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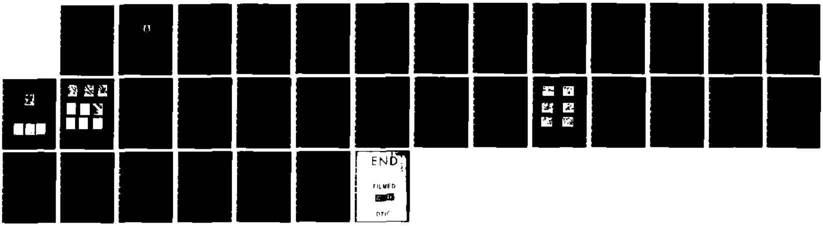

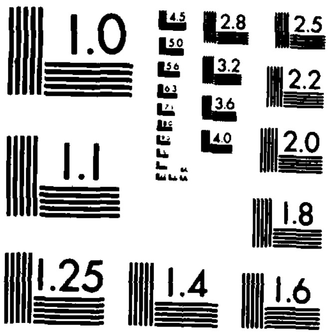

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Table of Contents

The Heat Treating of Conductive Films Made from DP 9061 Paste

Krystyna NIEMIROWICZ

This article treats the mechanism of the physicochemical phenomena occurring during the heat treating of conductive films made from PdAg paste. The effect of the method of the carrying out of the baking process on the structure of the films and thereby on their electrical and mechanical parameters is explained. Numerous figures and photographs illustrate the results of the investigations of the X-ray, thermodifferential, and thermogravimetric microanalysis.

1. Introduction

The inert thick-film structures in hybrid microcircuits are made with the employment of the screen printing method during the application of conductive, resistive, and dielectric pastes on a ceramic plate and during the subjecting of them to appropriate heat treatment. During this treatment there occurs a series of reactions, which make it possible for the films to acquire specific electrical and mechanical parameters.

1.1 Physicochemical Reactions Occurring in Films during the Heat Treating Process

The constituent operations of the heat treating process of films are:

- drying,

- the removal of the organic components in the low-zone part of the furnace,

- baking.

The more volatile organic components are removed from the films during the course of the drying. The process occurs at a temperature of about 125° C over a period of 15 min. Improper drying can be the cause of the formation of cracks and blisters in a film. Drying too quickly or at too high a temperature leads to extensive contracting or running of the film on the substrate. This process takes place in tunnel furnaces or under infra-red lamps.

The baking process is conducted in tunnel furnaces. The combustion of the less volatile organic substances occurs in the low-zone part of the furnace. In the high-temperature zone there occurs the sintering and the fusion of the film components and reactions between;

- the paste components,
- the paste components and the substrate,

- the paste components and the furnace atmosphere,

- the components of various pastes, which are in contact with one another

1.2. Reactions Between Paste Components

Reactions between metal components are limited to the processes of the sintering and the fusion of the individual metal grains, in which the character of the bonds created between the grains has a fundamental effect on the conductivity of the film. The processes occurring at low baking temperatures do not have the character of chemical reactions and encompass only the points of the mutual contact of the particles. The sintering and the fusion of the grains occurs at intermediate temperatures. At high temperatures there occurs the fusion of the components and the formation of practically homogeneous bonding.This process can be described as follows:

$$Pd \xrightarrow[330^{\circ}C]{O} PdO \xrightarrow[520^{\circ}C]{Ag} PdAg + PdO$$

The resistance of the pastes decreases in proportion to the increase in the baking temperature, because the resistance of the bonds between the metal grains decreases.

Reactions between the metal components and the binder. The noble metals, which do not readily enter into reactions with the other components of the paste, generally perform the role of the base material in the conductive pastes. However, it happens, that at high temperature the metal grains are covered with oxide, which is soluble in the glaze. Reactions of this type mainly occur on the surface of the grains, affect the character of the contacts between the particles, and are the cause of the increase in the resistance of the film.

Reactions between the metallic and the organic components. The organic components, which are incompletely removed in the initial baking phase, at high temperature create carbides, which are located on the surface of the metal particles and increase the resistance.

