تحليل وتنفيذ محول نبضي عالي الاستطاعة وعالي التردد لمعدِّلات الرادارات النبضية

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(تاريخ الإيداع 10 / 1 / 2020. قُبِل للنشر في 26/ 6 / 2021)

□ ملخّص □

تعمل صمامات الأمواج المكروية المُستخدمة في بعض الأنظمة الرادارية تحت جهد عالي وباستطاعة عالية، حيث يتم توليد نبضات الجهد هذه بواسطة وحدة تغذية عالية الاستطاعة تُسمى في الأنظمة الرادارية بالمعدِّل، ويُعد المحول النبضي عالي الاستطاعة أحد الأجزاء المهمة للمعدِّلات الحديثة وعنصر أساسي في أنظمة الاستطاعة حيث يقوم بالعديد من الوظائف كتحويل الجهد (رفع أو خفض)، عزل كهربائي، فصل الضجيج، تحسين جودة الاستطاعة. كما للمحول النبضي إيجابيات من حيث البنية المدمجة والتكرارية الممتازة.

وبما أن شكل نبضة الخرج وخاصةً زمن الصعود والهبوط يحدده تصميم المحول النبضي وعناصره الطفيلية كالذاتية الشاردية، المكثفة الموزعة، الذاتية المغناطيسية، ومعدَّل الرفع. وكلما كان المحول النبضي مُدمج كلما كان له عدد لفات أقل وبالتالي له ذاتية شاردية ومكثفة موزعة أخفض، ولذلك من المهم جداً تحديد القيم المسموحة لهذا العناصر الطفيلية والتي لها الأثر الأساسي على شكل نبضات الجهد والتي بدورها تؤثر على عمل الرادار ومواصفاته.

في هذه الدراسة، نوضِّح المبدأ، والنمط، والخصائص المميزة لهذا المحول النبضي عالي الاستطاعة، ومن ثم نقوم بتسجيل نتائج النمذجة لطريقة التصميم ونتائج البناء العملي، حيث أن هدف هذا الطرح هو الحصول على نبضات جهد عالي بمواصفات جيدة كزمن صعود وهبوط قصير للنبضة، وعدم هبوط جهد وعرض نبضة خرج واسع. الأمر الذي سيساعد ببناء معدِّلات نبضية عالية الاستطاعة لاستخدامها في تحديث راداراتنا السورية.

الكلمات المفتاحية: الاستطاعة العالية والتردد العالي، المعدلات الرادارية النبضية، الصمامات المكروية، المحول النبضي.

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Analysis and Implementation of High-Power High-Frequency Pulse Transformer for Radar Pulse Modulators

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(Received 10 / 1 / 2020. Accepted 26 / 6 / 2021)

□ ABSTRACT □

Vacuum microwave devices, which are used in some of radar systems, work under high power pulse voltage, and this pulse voltage are generated by high power supply which called the modulator in radar systems, one of important part of modern modulators is the high-power pulse transformer which is an indispensable component of power system which performs many functions such as voltage transformation, electrical isolation, noise decoupling and power quality improvement. Relatively, pulse transformer has the advantages of compact structure and excellent repetitiveness.

Because of the output pulse shapes, especially the rising and falling phases are determined by the design of the pulse transformer and its parasite elements such as its leakage inductance, distributed capacitance, magnetization inductance, and step-up ratio.
The more compact the impulse transformer is , the fewer turns it has and hence they are having low leakage inductance and distributed capacitance, so it is very important to determine the allowed values of these parasite elements to obtain the desired shape of voltage pulses which have the essential effect on radar working and its specifications.

In this paper, the principle, type and characteristics specification of this high-power pulse transformer are shown. And reporting the simulation results of design method, and construction results, where aiming at this purpose is to obtain high voltage pulses with good specification as a short rise/fall time, non-droop voltage and expanding output pulse-width, which will be helped in building of high-power pulse modulators to use it for modern our Syrian radars.

Keywords: High power and High Frequency, Radar pulse modulators, Microwave tubes, Pulse transformer.

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INTRODUCTION:

In many pulsed-power applications, e.g., the medical, accelerator, or radar researches, rectangular pulses with a flat top, a fast rise/fall time, and variable pulse width are required. For generating such pulses with variable pulse width, many different modulator types can be used, i.e., direct-switch modulators [1-2], multicell-type generators (e.g., Marx generator) [3-4-5], and transformer-based modulators [6-7-8-9], as well as a combination of it. In all of these modulator types, the achievable rise and fall times of the pulses are mainly determined by the parasitic capacitances and inductances in the pulse transformer. Pulse transformers capable of transmitting substantially rectangular voltage pulses, with durations of less than one millisecond. Several applications of them, need medium or high voltage pulses (1 up to 700kV) that medium or high voltage pulse transformer increases the output pulse voltage to the value required for the load. The usually large number of turns in the secondary winding (the transformer ratio is frequently 1:10)، together with the insulation gap between windings and between winding layers increase the value of the equivalent parasitic elements (leakage inductance and inter-winding capacitance). These elements extend the pulse rise-time and cause overshoot and oscillations. Hence, the design of the pulse transformer is critical, not only because all materials must sustain the medium or high voltage across them, but also because the output pulse shape heavily depends on several transformer parasitic parameters that are difficult to master [10].

Pulse transformer modeling is done by two methods: firstly, the well-known lumped parameter theory of transformer is used [10, 11]. Most pulse transformer models treat each winding as a single circuit element. This limits analysis of these types of models to the bulk properties of the model. Details of winding interaction with parasitic capacitances can only be lumped into a single circuit model element and these values are usually determined by measurement. This can limit the designer to a trial and the error approach to the subtleties of pulse transformer design. Secondly, transformer considers as a distributed parameter circuit [12, 13]. However، nonlinear core is not included [14]. The windings are separated into multiple sections and all combinations of mutual inductances are calculated. The distributed capacitance between the core and primary, the primary and secondary, and the secondary to case are included. The individual inductance and coupling coefficients are calculated based on the magnetic inductances and the mutual air. These values are used in a circuit model developed in PSPICE. Especially, this method is used for simulation of air core pulse transformer [15-17].

Other related works on pulse transformer are harmonics، thermal and mechanical force using finite element method (FEM), reducing size, and electromagnetic interference (EMI) and so on [18-21].

