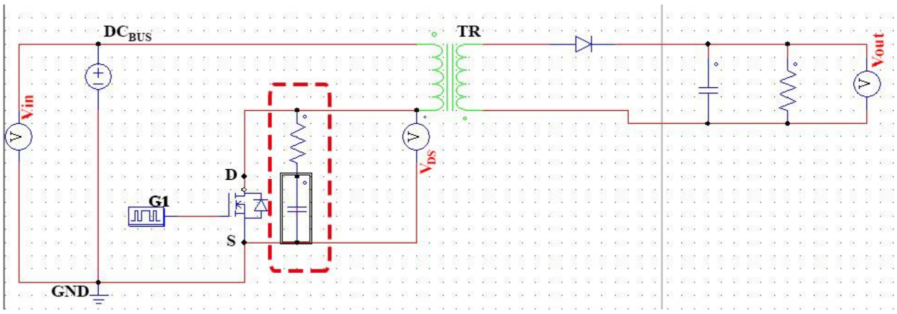
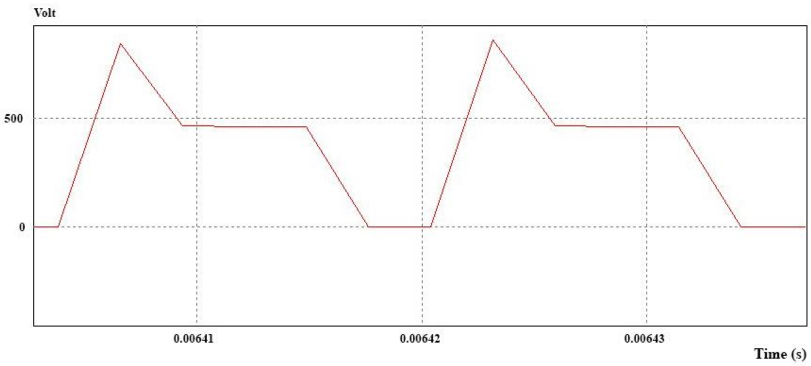


Figure 10. 4 Flyback Converter circuit diagram, serial connection of RC which is paralleled between drain and source pin of MOSFET on simulation program

When Figure 10 is applied on simulation program, the signal between drain and source of MOSFET are noted as below output signal. When this MOSFET signal is examined, peak value, settling time and overshoot values are added on Figure 11, numerically. On the graph, the horizontal axis represents the time, the vertical axis the voltage.



Peak (Voltage)	Settling Time (uS)	Overshoot (Voltage)
853	6	393

Figure 11. Measured signal between drain and source pins of MOSFET on simulation program in case of serial connection of RC which is paralleled between drain and source pin of MOSFET. Also, Peak, Overshoot and Settling time values are indicated

In the fourth step of simulation works, the circuit was set up which can be expressed as parallel connection of RC that is paralleled between positive side of DC BUS signal and Drain pin of MOSFET. Psim simulation program circuit representation is indicated in Figure 12.

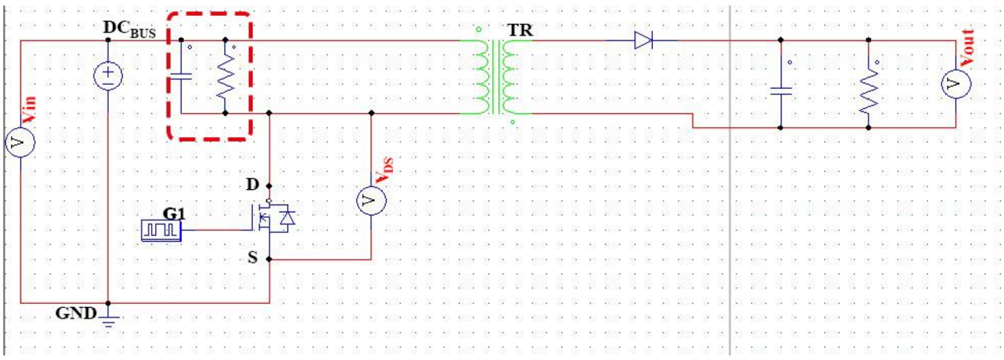
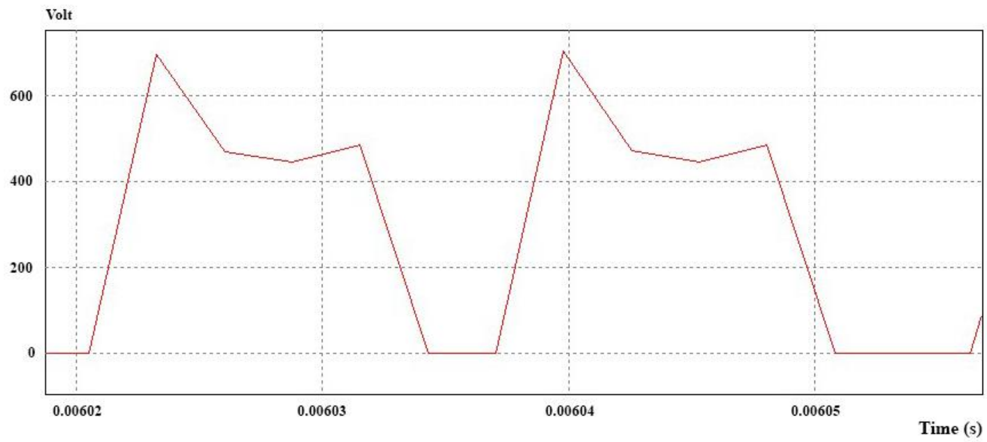


Figure 12. Flyback Converter circuit diagram, parallel connection of RC which is paralleled between positive side of DC BUS signal and Drain pin of MOSFET on simulation program

When the circuit in Figure 12 is implemented on simulation program, drain and source pins of the MOSFET is observed. Acquired waveform from simulation program could be seen in Figure 13. On the graph, the horizontal axis represents the time, the vertical axis the voltage. Similar to the previous situation, peak value, settling time and overshoot values are noted in Figure 13.



