# THE POWER AMPLIFIER DEDICATED FOR SET-UP TO THE MEASURE PARAMETERS OF MAGNETIC DEVICES

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ABSTRACT

The paper presents the worked out and constructed by the authors power amplifier designed to be used in systems for measuring of parameters of magnetic devices. This amplifier makes possible amplification of the input signal in a wide range of frequency and amplitude of the output voltage. The construction of the system and the results of measurements of characteristics of the constructed amplifier as well as of the system for measuring the characteristics of the pulse transformers are described.

## INTRODUCTION

The impulse-transformers are important components of switched-mode power supplies. In spite of the simple construction of these elements, containing only the ferromagnetic core and the windings, much attention in the literature concerning power electronics is paid to designing impulse-transformers [1, 2, 3, 4]. Parameters of magnetic elements, such as choking-coils and transformers contain all: electric, magnetic and thermal parameters [5]. Magnetic parameters refer to the ferromagnetic core, while electric parameters are, among other things, inductance and series resistance of the choking-coil, winding capacitance, the turn ratio of the transformer, watt-hour efficiency, series resistance of windings. In turn, thermal parameters, describing efficiency of the removed of the heat generated in the elements are their own and mutual transient thermal impedances. Every mentioned group of parameters of materials or magnetic elements demands the measurement in the specific measurement set-up [5].

To measure dynamic characteristics of magnetisation, e.g. the core of the impulse-transformer, the source of a sinusoidal signal of high amplitude and the high value of the output current is needed. The signal from this source will produce in the core the magnetic force of the value H, at which the magnetic flux density B attains the saturation flux density.

Due to a lack of commercial solutions and in order to assure suitable conditions of the measurement a special power amplifier was designed and constructed. In the construction of this amplifier the accessible module of the operating amplifier of the power of the type MP of the firm Apex was applied [6]. The paper presents the project of the power amplifier and describes its construction. Furthermore, some results of investigations of the prototype are shown.

## 1. THE DESCRIPTION OF THE MODULE MP38

The construction of the power amplifier is based on the module MP38, made in the hybrid technology. In the output stage of the amplifier the producer applied the power MOS transistors. The circuit is on the ceramic isolating plate, cemented with the aluminium-basis dissipating heat, which allows obtaining the power dissipated up to 125 W. The module is designed to the supply voltage from ±15V to ±100V. The maximum output current of the module is equal to 25 A [6]. The producer assures the correct operation of the module within the range of temperature from –40°C to +85°C. In Fig. 1 the internal structure of the module MP38 is presented [6].