To contribute to a better understanding of pulse transformer operation considering leakage inductance and inter-winding capacitance, this paper proposes a mathematical model based on the flux linkage as state variable. Our main aim is to identify a critical values causing unsuitable rise time of the output, especially damaged output pulse completely. It is interesting to demonstrate conditions for leakage inductance of windings، pulse frequency, and leakage capacitance that are destroying output pulse that hasn't been discussed clearly in the literature up to now. Finally, results of simulation are able to show rated value of pulse transformer parameters. If parameters of pulse transformer are not allowable value obtaining measurement and calculation, we must choose methods for reduction of them, such as using auxiliary windings or active shielding and so on [10, 22].

Therefore، this model is then used to suggest approachable parasitic elements to optimize the design of a medium or high voltage pulse transformer. Using two auxiliary winding for improvement of technical characteristics of output pulse is explained and new prove based on characteristic roots method is done.

The remaining of the paper is structured as follows, first, the basic structure of equivalent circuit of pulse transformer is described, then PSPICE simulation verifications are obtained in order to show the effect of parasite elements on the high voltage waveform, and also experimental results verified the proper performance of the proposed construction. Finally, our conclusion.

RESEARCH OBJECTIVES AND IMPORTANCE

The good design of high-power pulse transformer is very important for solid state modern modulator specially in Radar systems area, because the influence of pulse shape on the Radar work and its specification like its ability to distingue between targets, and radar unambiguity range.

This research aims to design and implementation of high-power high frequency pulse transformer to use it in high power pulse modulator in order to renew the Syrian radar systems.

THEORETICAL INTRODUCTION

1. General elements of the pulse modulator

In all of these modulator types, the achievable rise and fall times of the pulses are mainly determined by the parasitic capacitances and inductances in the power circuit, which usually consisting of a Pulse capacitor, bank capacitors, Power switches, Pulse transformer, and the load which is shown as a block diagram in Fig. (1).

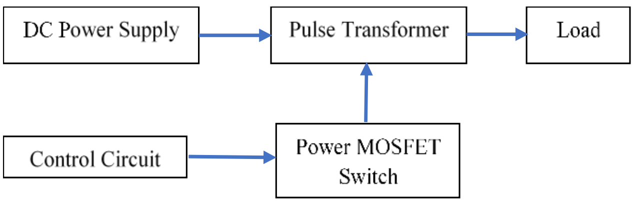

Fig.1. Block diagram of pulse modulators

In [23] we proposed new design of high-power solid-state switch that exist in pulse modulator to drive high voltage pulses that are applied on high power microwave tube in radar transmitter.

This work concern about second important part of pulse modulator which is pulse transformer.

2. Pulse Transformer equivalent circuit

The influences of a transformer’s parameters can be best understood by considering the equivalent circuit, which shows a typical output pulse waveform. Assuming the pulse transformer is properly matched and the source is delivering an ideal rectangular pulse, the transformer should have low values of leakage inductance and distributed capacitance while having a high open circuit inductance. This will limit the deterioration of the pulse shape. In addition, the fact that the source will never produce an ideal rectangular pulse adds to the problems of distortion.

A basic scheme of IEEE equivalent circuit for Pulse Transformer is shown in Fig. (2) [24-25]. It is be noted that a higher transformer turn ratio means a lower drain source voltage, but it means the higher parasitic elements of transformer, and the higher leakage inductance of transformer makes high amplitude spikes on switch drain and non-desirable rise time of output pulse voltage [26].

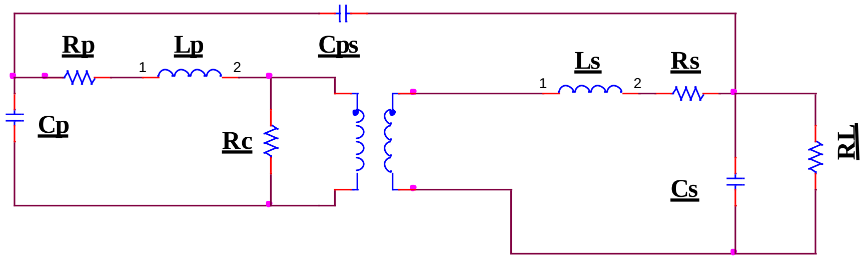

Fig.2. Basic scheme of IEEE equivalent circuit for Pulse Transformer.

Our aim is to eliminate these spikes on switch drain and obtain desired rise time of output pulse voltage, so we have to determine limited values of these parasite elements shows clealy in fig. (2), where: R_p, dc resistance of primary winding; L_p, Primary inductance that is mutually coupled to the secondary; C_p, primary shunt and distributed capacitance; R_s, dc resistance of secondary winding; L_s, secondary inductance that is mutually coupled to the primary; C_s, secondary shunt and distributed capacitance; C_{ps}, primary-to-secondary capacitance (inter-winding capacitance); R_c, core losses expressed as a shunt resistance in parallel with the primary winding; R_L, load resistance on the secondary winding.

3. Typical Pulse Parameters

Using PSPICE program, Fig. (3) shows first obtained result of high voltage by simulate the equivalent circuit of pulse transformer, and that without determine any specific parameters to show all pulse parameters to make some definitions instead of understanding pulse parameters [24, 25].

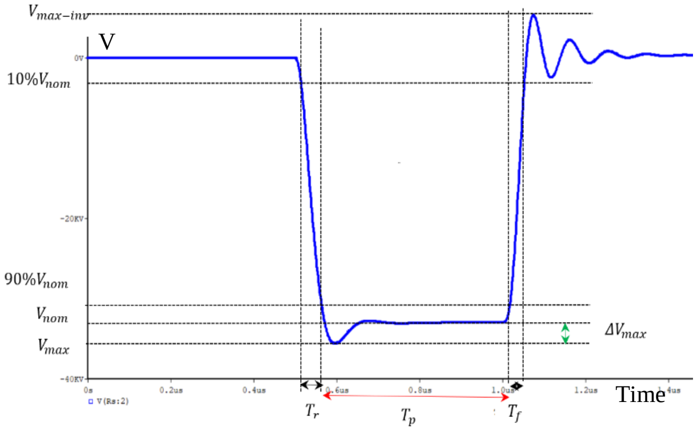

Fig.3. High-Voltage Pulse shape

Peak working voltage: The maximum instantaneous voltage stress that may appear under operation, including abnormal and transient conditions.

