GATE DRIVER PULSE TRANSFORMERS

It deals with the basic parameters of pulse transformers, and a simple method for selecting, calculating and manufacturing them is offered.

When we use pulse transformers, to excite either power semiconductors, bipolar transistors, MOSFET´s, IGBT´s, Thyristors or other four-layer devices, we do it first and foremost because of their isolation capacity. They guarantee a total separation between the power part and the converter control circuit, also allowing other useful functions, such as impedance coupling and voltage and current levels, forming part as an important element of the pulse amplification stage.

Today there are several companies that are dedicated to the manufacture and marketing of pulse transformers, covering almost all design needs, so that you as an engineer or electronics enthusiast can simply choose to purchase one and use it in your application, or you can manufacture your own transformer according to your needs. In either case, I think this article can be useful, since in it we will summarize the fundamental parameters that must be taken into account when selecting a transformer, as well as the calculation and manufacturing procedure of them.

Few devices can transmit a pulse with less propagation delay than a high frequency transformer, but it is so, provided it has been calculated and manufactured correctly. An ideal pulse transformer would be capable of transmitting a square pulse instantaneously and without any distortion, as shown in Fig1.

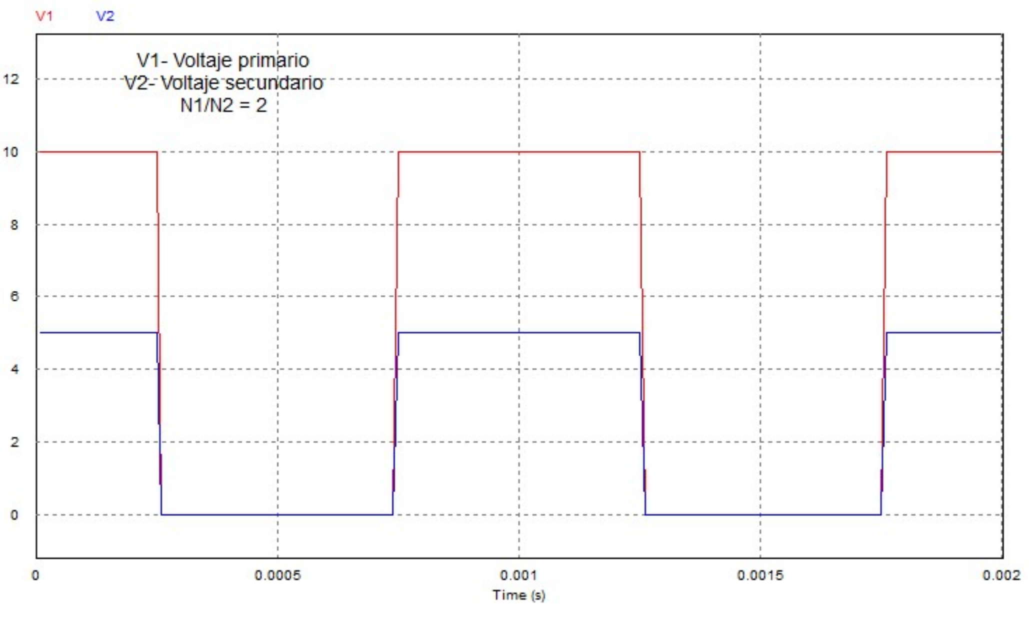


Fig.1. Transmission of a pulse in an ideal transformer.

This is impossible in real life. Each transformer has associated parasites, which prevent the transmission from being instantaneous, and which cause the signal to be distorted when passing from one winding to another.

Fig.2. Passing a 106 kHz pulse through the Murata 1002C transformer to a 50A MOSFET Gate.