Peak (Voltage)	Settling Time (uS)	Overshoot (Voltage)
693	5	232

Figure 13. Measured signal between drain and source pins of MOSFET on simulation program in case of parallel connection of RC which is paralleled between positive side of DC BUS signal and Drain pin of MOSFET. Peak, Overshoot and Settling time values are indicated

In the last step of simulation work, another RC circuit location trial is examined. In this simulation work, serial connection of RC which is paralleled between positive side of DC BUS signal and Drain pin of MOSFET is set up on simulation program. The circuit representation is shown in the Figure 14 as below.

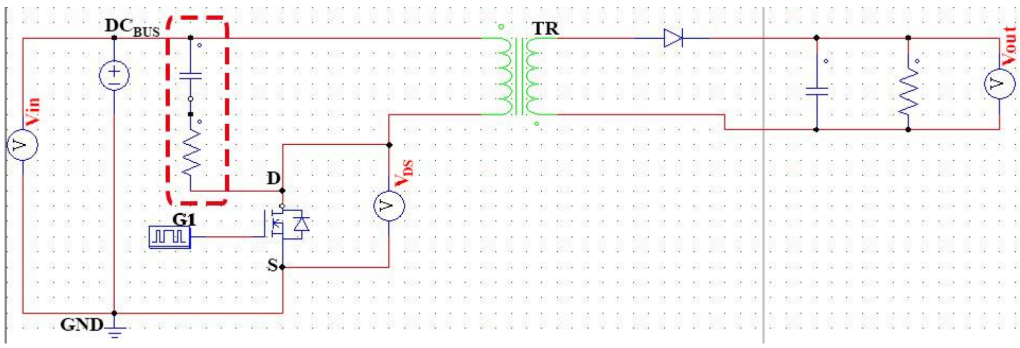
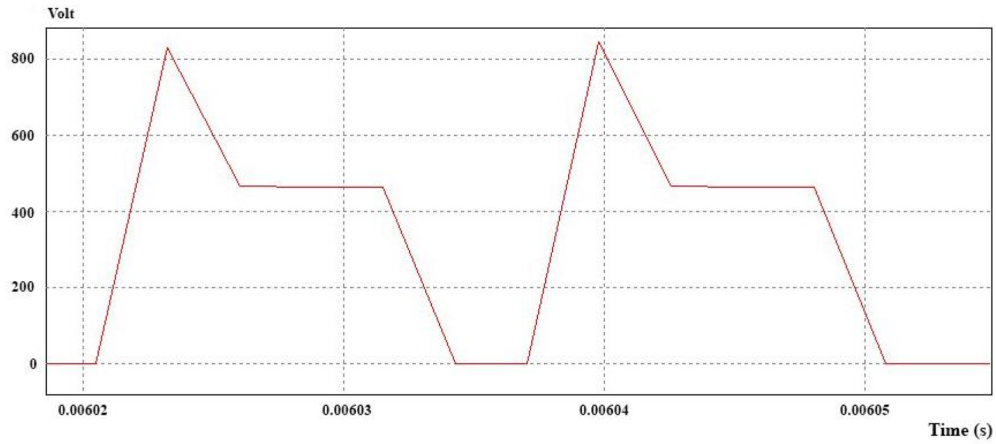


Figure 14. Flyback Converter circuit diagram, serial connection of RC which is paralleled between positive side of DC BUS signal and Drain pin of MOSFET on simulation program

The output between drain and source of MOSFET is obtained from simulation program. Obtained waveform is shown Figure 15. On the graph, the horizontal axis represents the time, the vertical axis the voltage. As in previous experiments, peak value, settling time and overshoot values are noted in Figure 15.



Peak (Voltage)	Settling Time (uS)	Overshoot (Voltage)
844	5	379

Figure 15. Measured signal between drain and source pins of MOSFET on simulation program in case of serial connection of RC which is paralleled between positive side of DC BUS signal and Drain pin ofMOSFET. Peak, Overshoot and Settling time values are indicated

The first method for assigning RC values and simulation works has been explained in previous paragraphs. In this section, about determination of RC values snubber circuit will be explained with details by using Rohm method (2016).

In Rohm method (2016), it obviously states that parasitic inductances and parasitic capacitances cause a resonance in input loop. In addition to this information, RC values calculation procedure is expressed in detail. The formulization of snubber resistor and snubber capacitor calculation is explained as below.

$$R_{SNUBBER} = 0.65 \times \sqrt{L_P} / \sqrt{C_{P2}}$$

$$C_{SNUBBER} = 8 \times C_{P2}$$

In this formula, C_{P2} can be calculated as divided by three of C_{P0}. C_{P0} is a capacitor that is connected between switch node and ground of circuit. C_{P0} is a capacitance value which the ringing frequency is decreased by a factor of 2. Therefore, in order to find snubber resistance and capacitance, there should be found C_{P2} and C_{P0} capacitance values according to formulization.

Before work on simulation program with RC values, there should be found C_{P0} capacitor value on real circuit that is specific on refrigerator compressor motor control board. The ringing frequency of obtained signals from simulation program does not readable. Because, in order to measure ringing frequency, at least 2 oscillation should be observed on signal.

According to Rohm method (2016), a target to find the capacitor value that halved the ringing frequency on refrigerator compressor motor control board. As it is seen on Figure 7, the ringing frequency of our circuit is 6.4 Mhz. Therefore, we expected to acquire approximately 3Mhz with addition of C_{P0} capacitor on refrigerator compressor motor control board flyback converter circuit. In this context, different capacitor values are connected on refrigerator compressor motor control flyback circuit. Firstly, 220 uF dc bus capacitor is selected as C_{P0} capacitor. The ringing frequency is obtained about 35Mhz as it could be seen in Table 1.