Input pulse shape: Current pulse or source voltage pulse applied through associated impedance. The shape of the input pulse is described by a current- or voltage-time relationship

***Pulse amplitude*, V_{nom}:** that quantity determined by the intersection of a line passing through the points on the leading edge where the instantaneous value reaches 10% and 90% of V_{nom} and a straight line that is the best least squares fit to the pulse in the pulse-top region (usually this is fitted visually rather than numerically). For pulses deviating greatly from the ideal trapezoidal pulse shape, a number of successive approximations may be necessary to determineV_{nom}.
rise time (first transition duration), T_r: The time interval of the leading edge between the instants at which the instantaneous value first reaches the specified lower and upper limits of 10% and 90% of V_{nom} Limits. Other than 10% and 90% may be specified in special cases.
Pulse duration (90%),T_p: The time interval between the instants at which the instantaneous value reaches 90% of V_{nom} on the leading edge and 90% of V_{nom} on the trailing edge.
Fall time (last transition duration), T_f: The time interval of the pulse trailing edge between the instants at which the instantaneous value first reaches specified upper and lower limits of 90% and 10% of V_{nom} on the trailing edge.
Tilt (droop), ΔV_{nom}: The difference between V_{nom} and V_{max} It is expressed in amplitude units or in percentage of V_{nom}.
Overshoot (first transition overshoot), V_{max}: The amount by which the first maximum occurring in the pulse-top region exceeds the straight-line segment fitted to the top of the pulse in determiningV_{nom}. It is expressed in amplitude units or as a percentage of V_{nom}.
Inverse overshoot (first transition overshoot), $V_{max-inv}$: The amount by which the first maximum occurring in the inverse pulse.
Trailing edge (last transition): That portion of the pulse occurring between the times of intersection of straight-line segments used to determine V_{nom} and the time at which the instantaneous value reduces to zero.
***Output pulse shape*:** Load current pulse flowing in a winding or voltage pulse developed across a winding in response to application of an input pulse. The shape of the output pulse is described by a current- or voltage-time relationship.

RESEARCH METHODS AND MATERIALS

1. Pulse Transformer Modeling Based on Flux Linkage as State Variable

In this section, we will describe an arrangement by which the voltage and flux linkage equations of a two-winding transformer can be implemented in a computer simulation. There is of course, more than one way to implement a simulation of the transformer even when we are using the same mathematical model. For example, we can implement a simulation using fluxes or current as state variable.

In our case, we will pick the total flux linkages of the two windings as the state variables. In terms of these two state variables, the voltage equations can be written as [27]

$$V_P = i_p R_p + \frac{1}{w_b} . \frac{d\varphi_p}{dt} \qquad (1)$$

$$V_s = i_s R_s + \frac{1}{w_b} . \frac{d\varphi_s}{dt} \qquad (2)$$

Where, φ_p is the flux linkage of primary turns, φ_s is the flux linkage of secondary turns, $w_b = 2\pi f$ is the base frequency at which the reactance are computed, i_p is the current in primary turns, i_s is the current in secondary turns, R_p is primary resistance, R_s is secondary resistance.

The flux linkage per second of the windings can be expressed as [27]

$$\varphi_p = x_{lp} i_p + \varphi_m \quad (3)$$

$$\varphi_s = x_{ls} i_s + \varphi_m \quad (4)$$

And

$$\varphi_m = x_m (i_p + i_s) \quad (5)$$

Where, $x_{lp} = w_b L_p,\ x_{ls} = w_b L_s, x_m = w_b L_m$

(L_p: *primary inductance*, L_s: *secondary inductance*, L_m: *mutual inductance*)

The current i_p can be expressed in terms of φ_p and φ_m using Equation (3) similarly, i_s can be expressed in terms of φ_s and φ_m using Equation (4).

$$i_p = \frac{\varphi_p - \varphi_m}{x_{lp}} \quad (6)$$

$$i_s = \frac{\varphi_s - \varphi_m}{x_{ls}} \quad (7)$$

Substituting the above expressions of i_p and i_s into Equation (5), we obtain

$$\frac{\varphi_m}{x_m} = \frac{\varphi_p - \varphi_m}{x_{lp}} + \frac{\varphi_s - \varphi_m}{x_{ls}} \quad (8)$$

Collecting the φ_m terms to the right, we obtain the desired expression of φ_m in terms of the two desired states, that is

$$\varphi_m \left(\frac{1}{x_m} + \frac{1}{x_{lp}} + \frac{1}{x_{ls}} \right) = \frac{\varphi_p}{x_{lp}} + \frac{\varphi_s}{x_{ls}} \quad (9)$$

Letting

$$\frac{1}{x_M} = \frac{1}{x_m} + \frac{1}{x_{lp}} + \frac{1}{x_{ls}} \quad (10)$$

Equation (9) can be written more compactly as

$$\varphi_m = x_M \left(\frac{\varphi_p}{x_{lp}} + \frac{\varphi_s}{x_{ls}} \right) \quad (11)$$

Using Equations (6) and (7) to replace the currents, Equations (1) and (2) can be expressed as integral equations of the two total flux linkages, that is

$$\varphi_p = \int \{ w_b V_P - w_b R_p \left(\frac{\varphi_p - \varphi_m}{x_{lp}} \right) \} \, dt \quad (12)$$

$$\varphi_s = \int \{ w_b V_s - w_b R_s \left(\frac{\varphi_s - \varphi_m}{x_{ls}} \right) \} \, dt \quad (13)$$

Collectively, Equations (6), (7), (11), (12), and (13) from a basic dynamic model of a two-winding transformer to which magnetic nonlinearity and iron losses may be added if necessary. In this model, the flux linkages are the internal variables, the terminal voltages are the required inputs, and the winding currents are the main outputs.

In the next section, pulse transformer modeling based on this modeling has been described.

2. Simulation of Pulse Transformer

In many applications of pulse transformer, we need a flat top portion of the high voltage output pulse and fast rise time. In order to achieve a rise time that is less than 400ns we must be improved the design of a pulse transformer by trade off among the droop, the core size, and the rise time [14, 18, 19, 25, 26]. For investigation on effects of leakage parameters in output pulse, simulation is done.