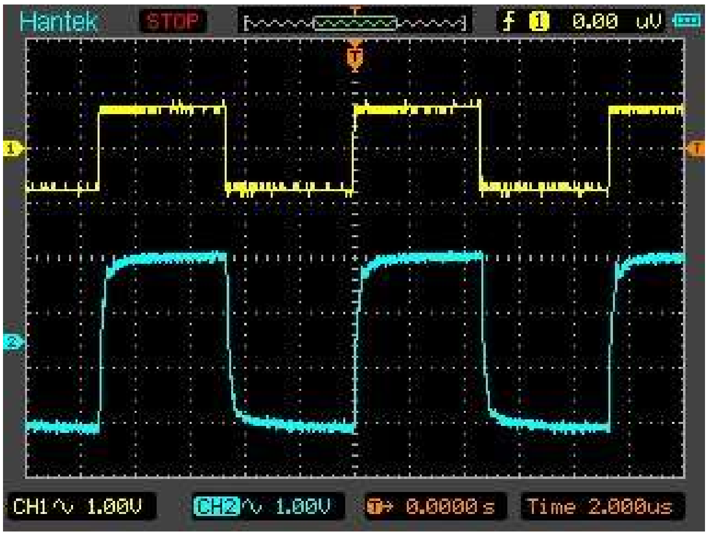


Fig.3. The same signal, but through the Murata 1013C transformer, with 4 uH of parasitic inductance only.

The higher the resistance of the windings and the parasitic inductances of both the primary and secondary, the longer the rise and fall times of the signal in the secondary. The core magnetization current causes the amplitude of the output pulse to be lost according as it increases towards the end of the pulse.

The parasitic capacitance between the windings and between the turns of each coil, in combination with the leakage inductances, cause the appearance of high-frequency oscillations that increase the distortion of the useful signal.

Finally, to increase the quality of a pulse transformer we must reduce the following parameters as much as possible:

- Leakage inductance (parasitic inductance)
- Winding resistance
- Parasitic capacitances between turns and between windings
- Core losses.

This is much more difficult than it may seem. The problem is that they tend to be in contradiction with each other, and what is more important: Any action on these unwanted parameters directly affects the good parameters, those that make transformers a truly useful part:

- L – Magnetization inductance
- Et – Product Volts microseconds. Area under the voltage curve over time that can assimilate a transformer without saturating.
- N – Transformation ratio
- Insulation voltage

The parasitic inductance Ls of a transformer arises mainly due to a decrease in the magnetic link M between its coils. Ls can be represented as an inductor with low inductance connected in series with the transformer windings.

The parasitic inductance increases dramatically as the number of turns of the windings increases, and as the separation distance between them increases. A low magnetic permeability of the core used also has a negative influence. Ls increases according as the transformation ratio moves away from one unit, since this worsens the link between the primary and the secondaries.

The main action for its reduction consists in guaranteeing a low number of turns N1, so that it does not exceed 30 turns, but we all know that the useful inductance of the primary depends on the square of N1, on the magnetic permeability of the material used and the dimensions of the core, so that, to guarantee a minimum required magnetization inductance, there is no other solution than to increase the size of the transformer.

The coupling between the windings can be improved by executing a two-wire or three-wire winding, in the case of three windings.

Fig.4. Three-wire winding of a pulse transformer

The three wires are taken in the hand, as shown in Fig. 3 and the three wound wires are rolled at the same time, to guarantee a better magnetic coupling between them. This method does not allow the placement of additional insulation between the coils, so the insulation voltage between them is determined by the characteristics of the wire used. For high voltage applications the use of special wires with reinforced insulation is recommended.

It should be noted that the two-wire winding increases the parasitic capacitance between the windings, as does the execution of an irregular and disorganized winding.

Another measure that reduces the parasitic inductance consists of not leaving half turns in any coil. A half turn is nothing more than a badly coupled turn.

The parasitic inductance of a transformer can be roughly calculated using empirical formulas available in the specialized literature, however, these formulas only serve to have an unreliable idea of how things will go.

The best approach is to measure the parasitic inductance directly. To do this, all but one of the coils should be short-circuited and its inductance measured either using an inductance meter or by indirect methods connecting it to a specific circuit.