Reactions between the components of the binder. The majority of the reactions occurs in the formation process and after the fritting of the glaze. However, it is possible, that the frit, added to the paste, contains oxides, among which, the reactions, forming the glaze, did not proceed to the end. In such a case these reactions proceed to the end during the baking of the film.

1.3. Reactions Between the Paste Components and the Substrate

Reactions between the metallic phase of the paste and the alundum grains practically do not occur. However, a process of slight dissolving of the alumdum in the vitreous phase of the paste and very abundant mutual dissolving of the glazes, contained in the paste and the substrate, were found.

1.4. Reactions Between the Paste components and the Furnace Atmosphere

The furnace atmosphere can be varied from highly oxidizing to highly reducing. Baking in an oxidizing atmosphere leads to theformation of oxides on the surface of the film, which are the cause of the increase in its resistance and of the deterioration of the soldering properties. Nitrides, which can be formed during baking in an air atmosphere, give the same effect /1/. A highly reducing baking atmosphere does not cause reactions with the metallic phase.

1.5. Reactions Between Paste Components of Various Types

The production of a thick-film microcircuit requires in successsion several of the following stages of the printing and the baking of films of various types. These films overlap each other and react during baking. A typical process taking place during baking is the diffusion of the metallic phase from the conductive films to the resistors, and its result will be a variation in the properties of both films.

1.6. Reactions Between the Vitreous and the Organic Phase

Incomplete removal and subsequent carbonization of the organic component leads to reaction with the glaze. For example the following reaction can occur: $PbO + C \rightarrow Pb + CO$ the carbon monoxide, being oxidized, can cause the formation of craters and cracks in the film.

2. An Investigation of the Heat Treating of DP 9061 Conductive Paste

The phenomena occurring during heat treating were observed using films made from DP 9061 paste as a means of illustration.

The program of the investigations was systematized into several basic groups:

The main investigations dealt with the materials going into the composition of the DP 9061 paste. The purpose of these was to study the chemical composition of the paste as well as the arrangement of the elements in the films made from it.

The investigations employing a derivatograph had as their purpose the observation of the heat treating process.

Investigations of test circuits (systems) relied on measurements of operational films made from the utilized paste.

The structural investigations had as their purpose the determination of the effect of baking temperature on the structure of the film.

2.1. Analytical Investigations

Spectral analysis was carried out employing a PGS-2 grid spectrograph in the 2,300-3,300 Å wavelength range. An arc of direct current of about 8 A was excitation source. The specimen for analysis amounted to 1 g. The specimen was dried before the analysis. Lines of the following elements were detected:

intense lines - Ag, Pd, Bi

slightly visible lines - Be, Si, Mn, Mg, Ca, Ti, Pt, Pb

Quantitative chemical analysis. The following elements were quantitatively determined on the basis of the results of the spectral analysis: Ag, Pd, Bi, Si, Pb. The following elements were not found in the paste: Mn, Ti, Mg, and Ca. The elements Pt and Be, identified in the paste, were not determined by the spectral analytical method.

The results of the analysis of the DP 9061 paste in weight %:

Ag - 44.2
Pd - 17.2
Bi - 10.3
SiO_2 - 1.65
Pb - 0.8

Taking into account, that Bi, Si and Pb occur in the paste in the form of oxides, the percentage content of the chief components in the paste is the following

Ag - 44.2
Pd - 17.3
Bi_2O_3 - 13.2
SiO_2 - 1.65
PbO - 0.96
Σ = 77.3%

The remaining 22.7% make up the organic substances in the paste /the resin and the solvent/. For the purpose of determining the quantity of solvent a sample of the paste was heated at a temperature for a period of 2 h /to a constant weight/ the weight loss of the sample amounted to 20 weight %. The presence of Bi_2O_3 in the paste /with a melting point of 704° C/ suggests, that the sintering process of the films occurs in the liquid phase.

Microanalysis Employing an X-ray Microanalyzer. Investigations were carried out on a JXA-3A microanalyzer of the Jeol firm; the operating principle of the microanalyzer was described among other things in works /3/ and /4/. The purpose of the investigation was the identification of the chemical composition of the grains occurring in the PD 9061 film and the obtainment of information pertaining to the surface and the linear distribution of the elements. The microanalysis was carried out on films 13 um thick baked at a maximum temperature of T_p=850° C. The distribution of elements was investigated on the surface as well as in cross sections through the films.. The cross sections were made at an angle of 30° to the plane of the ceramics and polished with the aid of 1200 carborundum, and subsequently were joined to each other with a metal film and carbon vaporized on them.