Table 1. Selected C_{P0} versus obtained ringing frequency on refrigerator compressor motor control board

Selected C_{P0} Capacitor	Ringing frequency
No RC component addition(current status)	6.4 Mhz
220 uf	35.3 Mhz
2 nf	5.7 Mhz
100 pf	5.3 Mhz

When the C_{P0} value is increased, ringing frequency is also increased. In line with this logic, the value of C_{P0} should be chosen smaller. Therefore, C_{P0} capacitor values are decreased until 100 pf which gives 5.3 Mhz ringing frequency. If this logic continues, about femto farad capacitor values could satisfy the demand which is half of ringing frequency. It does not reasonable to supply and obtain capacitor values in femtofarad value in our experimental environment. Due to this reason, it does not continue Rohm method(2016) recommended capacitor value on our refrigerator compressor motor control board.

Besides having an idea about the results by working with the simulation program, it is also important to prepare an experimental environment and observe what kind of results obtained in the real environment. In this paper, the refrigerator variable speed compressor motor control board is used to realize flyback converter snubber effects. Experimental studies were carried out on the flyback converter region on the refrigerator compressor motor control card. Flyback converter region is shown on refrigerator compressor motor control hardware in Figure 16.

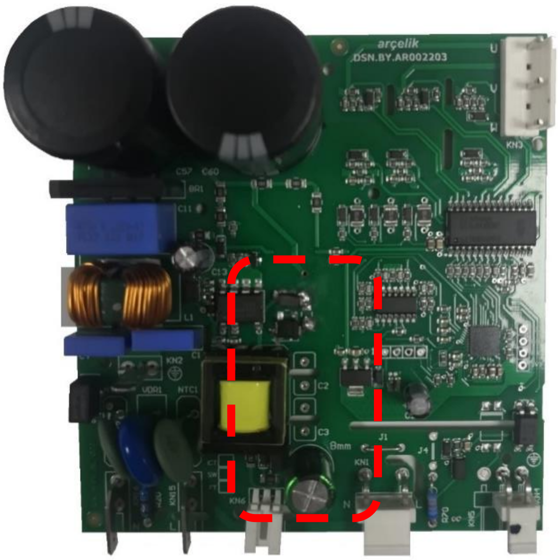


Figure 16. The indication of flyback converter region on refrigerator compressor motor control board

Variable speed compressor is placed at the back side of refrigerator. There is an evaporator tray on the variable speed compressor. Also, refrigerator compressor motor control board is combined with variable speed compressor on cooling product. AC power supply at home enters the refrigerator compressor motor control boards.

Electronic component modification on refrigerator compressor motor control board has been conducted with the help of auxiliary bread board. Because flyback converter structure has been already implemented on PCB of refrigerator compressor motor control board. Therefore, RC circuit modifications are executed on bread boards.

In order to measure between drain and source of MOSFET, Teledyne Lecroy (HDO4054) brand oscilloscope was used. Two wire are soldered on refrigerator motor control board for connection of oscilloscope. Each measurement is executed with variable speed compressor connected to variable speed compressor motor control board. Also, experiments are executed at Arçelik Refrigerator - Compressor Plant R&D laboratory, Turkey. The experiment environment could be seen in Figure 17 with details.

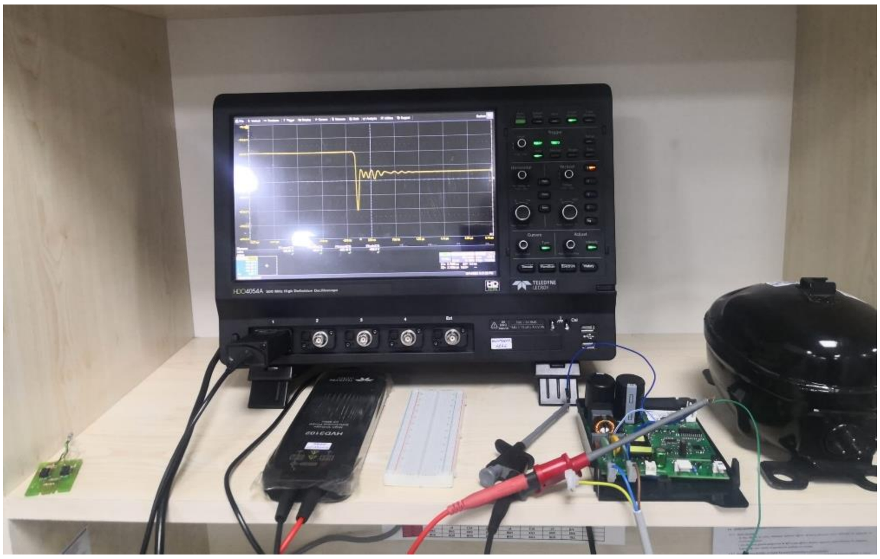


Figure 17. Indication of experimental environment which includes, ossiloscope, variable speed compressor, refrigerator compressor motor control board

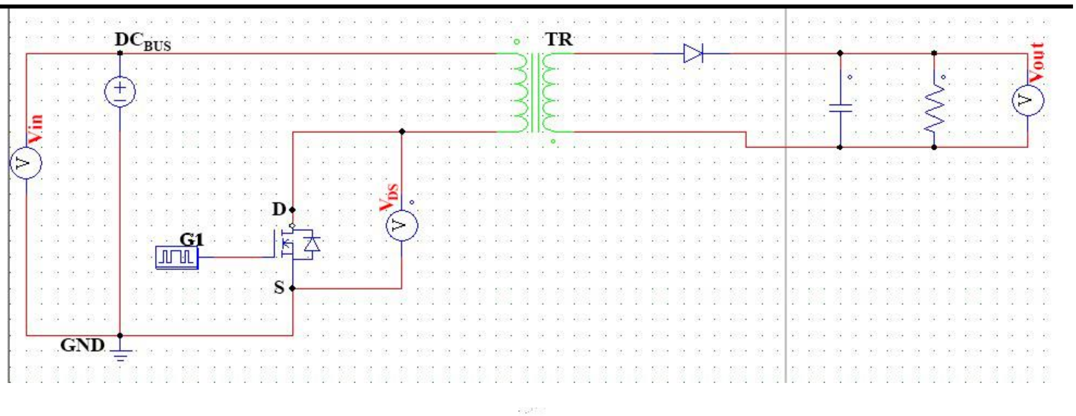
Experimental works is another important point for many projects. The detailed information about experimental test environment was given in previous pharagraphs. After simulation works with different scenarios of RC circuit addition, combination of RC circuits is applied on experimental test environment.