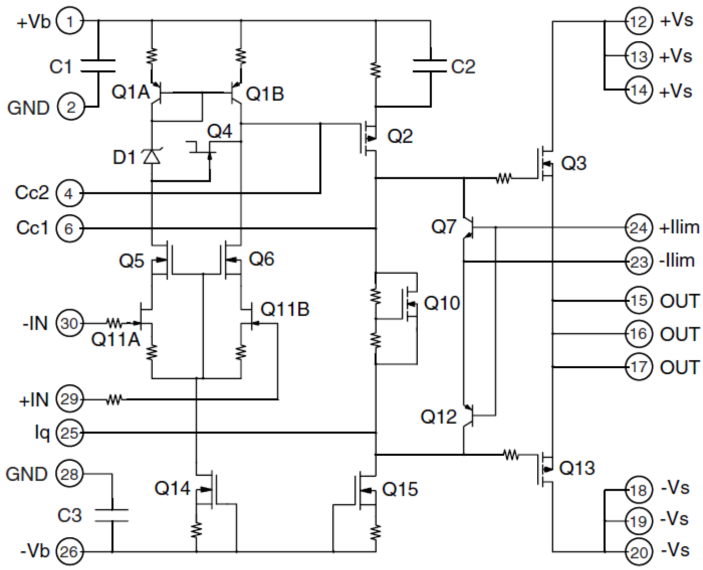


**Fig. 1.** Diagram of the module MP38 [1]

This is a typical operation amplifier made in the hybrid technology, additionally equipped with the output power transistors Q3 and Q13 and a circuit limiting the output current. Transistors Q7 and Q12 operate in the circuit limiting the output current. Additionally, inputs raising the voltage in the amplifier allow it to operate with a part of the signal at higher values of the supply voltage than the high current output stage. The four-line-method of the measurement current makes it possible to limit the output current without taking into account internal or external excrescent resistances of the output lines. The input IQ allows switched off of the quiescent current in the output stage, which allows, in turn, the amplifier to operate in class C and to decrease power losses when the input voltage is equal to zero [7]. The input +IN is a non-inverting input of the amplifier, whereas –IN is an inverting phase input. Pins +Ilim and –Ilim are inputs of the overcurrent protection circuit of the amplifier. The supply voltages of the input and output stages, respectively, are connected to pins +Vb, –Vb and +Vs, –Vs. CC1 and CC2 are the inputs of the phase compensation of the amplifier.

## 2. DESIGN AND CONSTRUCTION OF THE AMPLIFIER

The elaborated amplifier, whose block diagram is shown in Fig. 2, contains the amplifying block with the module MP38 and the power supply block.

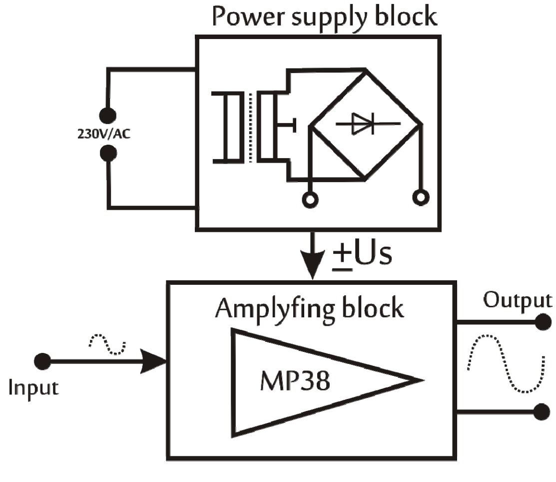


**Fig. 2.** Block diagram of the power amplifier

The application circuit of the considered amplifying block is shown in Fig. 3. The construction of the amplifying block was adapted on the basis of the catalogue data [6] and the application note [8].

The module MP38, in spite of the fact that it is a complete power operating-amplifier, demands additional external elements. Capacitors C3 and C9 fulfil the role of the filter of the power supply. Additionally, blocking capacitors C1, C2; C5, C6; C7, C8; C10, C11 connected parallelly with one another for the purpose of extending the admissible voltage were connected serially. The resistor R3 limits the output current of the amplifier to the value equal to 3A.

Diodes D1, D2, D3, D4 protect the amplifier against too high voltage between removals of the module MP 38. The capacitor C4 and the resistor R4 are accountable for compensation of the phase. The values of these elements depend on amplification Ku equal to the quotient of resistance of the resistors R2 and R1.