Another thing is the capacitance, you need a Tester capable of measuring picofarads between the windings. The inter-turn capacitance cannot be measured.

Measuring the resistance of the windings is the easiest task, and to ensure that it is adequate you only have to choose copper wires with a diameter greater than 0.23 mm.

Maximum recommended values for parasitic parameters of a gate control pulse transformer

PARAMETER	50 kHz	200 kHZ	500 kHz
Resistance, OHM	0.5	0.5	0.5
Capacitance, pF	100	80	50
Ls, μH	8	4	0.5

Once we have talked about the main parameters that characterize a pulse transformer, let's move on to the practical use that we can make of them. First, we will see how to select a commercial transformer for a specific application, then we will carry out the complete calculation for the manufacture of our own transformer.

Example 1.

Select a commercial transformer, to be used in controlling the IXFH12N100 MOSFET of an 800W power supply with the following data:

Switching frequency	200 kHz
Maximum Duty Cycle	50 %
Driver supply voltage	20V DC
Transformer connection	Unipolar
Power circuit voltage	600V DC

Solution.

Using the graph in Fig. 5, we conclude that the inductance of the primary of the transformer L_p *must be greater than 1000 uH, for a frequency of 200 kHz.*

Lower values are not recommended, since the magnetization current would increase:

$$I_s = V/(2.\pi.f.L_p)$$

Current that does not intervene in the transmission of the pulse, and only increases the losses

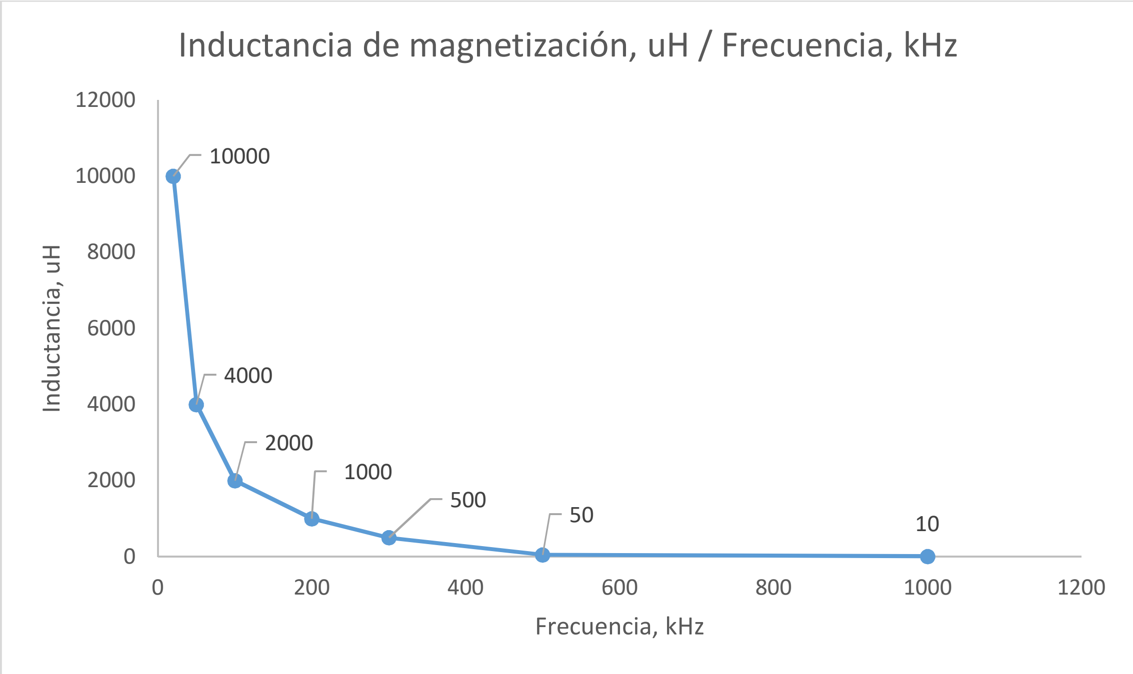


Fig.5. Magnetization inductance of the primary recommended for different frequencies.