Figure 4 shows the SIMULINK simulation that is in accordance with the flow diagram based on flux linkage as state variable. In addition to, leakage capacitance and load model is defined in accordance with bellow equations [27]:

$$V_s = \frac{1}{C_{eq}}\int i_c dt = w_b B \int \left(-i_s - \frac{V_s}{R_o}\right) dt \qquad (14)$$

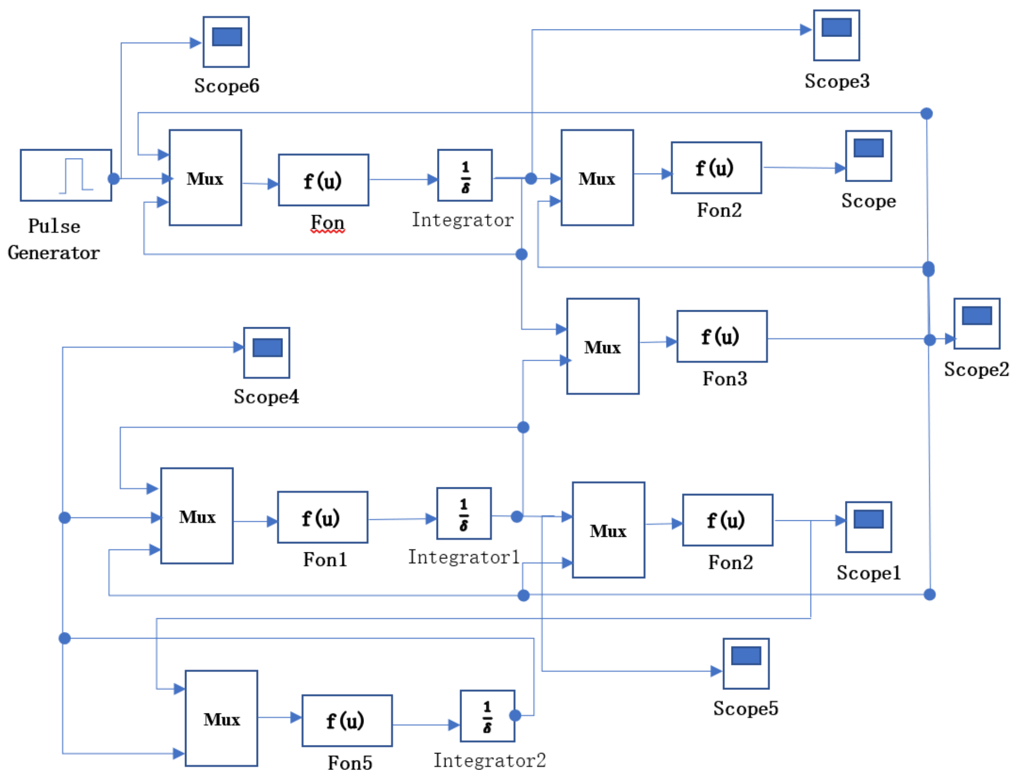

Fig. 4. MATLAB SIMULINK Simulation of pulse transformer based on flux linkage as state variable

Table 1- Transformer parameters (f=1 kHz, Transformer ratio: 1:10) [28]

Parameter	Calculated value
R_p	0.1
R_s	0.14
x_{lp}=x_{ls}	0.62
R_o	50
w_b	6283
x_c	79577
x_m	50

RESULTS AND DISCUSSION

We suggest the specifications of high-power short pulse-width modulator related to some real application in Syrian radar systems as the following;

Output pulse voltage (Cathode voltage) = -40 KV. Output pulse current (I_{Load}) = 25 A.
Load (magnetron) resistance (R_{Load}) = 1.6 kΩ, 1000 W. Pulse width (PW) = 500 ns.
Pulse repetition frequency (PRF) = 1 KHz.

Initial simulation has been done in f=1 kHz (parameters of pulse generator: amplitude: 500V, periods: 0.001s, pulse width 5% of period) with calculated parameters (Table 1). Result of simulation is illustrated in Figure 5.

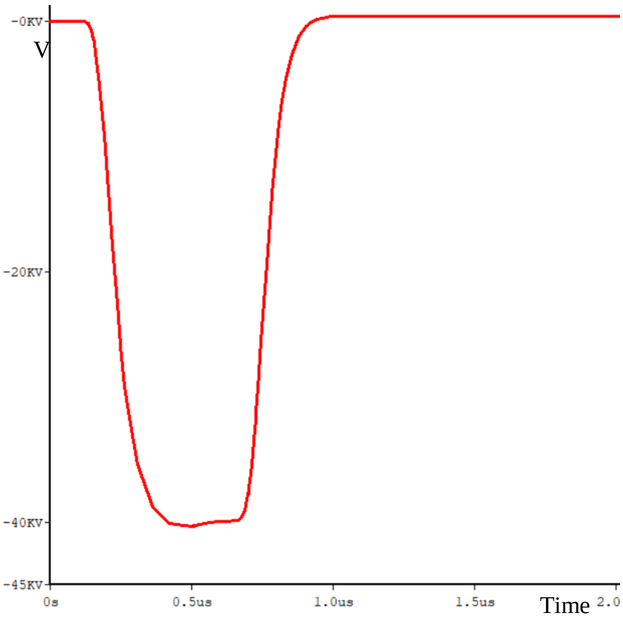

Fig. 5. Waveform of V_S (periods of pulse transformer: 0.001s)

This simulation is repeated in f=10 kHz (Table 2 and Figure 6), where we notice that the rise time of pulse is high and we obtain unwanted waveform.

Table 2- Transformer parameters (f=10 kHz, Transformer ratio: 1:10) [28]

Parameter	Calculated value
R_p	0.1
R_s	0.14
x_{lp}=x_{ls}	6.28
R_o	50
w_b	62831
x_c	3200
x_m	500

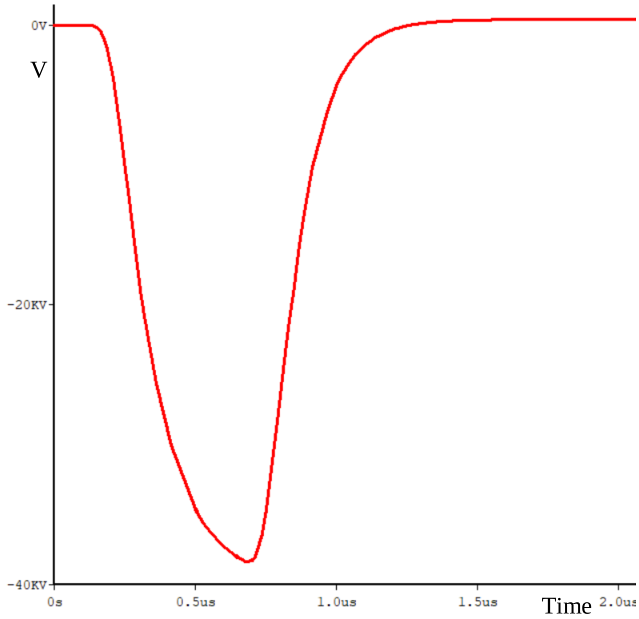

Fig. 6. Waveform of V_S (periods of pulse transformer: 0.0001s)

The different result between fig. 5 and fig 6 is related to different pulse frequency, where the higher frequency the more distortion in the shape of the pulse>
Effects of leakage inductance in medium frequency (5 kHz) is shown in Figures 7, and effects of inter-winding capacitance in medium frequency is shown in Figures 8. Therefore, we can predict output waveform of pulse transformer based on changing in period of input pulse, leakage inductance and inter-winding capacitance, where we obtain unwanted waveform.