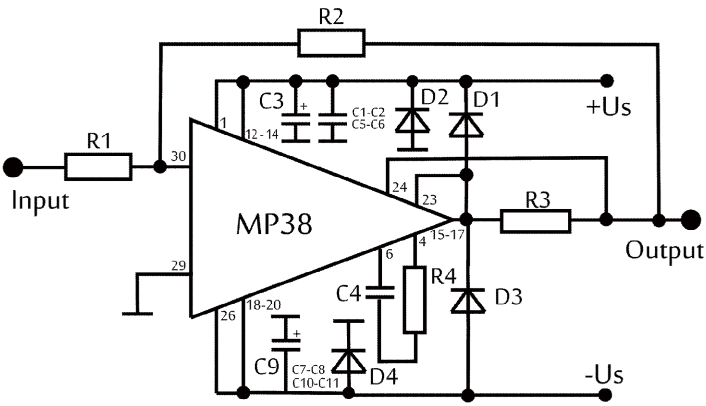


**Fig. 3.** Application diagram of the amplifying block

The amplifying block is supplied by the voltage to ±100V from the power supply block, whose diagram is presented in Fig. 4. The power block consists of the ring transformer of the power equal to 500 VA, which possesses the divided secondary winding of the RMS value of the output voltage equal to 70 V. The Greatz's bridge of the type KBPC 5010 is connected to these windings and the filter consisted of six capacitors of capacitance 1000 μF and the nominal voltage equal to 400V is connected with the output of this bridge. In spite of the fact, that the module MP38 can be supplied by the voltage ±100V, the authors decided to lower the supply voltage to the value ±96V. For this purpose, 10 rectifying diodes are connected in series with every output of the power supply. This solution assures some margin of safety for the expensive module MP38.

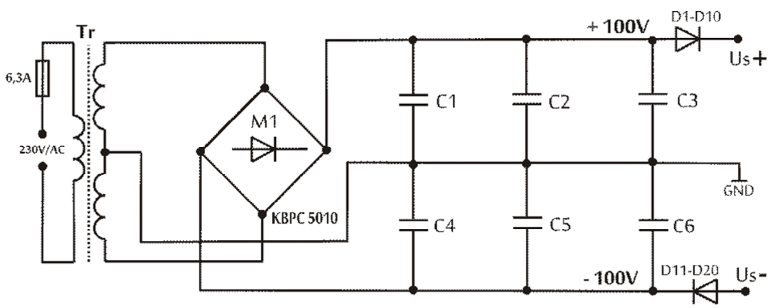


**Fig. 4.** Diagram of the power supply block

The amplifier was mounted on two printed circuit boards (PCB). The first one includes the amplifying block designed as the two-sided boards, and the second includes the power supply block as one-sided board. On the PCB of the power supply block six capacitors C1 - C6 are located, whereas the rectifier is situated on the heat-sink mounted after body of the case of the amplifier. Diodes D1-D20 are situated on the PCB of the amplifier. For the purpose of the reverse voltage of the diodes, each diode is shunted by a resistor of resistance 1 kΩ.

The PCB of the amplifying block shown in Fig. 5, was designed in such a way, that one could place on it the module MP38 and simultaneously screw this PCB to the heat-sink. Paths on the PCB, for large values of currents in the amplifier are wide and they have the layer of solder.

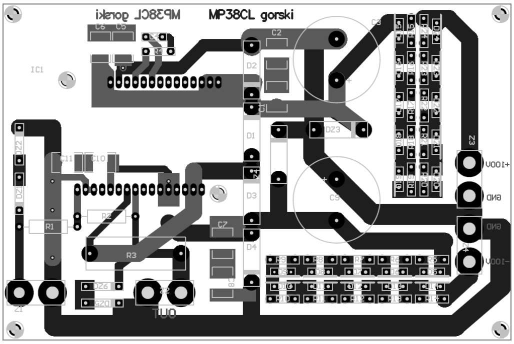


**Fig. 5.** PCB of the amplifying block

During the operation of the amplifier on the PCB of the module MP38 a lot of heat is dissipated and its removal demands the use of the heat-sink of adequately large dimensions. For the considered construction of the amplifier and the maximum output current equal to 3A it was possible the aluminium heat-sink of the dimensions: L = 60 mm, W = 190.5 mm, H = 50 mm, which simultaneously became the screwed rectifying bridge. the PCB of the amplifier block is also screwed to the heat-sink by means of funnels of distance. In Fig. 6 the distribution of elements inside the case of the amplifier are shown.