Let us calculate the parameter Et required for our case.

The transformer connection is unipolar, that means that it has one end connected to the negative of the 20V source and the other end is connected through a capacitor at the output of a push pull stage, as shown in Fig. 6

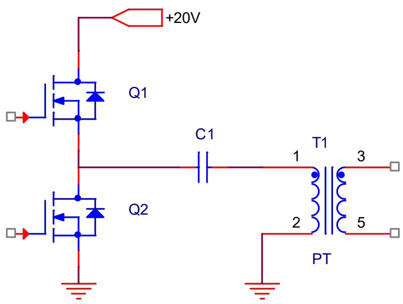


Fig.6. Unipolar connection of the pulse transformer.

According to this configuration, the voltage applied to the primary $V_p = \frac{20V}{2} = 10V$

According to the data, the switching frequency is 200 kHz and the maximum pulse time is half the period, then we have:

$$E_t = 10V \ x \ 2.50\mu s = 25 \ \ V\mu s$$

A control signal on the gate of the MOSFET IXFH12N100 of ± 10V, is more than enough to keep it in saturation state, so we can assume the 1: 1 transformation ratio.

Last but not least, we still have the insulation voltage. This is a 600V DC application. Taking into account the overvoltage peaks caused during switching, the voltage on the transformer secondary can reach 800...900V. We choose an insulation voltage of 1000V.

Finally, summarizing we have the following parameters that our candidate should meet:

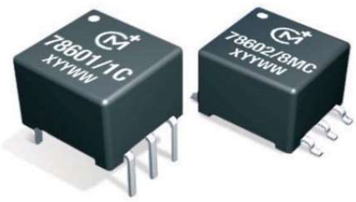
INDUCTANCE OF THE PRIMARY	Lp >=1000 uH
VOLTS/MICROSECONDS	Et >= 25
TRANSFORMATION RATIO	N = 1:1
INSULATION VOLTAGE	1000V
PARASITIC INDUCTANCE	Ls <= 4 Uh
PARASITIC CAPACITANCE	Cs <= 100 pF

We select the Murata 78601/16C transformer that meets all our requirements:

Murata Power Solutions

786 Series

General Purpose Pulse Transformers



FEATURES

- RoHS compliant
- 4 Configurations
- Primary inductance to 10mH
- 1kVrms isolation
- Industry standard pinout

SELECTION GUIDE

Order Code	Turns Ratio ±2%	Min. Primary Inductance µH	Primary Min. Volt-time Product, Et Vµs	Typ. Leakage Inductance µH	Typ. Interwinding Capacitance pF	Max. DC Resistance Ω	Isolation Voltage Vrms	Winding Configuration
78601/4C	1:1	100	4	0.19	8	0.17		
78601/3C	1:1	200	6	0.20	14	0.25		
78601/2C	1:1	500	10	0.25	22	0.34		
78601/8C	1:1	1000	15	0.29	35	0.45	1000	1
78601/1C	1:1	2000	20	0.47	49	0.60		
78601/16C	1:1	4000	28	0.47	78	0.84		
78601/9C	1:1	10000	56	0.86	121	1.30		
78602/4C	1:1:1	100	4	0.11	12	0.18		
78602/3C	1:1:1	200	6	0.17	19	0.24		
78602/2C	1:1:1	500	10	0.27	32	0.34		
78602/8C	1:1:1	1000	15	0.35	47	0.46	1000	2
78602/1C	1:1:1	2000	20	0.60	72	0.66		

CALCULATION AND MANUFACTURE OF A PULSE TRANSFORMER FOR GATE CONTROL

To proceed with this task, it is necessary to have a series of specific data on the working conditions of the pulse transformer, as well as the characteristics of the semiconductor device or devices to be controlled.