In this section, experimental works are explained step by step. Two RC snubber values estimation methods was evaluated in simulation part which is Ridley & ROHM methods. However, second method RC values is not feasible for our refrigerator compressor motor control board circuit as explained in previous part. For this reason, first method RC values was implemented on refrigerator compressor motor control board and explained in detail. In addition, different combination of location of RC circuit is implemented on refrigerator compressor motor control board as simulation works are executed on previous section of paper.

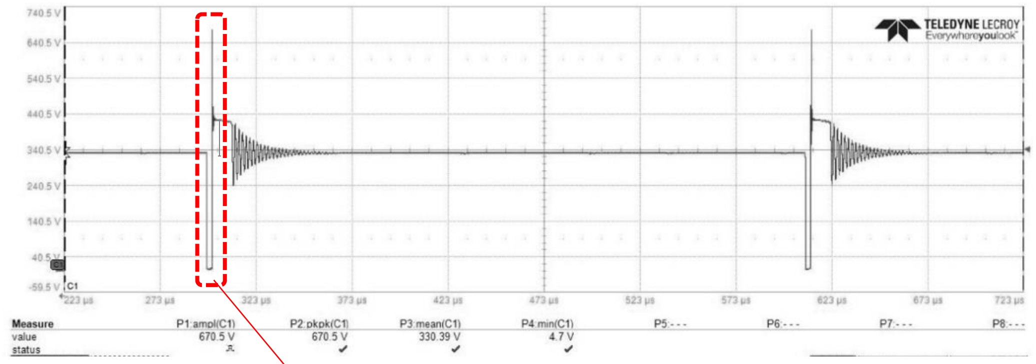
The first experiment is about no snubber on flyback converter of refrigerator compressor motor control board as default. The purpose of this experiment is that see current state of refrigerator compressor motor control board in case of the signal between drain and source of flyback converter MOSFET. The simulation result was shown in previous section without snubber RC on flyback converter. In this case, the circuit representation for refrigerator compressor motor control board is indicated as Figure 18. The experimental result is shown in Figure 18. The signal which is captured by way of oscilloscope measurement, between drain and source of flyback converter MOSFET. The settling time, peak and overshoot value are indicated in table which is located in Figure 18.

Peak	Settling Time	Overshoot
670,9	50	340,5

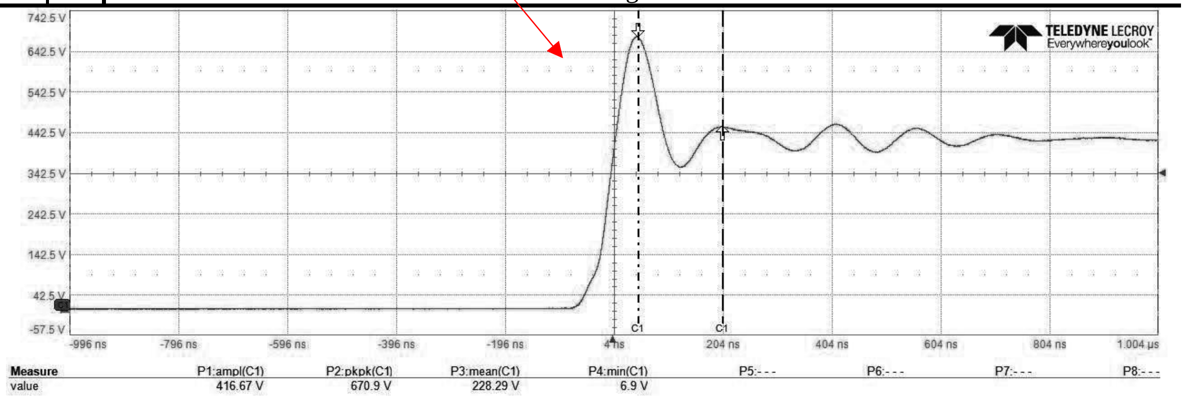
a. Peak, Overshoot and Settling time values



b. Flyback Converter circuit representation without snubber on simulation program



c. Obtained signal waveform which is measured between drain and source pins of MOSFET on simulation program in case of no snubber. Red dashed border indicates the zoomed format of signal.



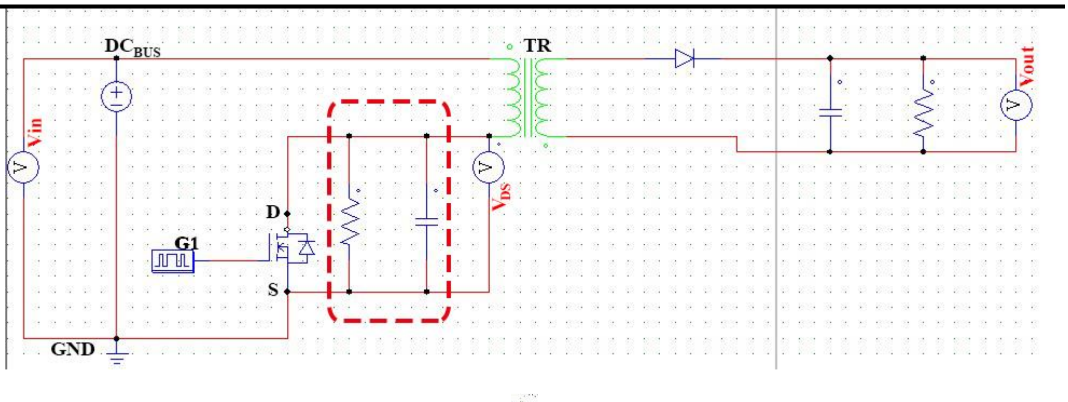
d. Zoomed signal in part C.