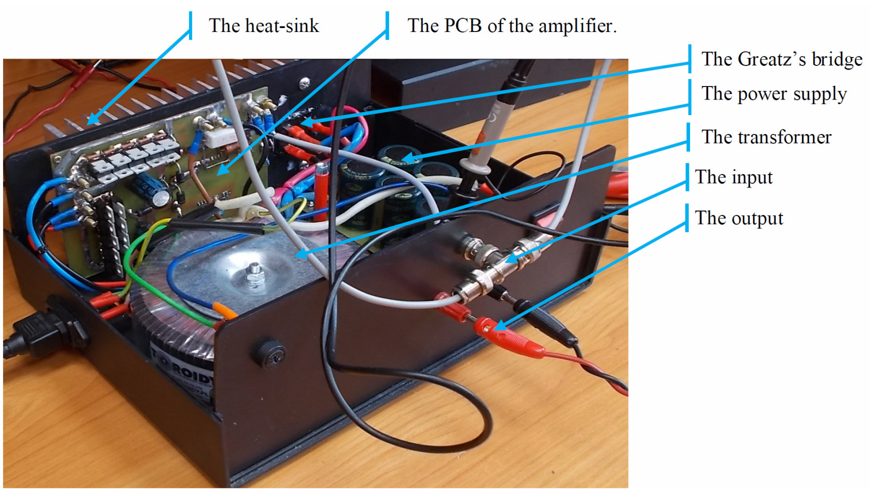


**Fig. 6.** Interior of the amplifier

## 3. RESULTS OF MEASUREMENTS

In order to test the constructed power amplifier the measurements of the dependence of: amplification Ku and the phase shift between the input and output signals on frequency, are performed.

In Fig. 7 the 3dB bandwidth, which is limited by frequency of the input signal equal to 450 kHz is shown. One can notice that the value of amplification is equal to 7 for signals of frequency equal to 200 kHz. While the frequency exceeds 300 kHz the amplification decreases visibly. The value of the phase difference between the input and output signals is also marked. This dependence is shown in Fig. 8.

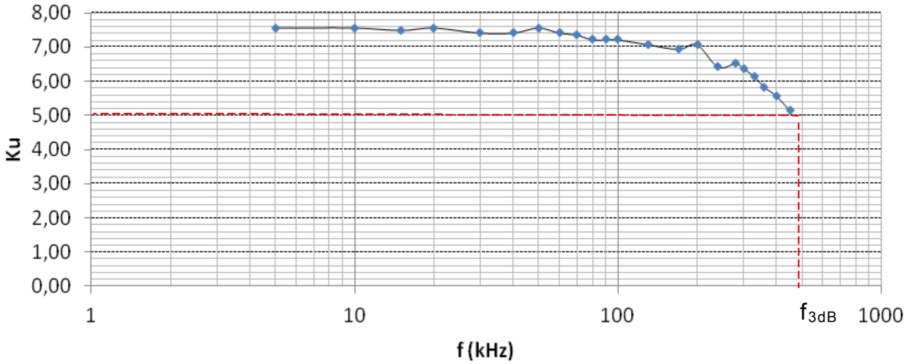


**Fig. 7.** Amplitude characteristics of the amplifier

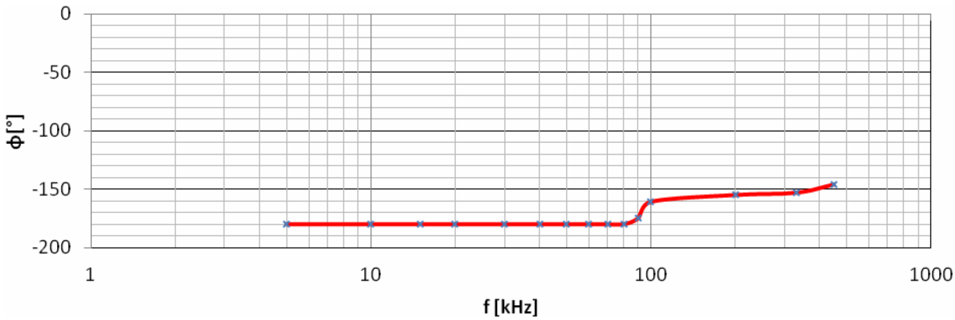


**Fig. 8.** Phase characteristics of the amplifier

The output signal is shifted in the phase by about 180° in relation to the input signal, which conforms to the principle of operation of the considered amplifier. At frequencies higher than 80 kHz the phase shift begins to decrease gradually attaining the value equal to –150° at f = 450 kHz. The dependence of amplification on the load resistance Ro at frequency f = 100 kHz for three values of the amplitude of this voltage equal in turn to 1 V, 10 V and 20 V is also measured. In every considered case the value of voltage amplification Ku in the range from 7.8 to 8.2 is obtained. The lowest value of amplification is obtained for load resistance Ro = 100 Ω [7].