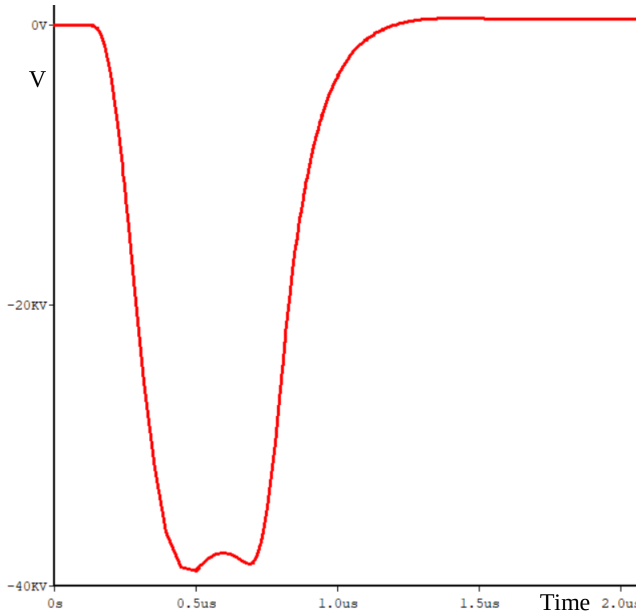

Fig.7. Waveform of V_s (periods of pulse transformer: 0.0002, x_{lp}=x_{ls} =1.24Ω others parameters according to Table 1)

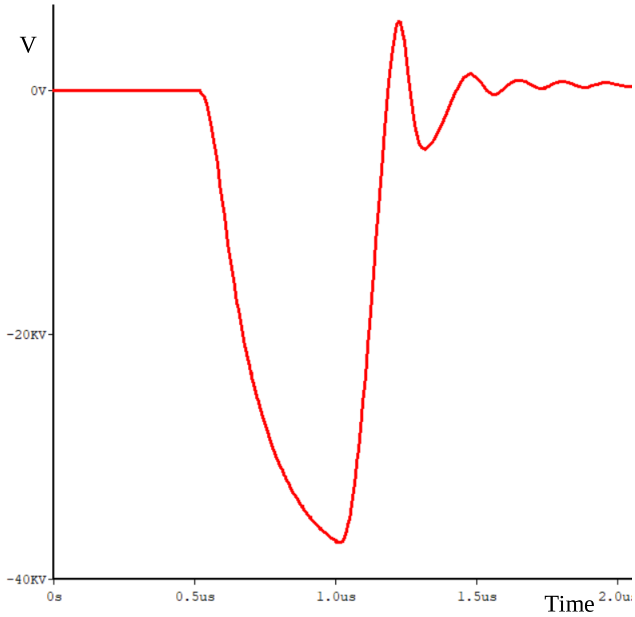

Fig.8. Waveform of V_S (periods of pulse transformer: 0.001, *C* = 2*nF* others parameters according to Table 1)

a) Effect on voltage droop:

The existence of DC Resistance of the primary winding R_p and DC Resistance of the secondary winding R_s is expressed as a series resistance in the primary and secondary windings, the voltage droop will appear and becomes considerable as these resistances become larger as it is shown in fig. (9) and fig. (10). We notice that the effect of R_p is more considerable than the effect of R_s, and we can find that the optimum value of R_p must be less than 0.01Ω, and the optimum value of R_s must be less than 10Ω.

These limited values of parasite DC resistances will be changed under another condition depending on pulse transformer specifications like its pulse width, repetition frequency and pulse transformer turn ratio…

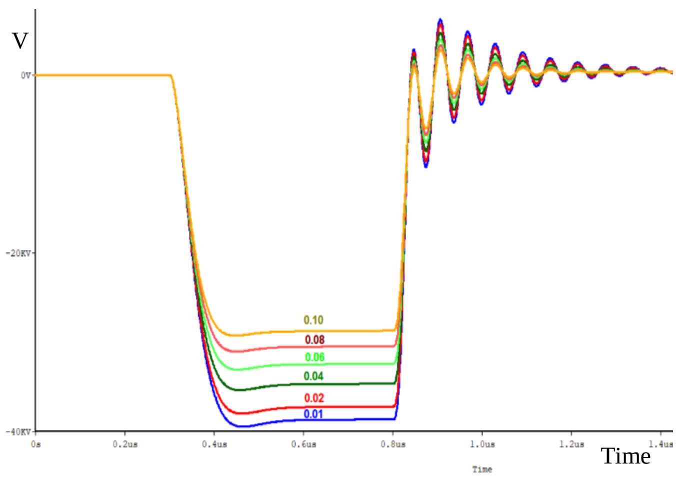

Fig.9. effect of R_p on voltage drop of pulse Transformer response (R_p: 0.01, 0.02, 0.04, 0.08, 0.1 Ω)

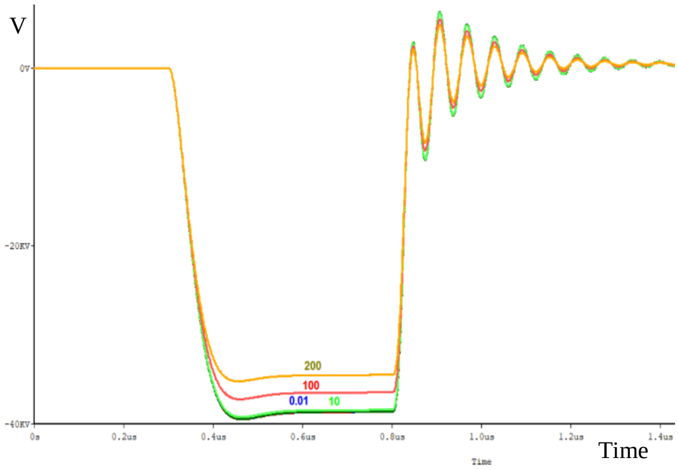

Fig.10. effect of R_s on voltage drop of pulse Transformer response
(R_s: $0.01, 10, 100, 200$ Ω)

The core losses R_c is expressed as a parallel resistance in the primary windings, so by contract this resistance must be large as it possible, because it expresses on the isolation between the turns, as it is clear in fig. 11.