List of input parameters for the calculation:

- Switching frequency, kHz
- Duty Cycle, 0...1 or as a % of the period
- Supply voltage, V
- Driver configuration, unipolar o bipolar
- Transformation ratio
- Number of secondaries
- Insulation voltage

It is about obtaining a transformer, minimizing its parasites, in such a way that the output signal is distorted as little as possible, has sufficient amplitude and has short fronts and edges, which guarantee a rapid on and off of the transistors and / or thyristors that are controlled, also complying with the insulation requirements.

Choice of core type.

We already know that, to obtain a high quality pulse transformer, it is crusial to minimize the number of turns of its coils, and at the same time to be able to guarantee the magnetization inductance recommended for the switching frequency, according to the graph in Fig. 5.

We should select a material with the highest possible magnetic permeability for a given frequency. Values between 4000 and 10000 are appropriate for frequencies below 400 kHz, materials N30, N87,3F3, SF-139 and many others can be used. The cores can be of any type, but the best results offer toroids and armoured EP and POT. In case of using the latter, or any other of the divided type, it is important trying to achieve the minimum possible air gap; even a thin layer of glue in the contact area has a negative influence on the μ_e value, so avoid applying glue on the inside.

The size must be sufficient to be able to reach the magnetization inductance with few turns. It must be achieved with less than 30 turns (the lower the number of turns, the lower the values of all the parasitic parameters of the transformer). For this purpose we can use the parameter $A_L$that appears in the data sheet of the magnetic cores. A_L is the inductance of the core for a given number of turns. The data sheet must be consulted carefully, since it may refer to 100 turns, or a single turn, depending on the manufacturer and the size of the core. The inductance depends on the number of turns in a quadratic relationship, so knowing the parameter A_L we can use the following formulas to calculate the turns necessary to obtain the inductance of magnetization, or inductance of the primary:

$N = \sqrt{\frac{L_p}{A_L}}$ if A_L is referred to a single turn

$N = 100.\sqrt{\frac{L_p}{A_L}}$ if A_L is referred to 100 turns

In both formulas, L_p and A_L should be expressed in the same units.

In case we have no knowledge of the parameter A_L, we should try to identify the effective magnetic permeability of the core by practical methods, and calculate or measure its inductance. Knowing the type of material and its geometric measurements, you can make use of the Apple available on the Web at ledoelectronics.com to calculate the inductance of different types of cores.

Once selected a core that guarantees us the recommended magnetization inductance, with a number of turns $N \leq 30$ we have to check that it does not saturate, taking into account the factor Et (volts microseconds)

$$N \geq \frac{V.t}{B.A_e.10^2}$$

Where

$V -$ is the voltage in volts applied to the primary of the transformer

$t -$ is the pulse time in microseconds. It is calculated knowing the minimum working frequency and the maximum Duty Cycle.

$B -$ is the maximum magnetic induction of the core in Tesla.

$A_e -$ is the cross-sectional area of the core in cm^2

If the number of turns meets the requirement of the above formula, then we can continue with the calculation of the remaining parameters. Otherwise, it would be necessary to look for a larger core.

The rest is a simple task. The largest diameter of the wires should be used that allow us a two-wire or three-wire winding if we have chosen a toroid. For the rest of the cores, a single layer winding per coil is recommended, and if we have two secondary windings, we should wind the primary between the two secondaries to improve the magnetic link. It is a good practice to use cables that directly guarantee the insulation voltage required by the application, since by adding additional insulation between the coils, we increase the parasitic inductance.

The transformation ratio is chosen so that the amplitude of the output voltage matches with the recommended values for the type of power semiconductor that needs to be controlled. The quality of the transformer worsens as the number of turns of the secondaries increases in relation to the primary, so it is good to maintain an 1: 1 ratio. Adapt the driver's power supply and use bipolar configurations for the transformer energization.