## 4. THE USES OF THE POWER AMPLIFIER

The considered amplifier was used to construct the measuring set to measure characteristics of magnetic elements with the use of the measuring set shown in Fig. 9 [5, 9]. The performed measurements of magnetization characteristics of the selected ferromagnetic cores and impulse-transformers including ring cores made from different magnetic materials and possessing different geometrical dimensions were performed.

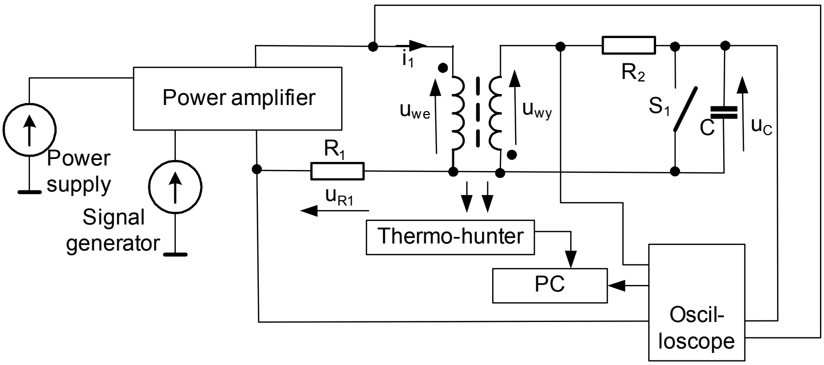


**Fig. 9.** System to measure characteristics and parameters of impulse-transformers [3]

Fig. 10 presents magnetization characteristics of the selected impulse-transformers including the following ferromagnetic cores: the ferrite core RTF-25-15-10 (F-867), the core made of powdered iron RTP-26.9-14-11 (T106-26) and the nanocrystalline core RTN-26-16-12 (M-070). The characteristics B(H) of the considered cores were measured at frequency equal to 10 kHz. On each of the mentioned cores two windings counting 20 turns of the copper wire in the enamel of the diameter 0.8 mm were wound.

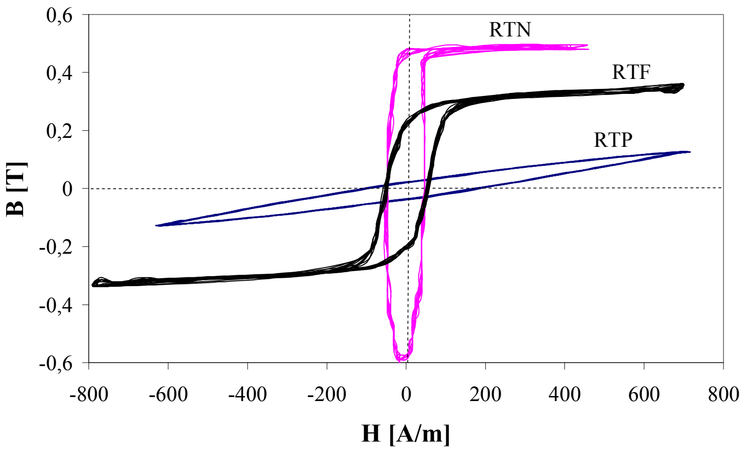


**Fig. 10.** Measured magnetization characteristics of the considered cores at frequency f = 10 kHz

For every considered transformer the magnetization curves of the cores contracted in these transformers, the transfers' characteristics of these transformers, temperatures of the core and the watt-hour efficiency of the transformer in a wide range of frequency and load resistance were measured. All the characteristics presented in the further part of this section are marked at the amplitude of the output voltage of the amplifier equal to 70 V and resistance $R_1 = 33\ \Omega$.