Microanalysis was carried out employing:

- accelerating voltage - 25 kV
- absorption current - 200 mA
- electron beam diameter - about 2 μm
- analyzing crystals - quartz, LiF, mica, KAP

Photographs 1 and 2 and the graph of the writing recorder illustrate the observations /Fig. 1/. The obtained information makes it possible to put forward the following proposals:

- The metal grains /with a shape close to spherical/, occurring in the films, constitute the PdAg alloy /Photo 1./,
- The dark regions of the surface relief with the appearance reminiscent of "holes" probably constitute the oxides /Bi_2O_3, SiO_2 and PbO/ occurring in the glaze /Photo 1/.
- The material binding the film with the ceramics is mainly Bi_2O_3; to a lesser degree SiO_2 and PbO /Fig. 1/.
- A concentration of PdAg grains is visible on the surface of the film /Fig. 1/.

2.2. Thermodifferential and Thermogravimetric Analysis

An investigation was carried out with the aid of an MOM OD-102 type derivatograph in a temperature range of 20-900° C in alundum crucibles and in an air atmosphere. Al_2O_3 was used as the standard substance. The weighed specimens amounted to 1 g.

The conditions for photographing the individual characteristics were the following:

T - 1200° C
TG - 500 mg
DTG - 1/10
DTA - 1/10

The rate of the increase in the temperature was 17.6° C/min /Fig. 2/.

In this figure besides furnace heating the cooling is also recorded, during which no changes are observed in the specimens. Visible on the thermogravimetric curve are the weight losses connected with the subsequent vaporization and the decomposition of the organic substances, contained in the paste. The thermal effects, connected with the changes in weight are emphasized on the thermodifferential curve. The weight changes of a specimen, read from the graphs, and the maximum temperatures of the thermal effects are set down in Table 1.

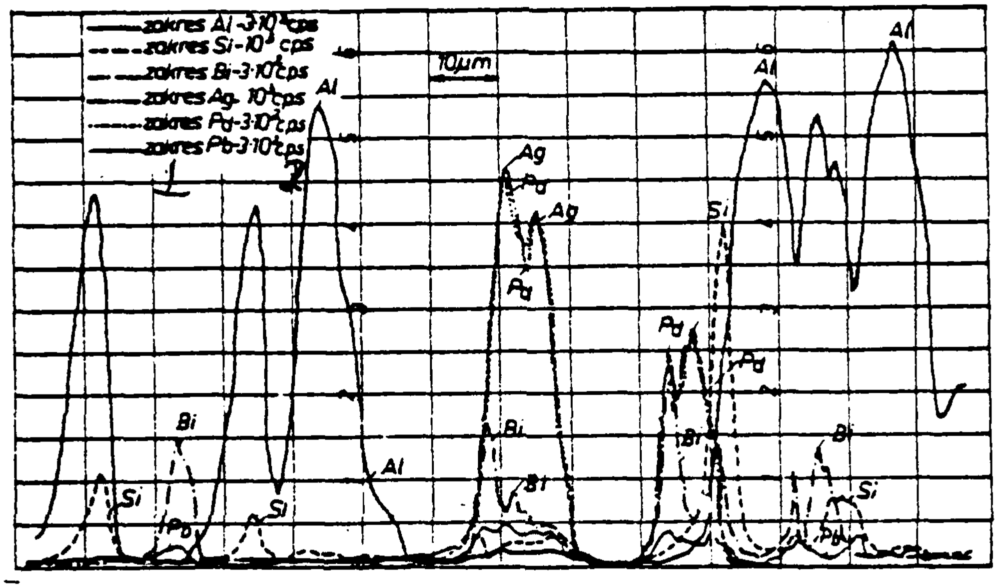


Fig. 1. The linear distribution of the elements on a cross section through a DP 9061 film /13 µm thick, T_p=850° C/. The direction of the analysis is presented in Fig. 32c.

KEY: 1 - range; 2 - cp.