Figure 18. Obtained signal waveform which is measured between drain and source pins of MOSFET on simulation program in case of no snubber. Also, Peak, Overshoot and Settling time values are indicated

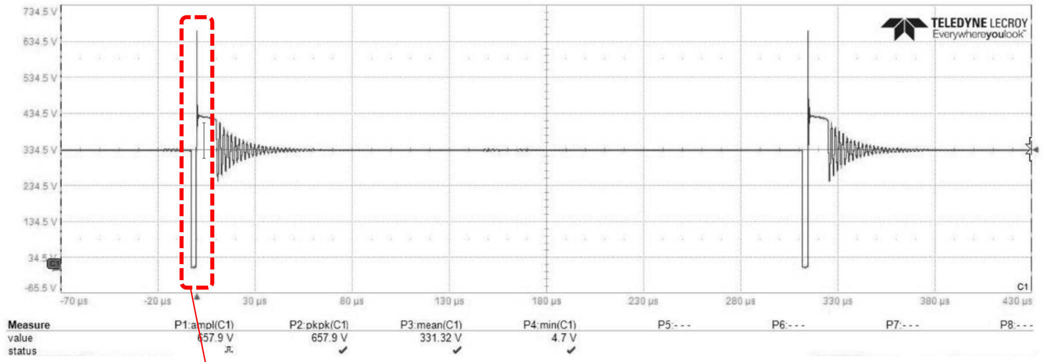
As the second step of experimental work, the RC circuit addition is implemented on refrigerator compressor motor control board. This modification could be expressed as parallel connection of RC which is paralleled between drain and source pin of MOSFET. In this circuit, all circuit component values are taken by refrigerator compressor motor control board except RC values. The circuit diagram of the set up circuit is shown as Figure 19. The output signal is gathered with using oscilloscope. The signal measurement is taken between drain and source pin of flyback converter MOSFET. In this measurement, the settling time, overshoot and peak values are examined and added on table.

Peak	Settling Time	Overshoot
656,5	50	325,2

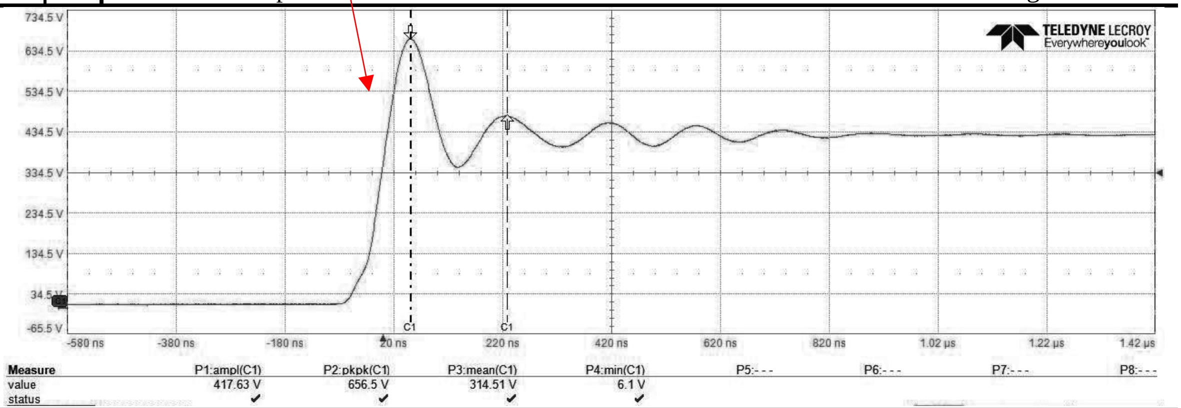
a. Peak, Overshoot and Settling time values



b. Flyback Converter circuit diagram, parallel connection of RC which is paralleled between drain and source pin of MOSFET on simulation program



c. Obtained signal waveform which is measured between drain and source pins of mosfet on simulation program in case of parallel connection of RC which is paralleled between drain and source pin of MOSFET. Red dashed border indicates the zoomed format of signal.



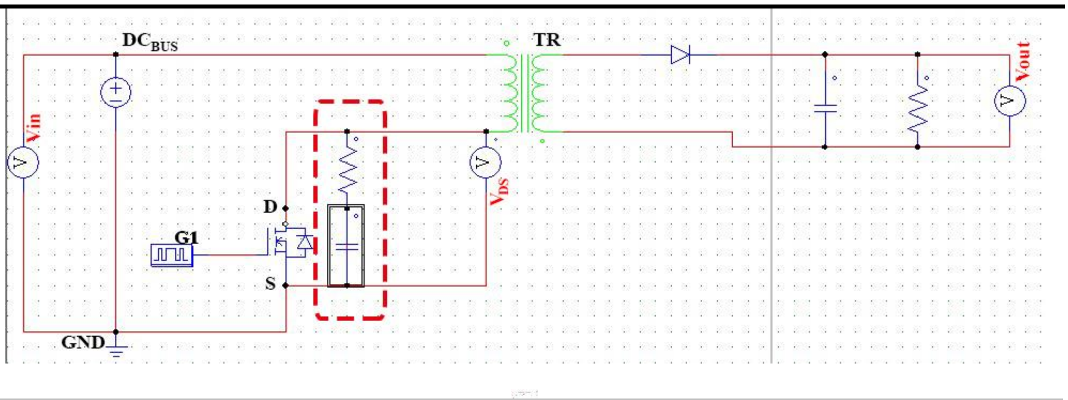
d. Zoomed signal in part C.