It is important to remember that transformers cannot pass the DC component. If the application requires a PWM regulation with wide margins, it is necessary to use a level restoring circuit in the secondary, such as those represented in Fig. 7.

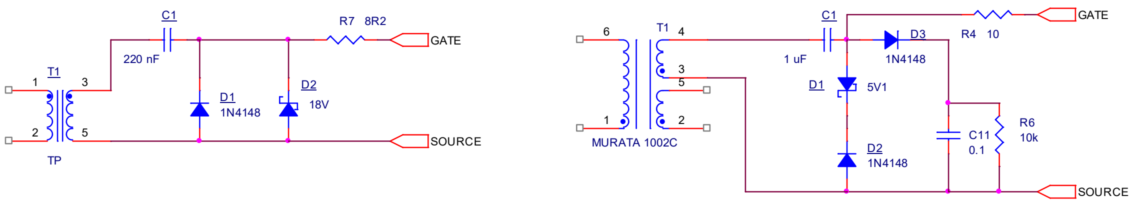


Fig.7. DC level restoring circuits.

Example 2.

Manufacture a pulse transformer to be used in the Driver represented in Fig8, with the following data:

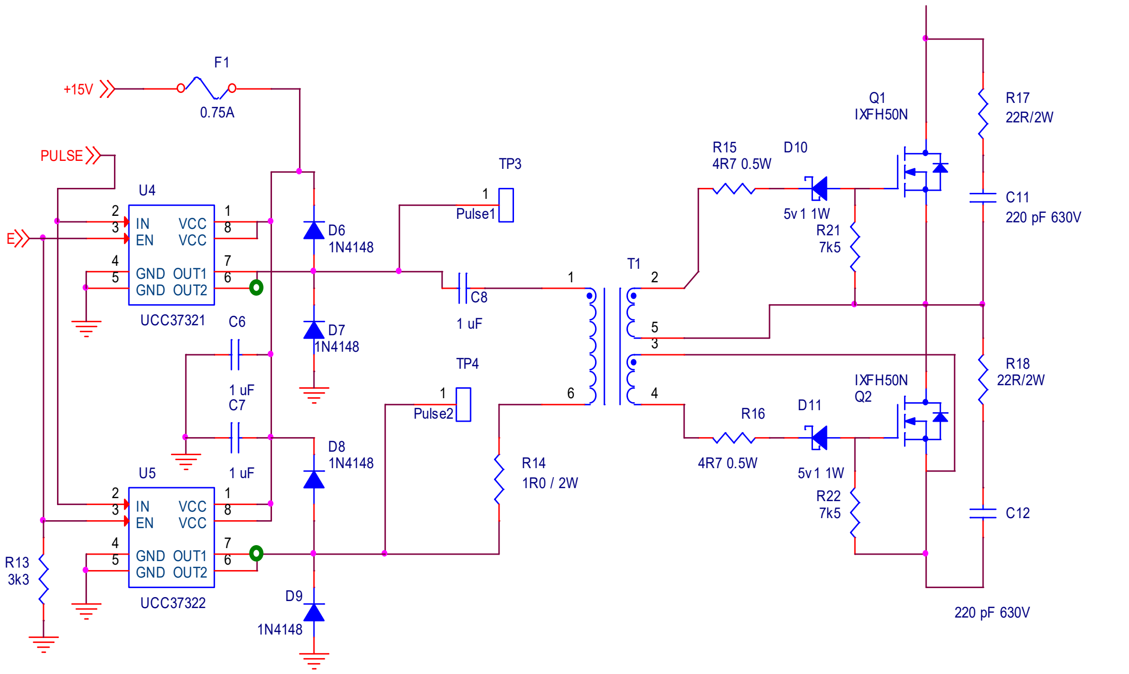


Fig.8. Practical circuit for the control of a half bridge of a converter used in induction heating.