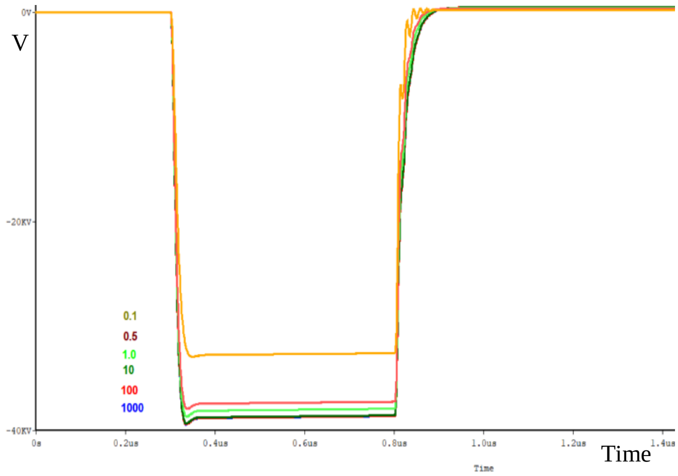

Fig.11. effect of R_c on voltage drop of pulse Transformer response
(R_c: $1000, 100, 10, 1, 0.5, 0.1$ Ω)

We notice that this resistance must be larger than 100Ω.

b) Effect on rise and fall time:

The existence of primary shunt distributed capacitance C_p, secondary shunt distributed capacitance C_s and primary-to-secondary capacitance (inter-winding capacitance) C_{ps}, rise time and fall time become larger as it is shown in fig. 12, fig. 13, fig. 14.

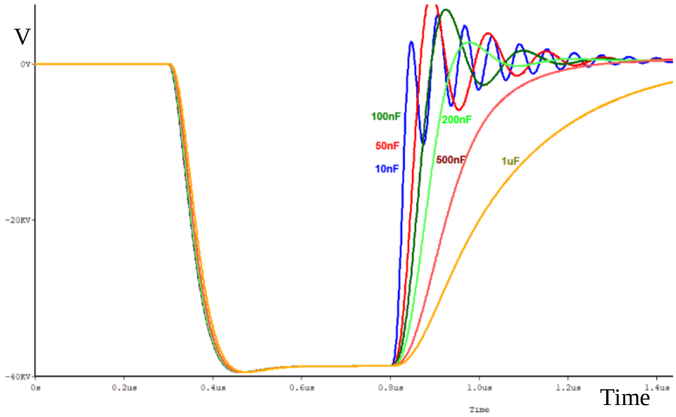

Fig.12. effect of C_p on rise and fall time of pulse Transformer response (C_p: 10, 50, 100, 200, 500, 1000 nF)

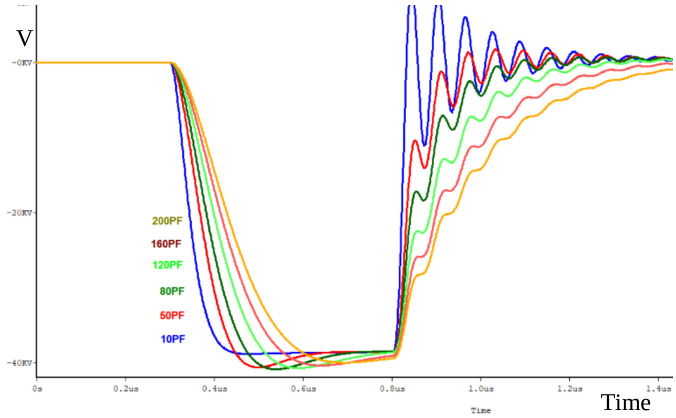

Fig.13. effect of C_s on rise and fall time of pulse Transformer response (C_s: 10, 50, 80, 120, 160, 200 pF)

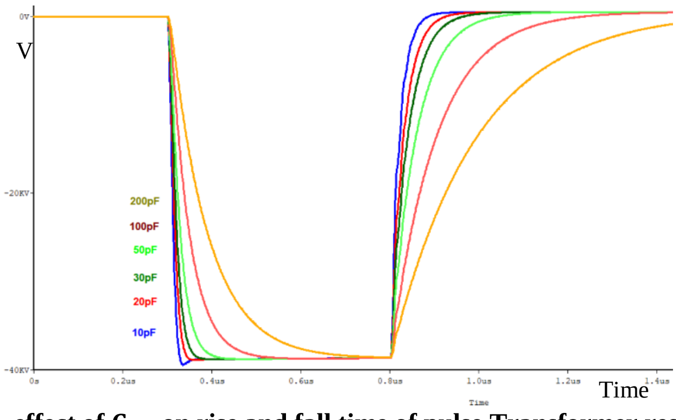

Fig.14. effect of C_{ps} on rise and fall time of pulse Transformer response (C_{ps}: 10, 20, 30, 50, 100, 200 pF)

We can find that the values of these capacitances must be under the following condition: C_p less than 10nF. C_s less than 10pF. C_{ps} less than 10pF.

c) Effect on overshoot, back and return swing:

Overshoot, back and return swing becomes larger because the existence of primary inductance that does not link the secondary (Primary leakage inductance) L_p, and Secondary inductance that does not link the primary (Secondary leakage inductance) L_s as it shown in fig. 15, and fig. 16, and as it is clear, their limited values will be for L_p less than 1nH, and for L_s less than 1μH.