As one can notice, the magnetization characteristics have a course similar to such characteristics given in the catalogue data of ferromagnetic materials and for each material they strongly differ from one other. Particularly the slope of the characteristics B(H), corresponding to magnetic permeability, changes even a thousand times. The lowest permeability has the core RTP, and the highest - RTN. The area of the hysteresis loop is the smallest for the core RTP. The range of saturation of the core was obtained only for the core RTF [5].

Fig. 11 illustrates the influence of load resistance on the watt-hour efficiency of the considered transformers.

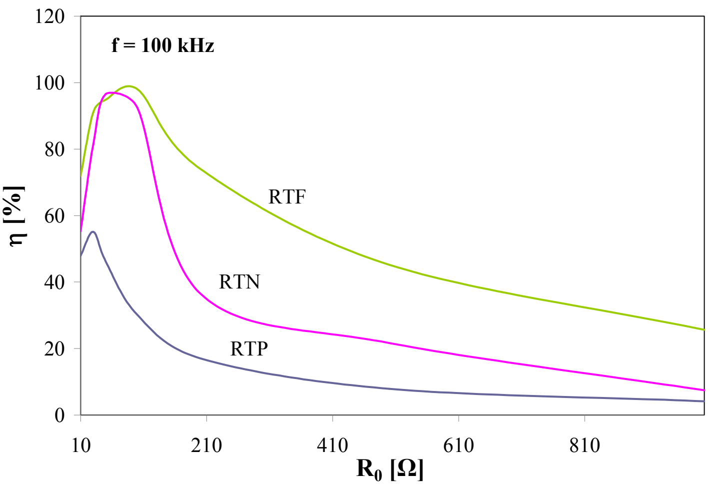


**Fig. 11.** Measured dependences of the watt-hour efficiency of the transformer on load resistance at f = 100 kHz

The dependence $\eta(R_0)$ possesses the maximum at load resistance in the range from 30 to 100 Ω, yet it is proper to notice that the maximum efficiency for the core RTP is almost twice smaller than for the remaining transformers. A decrease of the watt-hour efficiency in the range of large values of load resistance results from the high value of the quiescent current, which becomes the dominant component of the current of the primary winding.

The Fig. 12 illustrates the dependence of the core temperature on load resistance. As one can notice, the temperature of the core RTP is considerably higher than the temperature of the remaining cores and increases with an increase in load resistance. This non-typical dependence $T_R(R_0)$ testifies to the fact that losses in the transformer are mostly due to losses in the core [5].

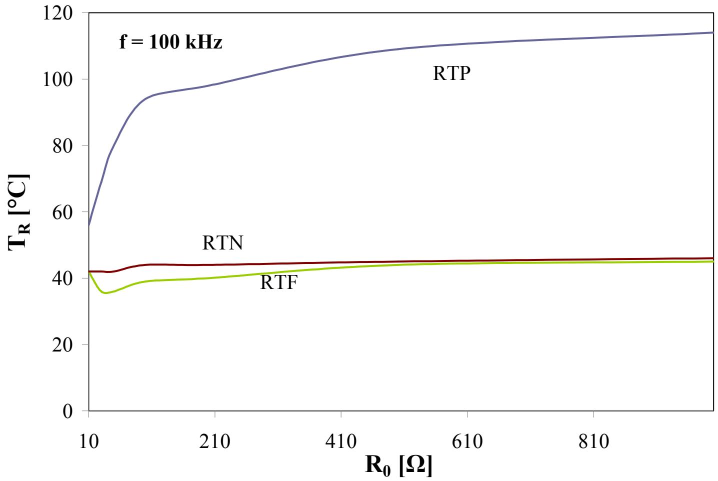


**Fig. 12.** Measured dependences of the core temperature of the transformer on the load resistance charge at f = 100 kHz

Figure 13 presents hysteresis loops B(H) of the considered ferromagnetic cores. The first investigated transformer was wound on the powder core RTP made from the material -2. As one can notice, the maximum value of magnetic flux density B equal to about 0.03 T and the maximum value of the magnetic force H equal to about 300 A/m were obtained for the signal of frequency f = 1 kHz. Simultaneously this hysteresis loop shows the smallest value of the coercive field and the smallest area. An increase in the frequency of the signal up to 100 kHz causes an increase in the maximum value of the magnetic force and an increase in the value of the coercive field, as well as an increase of the loop area, which testifies to an increase in the value of power losses in the core.