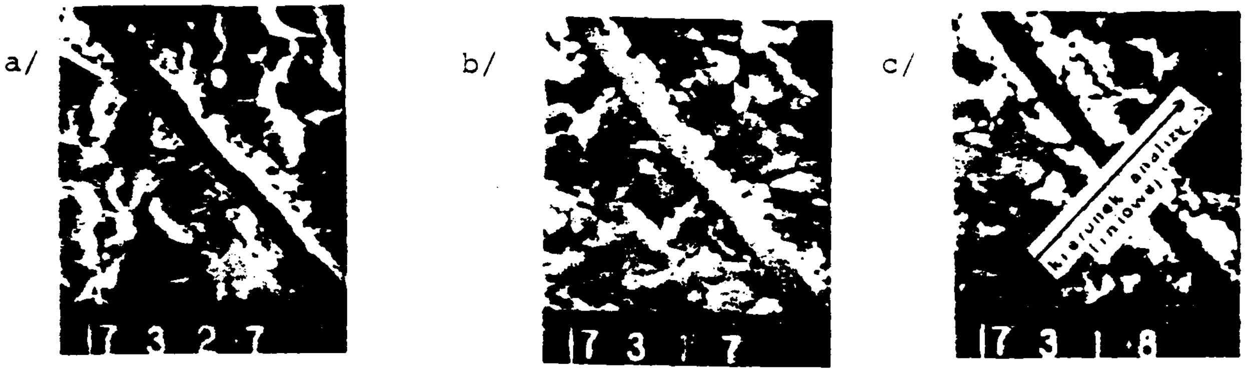
a/

Surface relief
/picture of secondary electrons/

b/

Photo 1. X-ray microanalysis of the surface of a DP 9061 film /13 um thick, T_p=850° C/, magnification 5000x:

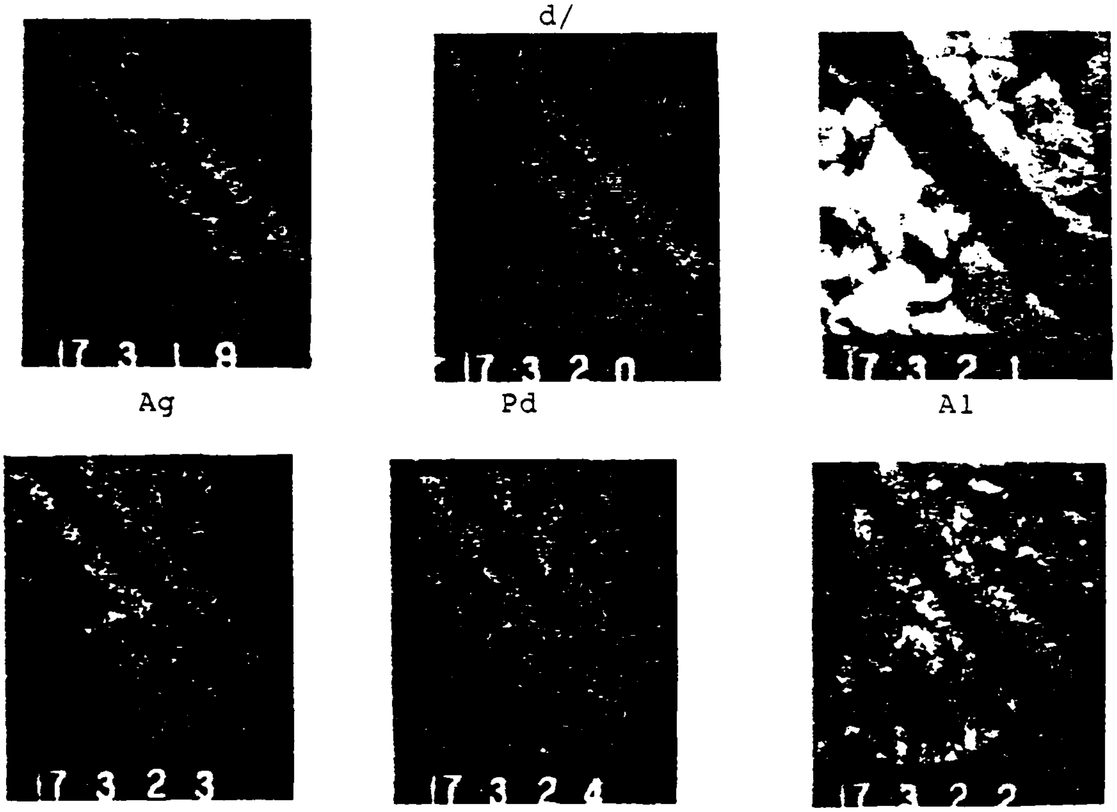
a/ surface relief / picture of secondary electrons/; b/ surface distribution of the elements.