Figure 19. Measured signal between drain and source pins of MOSFET on simulation program in case of serial connection of RC which is paralleled between drain and source pin of MOSFET. Peak, Overshoot and Settling time values are indicated

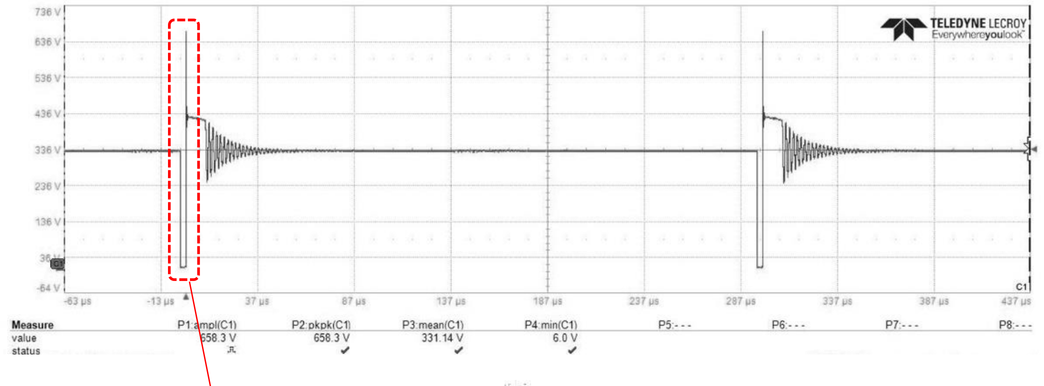
In the third step, different combination of RC circuit location is implemented which is compatible with simulation section. In this part, set up circuit could be represented as serial connection of RC which is paralleled between drain and source pin of MOSFET. The combination of RC circuit is implemented on refrigerator compressor motor control board. The schematic representation of flyback converter circuit with addition of RC values is shown in Figure 20. The signal is measured that between drain and source pin of flyback converter MOSFET. The obtained signal is examined with criteria of settling time, overshoot value and peak value. All mentioned and related values are processed on the Figure 10.3 with detail.

Peak	Settling Time	Overshoot
658,3	50	327,2

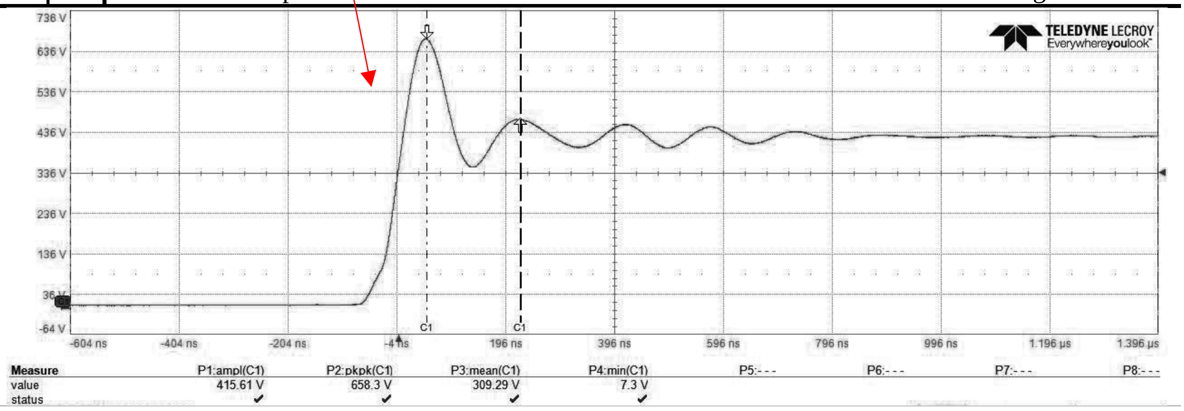
a. Peak, Overshoot and Settling time values



b. Flyback Converter circuit diagram, serial connection of RC which is paralleled between drain and source pin of MOSFET on simulation program



c. Obtained signal waveform which is measured between drain and source pins of MOSFET on simulation program in case of serial connection of RC which is paralleled between drain and source pin of MOSFET. Red dashed border indicates the zoomed format of signal



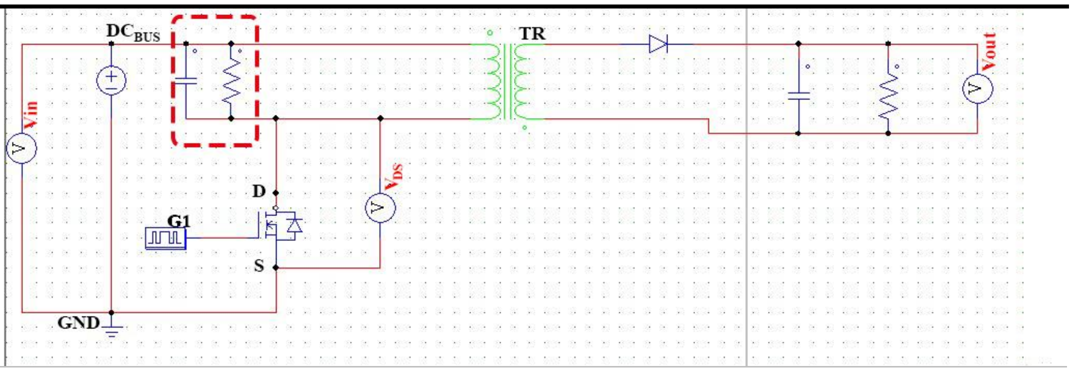
d. Zoomed signal in part C.

Figure 20. Measured signal between drain and source pins of MOSFET on simulation program in case of serial connection of RC which is paralleled between drain and source pin of MOSFET. Peak, Overshoot and Settling time values are indicated

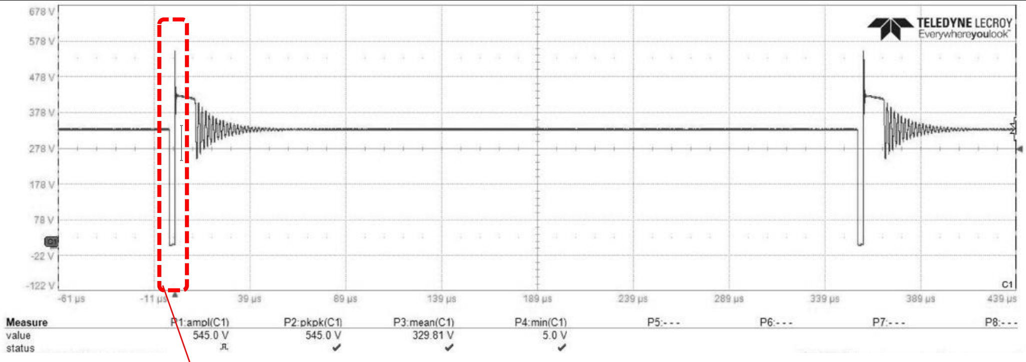
In the fourth and fifth step, the location of RC circuit is shifted from between drain and source pins of mosfet to between dc bus signal and drain pin of mosfet. As a mention from fourth step, the circuit could be expressed as rarallel connection of RC which is paralleled between positive side of DC BUS signal and Drain pin of mosfet. The set up circuit is shown as schematic view on Figure 21. Also, settling time, peak value and overshoot values of oscilloscope measured signal are indicated on Figure 21.