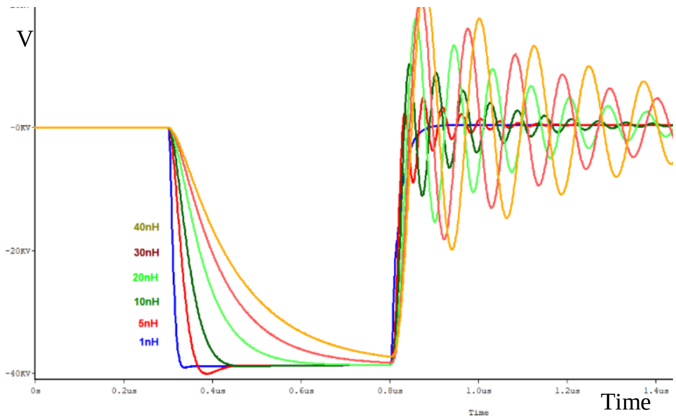

Fig.15. effect of L_p on overshoot and back swing of pulse Transformer response (L_p: 1, 5, 10, 20, 30, 40 nH)

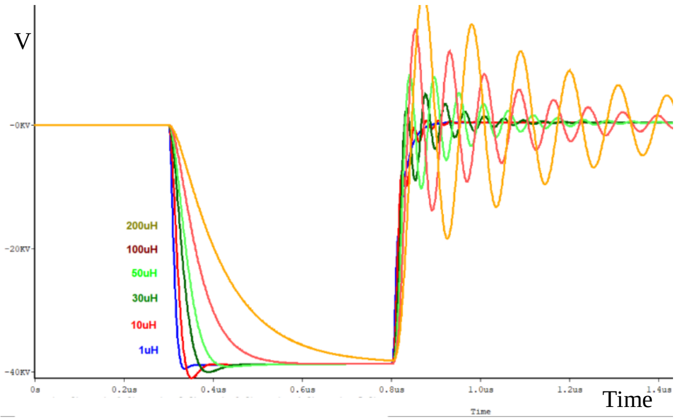

Fig.16. effect of L_s on overshoot and back swing of pulse Transformer response (L_s: 1, 10, 30, 50, 100, 200 μH)

Experimental Setup

By taking all previous conditions of parasite elements limited values in consider, which are:

R_p must be less than 0.01Ω, R_s must be less than 10Ω. R_c must be larger than 100Ω.

C_p less than 10nF. C_s less than 10pF. C_{ps} less than 10pF. L_p less than 1nH, and L_s less than 1μH. Now, we can move to the real experimental setup.

A. *System setup*

The specifications of the prototype are the same as the simulation procedure.
The pulse transformer implementation is shown in fig. (17).

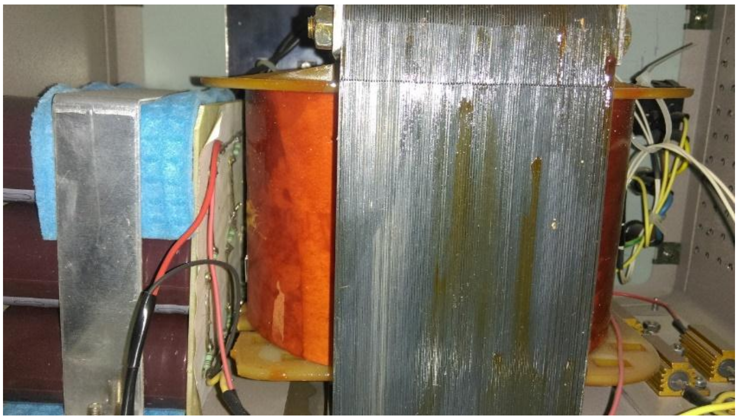

Fig. 17. Transformer double ferrate U93 core, 1 :10.

Notices:

- The remaining source of droop is due to the high-power transformer itself, and arises from its magnetizing current, which is inversely proportional to the inductance of its primary winding. A large primary inductance will reduce the droop, but the additional number of the primary and secondary turns will increase the leakage inductance and parasitic capacitance, which will slow down the rise time. Fast rise time is required for short pulses, so that there will be a trade off with the allowable droop for long pulses.
- The choice of a cut or uncut core for the high-power step-up transformer depends on several trades-offs. The uncut core has lower iron losses and this may be important when operating at high duty cycles.

Another advantage of cut cores is that they do not need a reset winding to remove remnant flux between pulses. This is because of the air gap and the reduced permeability, which results from it.

On the other hand, due to the air gap, the primary inductance for a given number of turns will be low, thus making it unsuitable for use with long pulses, since the droop will be high. In addition, both the primary and secondary winding will have many more turns than for a cut core, so that there may be pulse distortion due to leakage inductance and parasitic capacitance effects. The resulting transient effects will make the current core less suitable for very short pulses. Uncut cores are more suitable for a wide range of pulse widths, but may be lossier that cut cores which are more suitable for medium length pulses.

B. E*xperimental results*

Fig. 18, shows the sequence of output high voltage applied to the load by using high voltage Probe. Fig. 19, shows the measured one output high voltage pulse applied to load without all specificities conditions of limited unwanted parasite elements.

Finally, if we built our pulse transformer under the conditions of allowed values of parasite elements we achieve our goal by obtaining high voltage (40KV) and short pulse-width (500ns) without over voltage pulses and oscillation, as it clear in fig. (20).

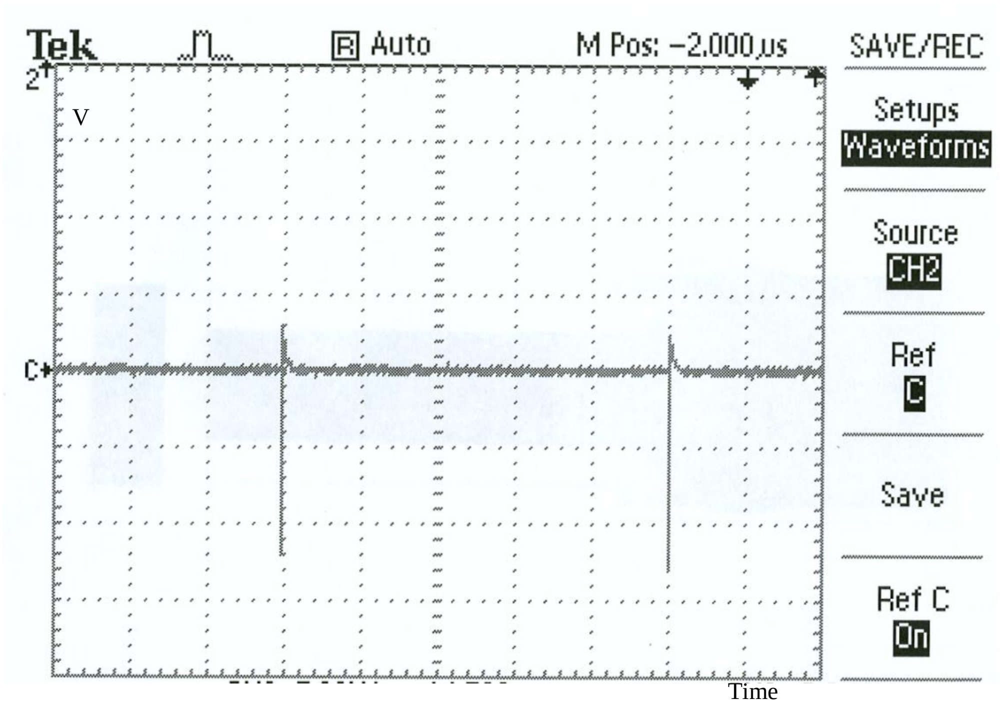

Fig. 18. Measured repetition of output high voltage applied to load (2KHz)