SWITCHING FREQUENCY	*170 kHz*
POWER SUPPLY VOLTAGE	*15V*
CONFIGURATION	*BIPOLAR*
DUTY CYCLE	*0.5*
TRANSFORMATION RATIO	*1:1.5:1.5*
INSULATION VOLTAGE	*500V*

The transformation ratio chosen is of 1.5 to compensate for the loss of amplitude in the Zéners D10 and D11 used to achieve a small dead time between turning on the MOSFETs.

According to the graph in Fig. 5 the recommended value of the magnetization inductance Lp = 1500 uH.

Let us try with the Epcos B64290L0045x830 toroid ring which has the following parameters as per its datasheet:

- *D = 16 mm, d = 9.6 mm, h = 6.3 mm*
- $\mu_r = 4300$
- $A_L = 2.77\ \mu H$ *(expressed for a single turn)*
- $A_e = 19.73\ mm^2 = 0.1973\ cm^2$

Calculating the number of turns of the primary:

$$N_p = \sqrt{\frac{1500}{2.77}} = 23.27 \approx 23$$

Verifying that the transformer does not saturate. The pulse time:

$$t = \frac{10^6}{170000}\ x\ 0.5 = 2.94\ \mu s$$

Applying the formula:

$$N_p \geq \frac{15V\ x\ 2.94}{0.2\ x\ 0.1973\ x\ 10^2} = 11.18$$

There is no danger of core saturation, we can continue with the calculations

The turns of the secondary windings:

$$N_{2A} = N_{2B} = 23\ x\ 1.5 = 35$$

We chose the 0.25 mm Triplex TIW-M wire for the three coils, and we carry out a three-wire winding all over the ring. The insulation properties of this wire far exceed the demands of today's application.

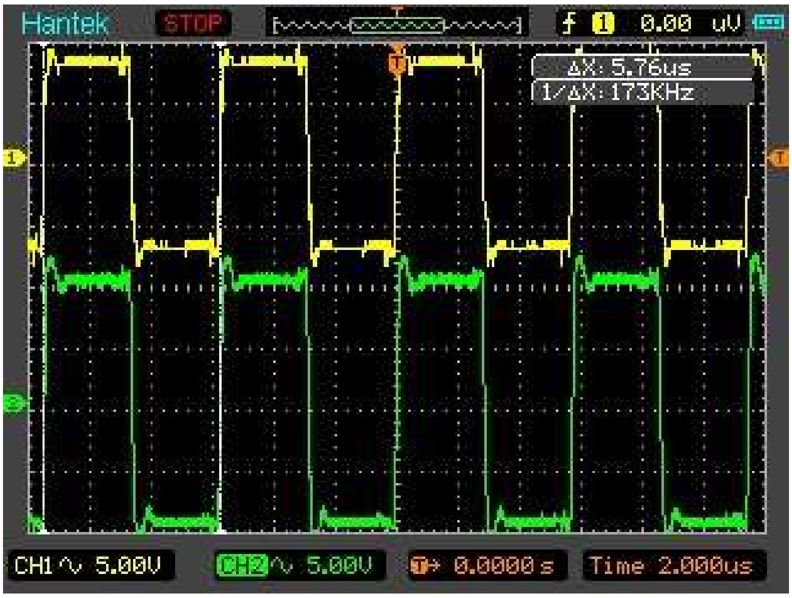


Fig.9. Signal in the primary and secondary of the transformer manufactured according to the calculations of Example 2.

The pulse transformers used as gate drivers can behave unexpectedly during the commutation transients that take place when turning on and off the equipment where they are used, even becoming saturated during the charging and discharging of the separation capacitor. This can cause unwanted pulses and alterations in the ignition sequence of the transistors and thyristors in the power circuit.

If in doubt, in medium and high power circuits it is recommended not to supply the power part until the control circuit has stabilized.

The selection and calculation method presented is not characterized by having a high theoretical rigor, but it is very effective and useful during prototype tests, and in the manufacture of homemade converters.