Peak	Settling Time	Overshoot
544,3	50	215,1

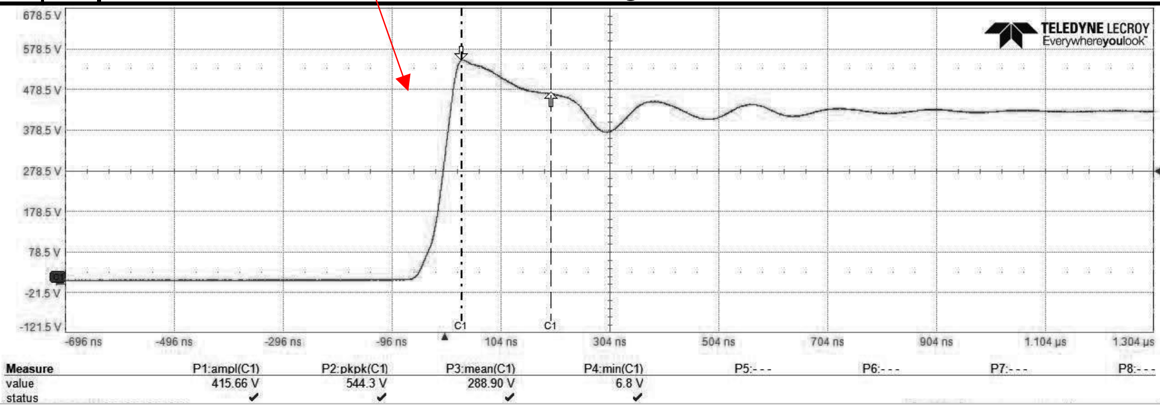
a. Peak, Overshoot and Settling time values



b. Flyback Converter circuit diagram, parallel connection of RC which is paralleled between positive side of DC BUS signal and Drain pin of MOSFET on simulation program



c. Obtained signal waveform which is measured between drain and source pins of MOSFET on simulation program in case of parallel connection of RC which is paralleled between positive side of DC BUS signal and Drain pin of MOSFET. Red dashed border indicates the zoomed format of signal



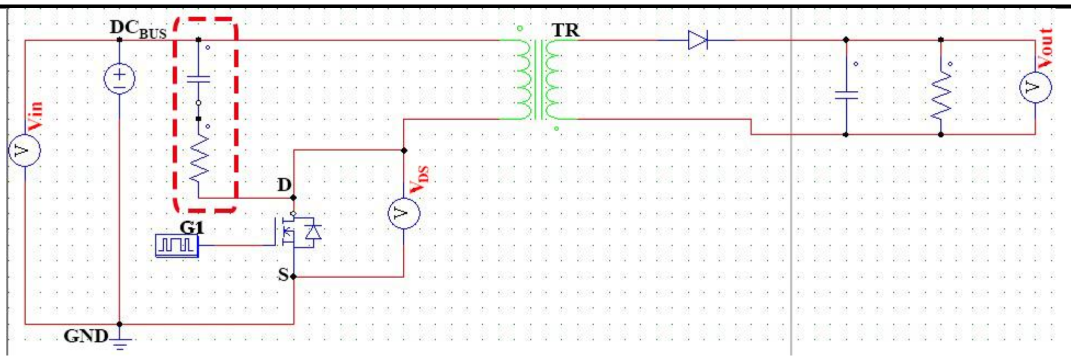
d. Zoomed signal in part C.

Figure 21. Measured signal between drain and source pins of MOSFET on simulation program in case of serial connection of RC which is paralleled between drain and source pin of MOSFET. Peak, Overshoot and Settling time values are indicated

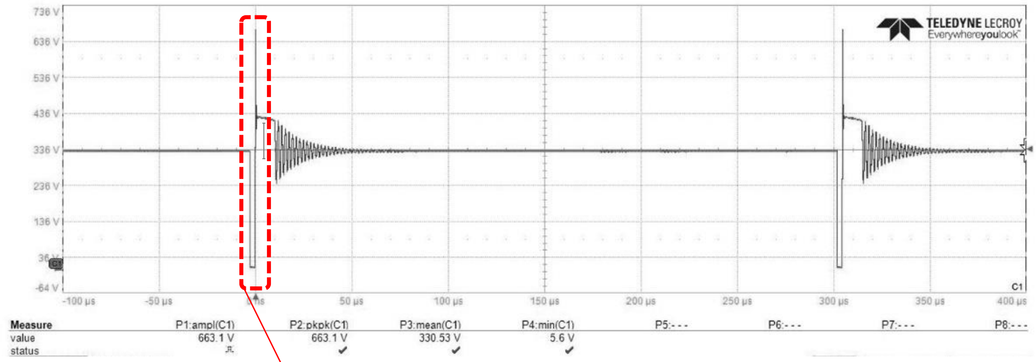
In the last step of experimental test, RC circuit location is represented as serial connection of RC which is paralleled between positive side of DC BUS signal and Drain pin of MOSFET. The schematic circuit is indicated in Figure 22. The drain and source pins are measured with aid of oscilloscope on refrigerator compressor motor control board Also, captured signal settling time, overshoot value, peak value is added on Figure 22.