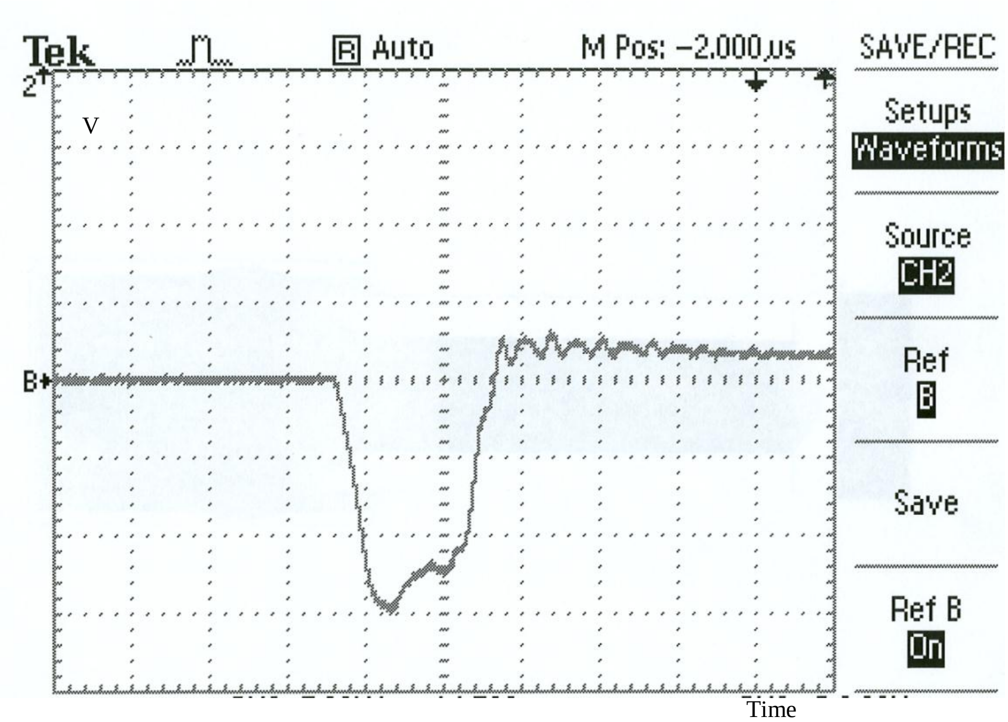

Fig. 19. Measured output high voltage applied to load which is unwanted

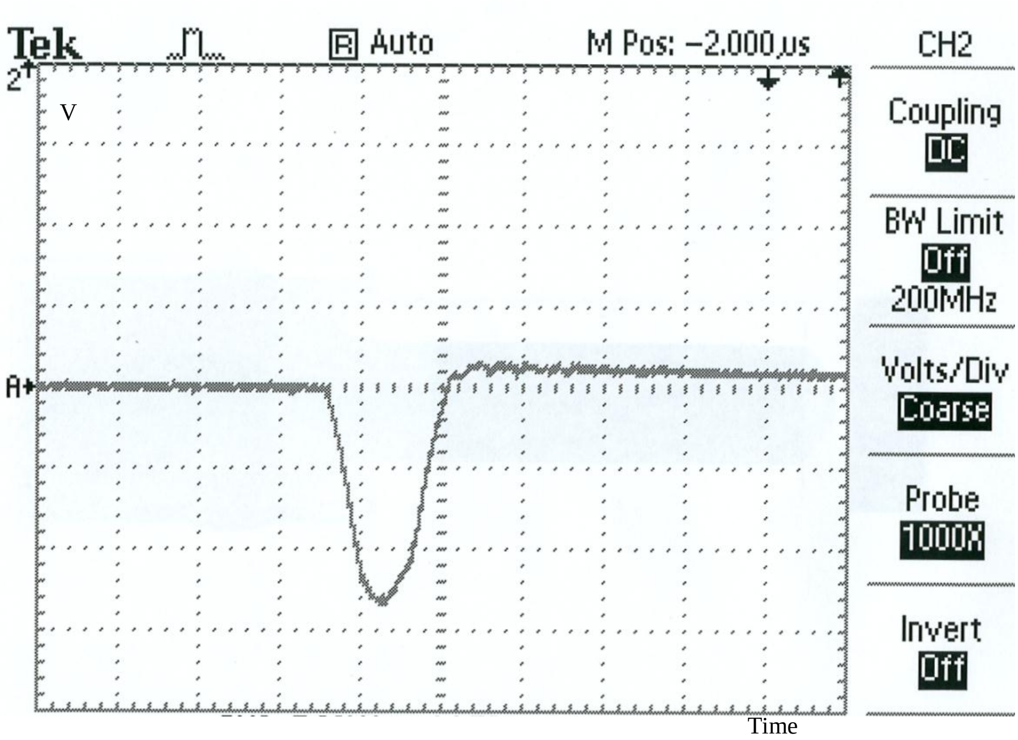

Fig. 20. Measured output high voltage 40 KV, with pulse width 500ns.

CONCLUSIONS AND RECOMMENDATIONS

High voltage pulse transformers are often used in association with high voltage pulse generating circuits to further increase the pulse output voltage level. However, because of the transformer parasitic elements involved, the transformer is the critical device in shaping the rising characteristics of the output pulse. In this paper, we simulated pulse transformer based on linkage flux as state variable method. It has been considered the leakage inductance and capacitance in simulation and the effect of pulse frequency. We have obtained conditions for these parameters causing unexpected output pulse. Finally, submitted model of pulse transformer using PSPICE simulation gave us the limits for the value of the parasitic elements of pulse transformer. Our investigation is useful for analysis of pulse transformer and has good points for selecting and setting leakage parameters of pulse transformer. Especially, it helps us in stages of pulse transformer designing.

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