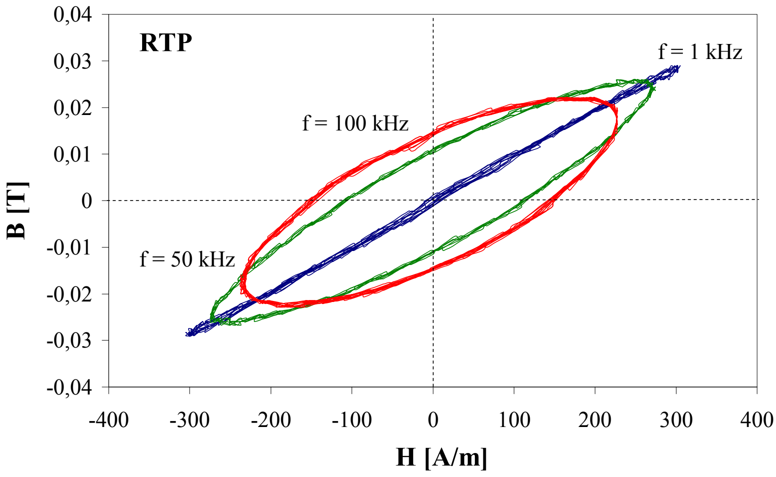


**Fig. 13.** Magnetization curves of the powder core

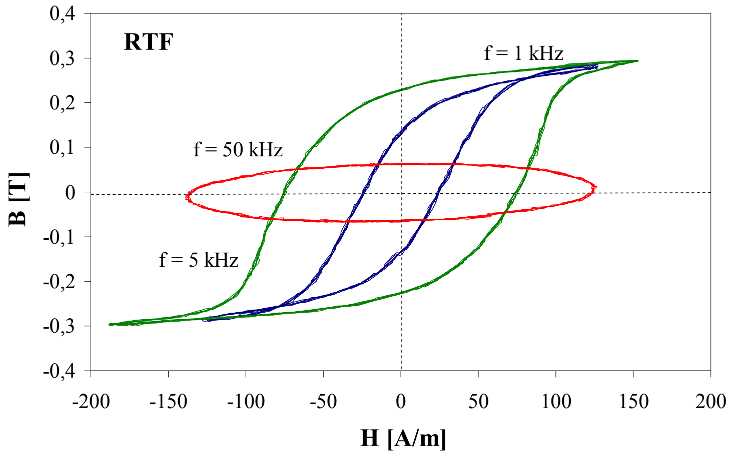


**Fig. 14.** Magnetization characteristics of the ferrite core

The second of the investigated transformers was made using the ferrite core from the material F-876. The obtained hysteresis loops B(H) is presented in Fig. 14. As one can notice the maximum value of the magnetic flux density is tenfold smaller than for the powder core. The magnetic force is twice smaller than for the powder core. It is due to a smaller size of the ferrite core and to the difference in the value of magnetic permeability. The maximum value of saturation flux density is reached for the signal of frequency f = 5 kHz. At the frequency f = 50 kHz the least values of magnetic flux density and the magnetic force were obtained. The greatest area of the loop was obtained for the voltage of the frequency 5 kHz, which testifies to the greatest losses of energy in the core.

## 5. CONCLUSIONS

In the paper the constructed by authors power amplifier was presented. It makes possible to amplify signals in a wide range of frequency and to obtain the wide range of amplitude of the output voltage. The amplifier can be used in the laboratory to measure dynamic characteristics of magnetization of the cores of impulse-transformers. During these measurements the source of the sinusoidal signal of high amplitude and for high value of the output current is indispensable. With the use of this amplifier some characteristics of magnetization of the selected materials and transformers dedicated to switched-mode converters were measured. The presented results of measurements confirm the usefulness of the constructed amplifier in investigating properties of magnetic elements.

## 6. ACKNOWLEDGEMENTS

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