Peak	Settling Time	Overshoot
661,7	50	331,2

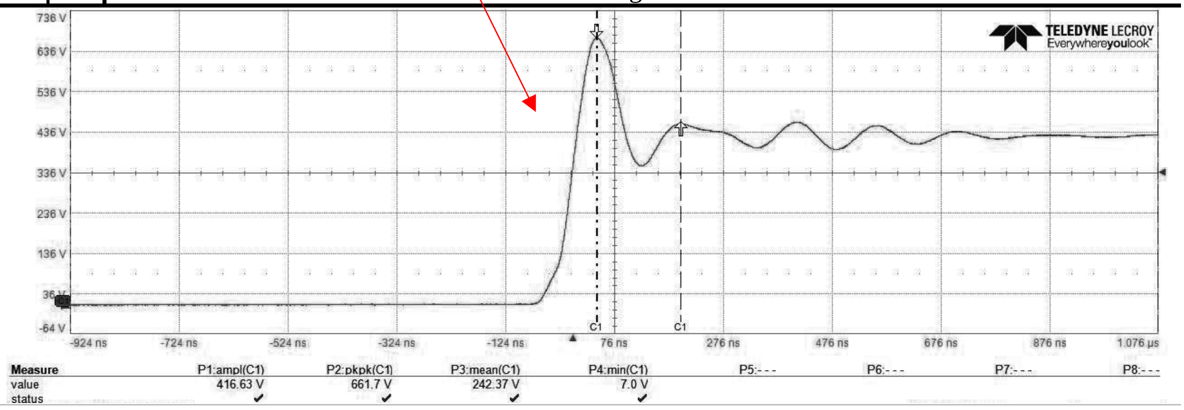
a. Peak, Overshoot and Settling time values



b. Flyback Converter circuit diagram, serial connection of RC which is paralleled between positive side of DC BUS signal and Drain pin of MOSFET on simulation program



c. Obtained signal waveform which is measured between drain and source pins of MOSFET on simulation program in case of serial connection of RC which is paralleled between positive side of DC BUS signal and Drain pin of MOSFET. Red dashed border indicates the zoomed format of signal



d. Zoomed signal in part C.

Figure 22. Measured signal between drain and source pins of MOSFET on simulation program in case of serial connection of RC which is paralleled between drain and source pin of MOSFET., Peak, Overshoot and Settling time values are indicated

3. RESULTS

Detailed table for three parameters could be seen in Table 2. When four location of RC circuit is examined, it could be said less peak and overshoot value are obtained with third location, according to simulation program Psim. The location of RC circuit is expressed as parallel connection of RC which is paralleled between positive side of DC BUS signal and Drain pin of MOSFET

Table 2. Peak, Settling time and overshoot values from no snubber situation to different location RC circuits in simulation program. RC location sequence is same as in simulation part

RC Location	Peak (Voltage)	Settling time (uS)	Overshoot (Voltage)
No RC	951	5	494
1	767	6	308
2	853	6	393
3	693	5	232
4	844	5	379

The circuits set up in the simulation study were also set up step by step during the experimental study. Table 3 indicates that no snubber circuit and four different location of RC circuit. Considering the peak value and overshoot value criteria, it is seen that third location of RC circuit is the most optimal method. Considering the settling time values, no significant difference was observed in all circuits.

Table 3. Peak, Settling time and overshoot values from no snubber situation to different location RC circuits on refrigerator compressor motor control board.. RC location sequence is same as in simulation part.

RC Location	Peak (Voltage)	Settling time (uS)	Overshoot (Voltage)
No RC	670	50	340
1	656	50	325
2	658	50	327
3	544	50	215
4	661	50	331

4. DISCUSSION

According to simulation program results, when evaluated in terms of settling time, it could not be said that there is a result that makes a significant or determinative difference. With the 3rd location, an improvement around 37% was observed compared to the circuit without any snubber circuit in case of peak value of signal during turn off instance. Also, at the same location of RC circuit, the improvement was achieved more than twice when the overshoot value was taken into account. Another consequence of this simulation work in case of RC snubber and snubberless case is that if RC circuit is used on four potential region of flyback converter, at least 25% improvement for overshoot value, %11 improvement for peak value will be obtained.

After evaluating the simulation results, experiments were carried out by making modifications on refrigerator compressor motor control board. With the 3rd location, an improvement around 23% was observed compared to the circuit without any snubber circuit in case of peak value of signal during turn off instance. Also, at the same location of RC circuit, the improvement was achieved around 58% when the overshoot value was taken into account.

5. CONCLUSION

Both simulation and experiments at laboratory were performed with 230 Volt AC and 50 Hertz frequency input voltage which simulates house grid. As in the simulation results, the 3rd circuit location of RC circuit gave the most optimum values in the experimental results in case of peak and overshoot value. At this point, it could be mentioned that the simulation and experimental results are compatible in terms of find optimum solution on flyback converter circuit of refrigerator compressor motor control board.

Although the experimental and simulation results are proportionally feasible with each other, they differ from each other in terms of numeric values which are peak value, settling time and overshoot value. On the other hand, minor differences could be seen in the waveform. There could be many reasons to not be able to transfer from real environment parameters to the simulation programs. Leakage inductance and leakage capacitance on real environment, refrigerator compressor motor control PCB path, traces and via effect, power sources losses, used component losses and their simulation models may have a couple of reasons for this deviation.

By using the RC values found by the method used, the electrical stress of the MOSFET in the flyback converter circuit is reduced. Also, one of the things that contributed to this situation is that using RC circuit in the most appropriate place on the refrigerator compressor motor control card. In this way, the longer-term working potential of the flyback converter MOSFET on the refrigerator compressor motor control card at customers home, has been occurred. In this way, there is chance to obtain an application with the potential to decrease the failure rate of the refrigerator compressor motor control board in case of MOSFET failures on flyback converter circuit.

In addition, due to voltage fluctuation in some regions, even higher peak and overshoot values may occur on the MOSFET of flyback converter. By applying this kind of methods, there was a potential to extend the life time of MOSFET by decreasing the peak and overshoot voltages. Looking at this situation from a broad perspective, besides reducing the service costs of the manufacturers, it also creates a beneficial situation for carbon emissions as less spare part boards will be produced and less fuel will be spent for spare part services. On the other hand, it has the potential to create a situation that will reflect positively on customer satisfaction.

CONFLICT OF INTEREST

The authors stated that there are no conflicts of interest regarding the publication of this article.

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