Surface relief

Picture of the chemical composition

KEY: direction of linear analysis



Ag Pd Al

Bi Pb Si

Photo 2. Microanalysis of the cross section through a DP 9061 film /13 um thick, $T_p=850^{\circ}$ C/; magnification 600x.

a/ relief of the surface of the cross section /picture of secondary electrons/; b/ relief of surface of cross section / picture of the secondary electrons/; c/ picture of chemical composition; d/ surface distribution of the elements.

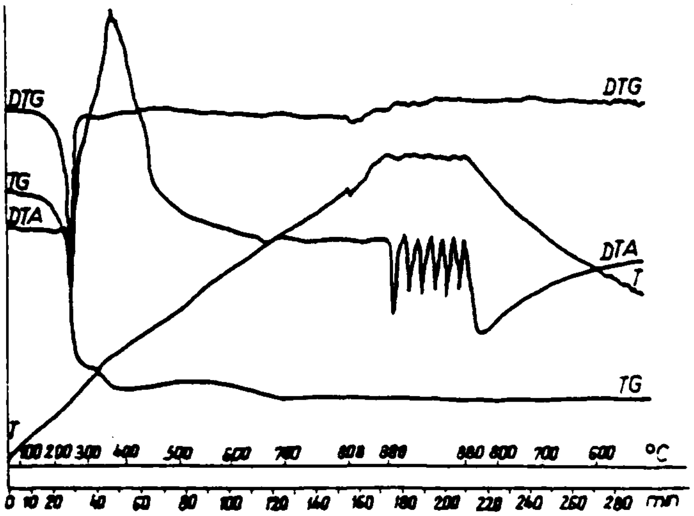


Fig. 2. Derivatogram of 9061 paste at a rate of temperature increase of 5.1°C/min

The information obtained as a result of the analysis of the DTA and the DTG attests, that in the first stage of the heat treating of the DP 9061 paste there occurs the evaporization of the solvent /in an amount of 20.2 weight % up to a temperature of 390° C/. A further increase in the temperature causes the decomposition of the organic substances, remaining in the paste. The decomposition process lasts up to a temperature of 720° C and causes a weight loss in the specimen in an amount of 1.8 weight %.

Table 1

Temperatures of the occurrence of the maxima, the thermal effects and the weight change in the DP 9061 paste

Zakres temperatury [°C] 1	**Temperatury kolejnych maksimów** [°C] 2	**Zmiana masy** [mg] 3
20 - 300	180 /egzo-/ 4 220 /endo-/ 5	-185
300 - 390		-17
390 - 720	410 /egzo-/ 4 660 /endo-/ 5	-18
720 - 840	735 /egzo-/ 4	+3

KEY: 1 - Temperature range; 2 - Temperatures of the successive maxima; 3 - Weight change; 4 - exo-; 5 - endo-.

The sintering process probably begins at a temperature of 660° C in the liquid phase. The presence of the liquid phase of bismuth oxide at the sites of contact of the metal grains causes the phenomenon of capilarity. Under the effect of the forces accompanying this phenomenon there occur motions of the grains, as a result of which the distances between them decrease. In the initial period, consolidation takes place by means of grain slips, in which the liquid phase plays the role of the "lubricant" facilitating the process. Since in the system is a certain number of particles directly in contact with each other, further consolidation can occur as a result of the dissolving of the solid phase in the liquids and its precipitation once again at another site in the system /in this case mainly the regions of grain contact dissolve, as a result of which the convergence of these grain centers occurs/. A small increase in the weight of the specimen /about 0.3%/ at a temperature of about 735° C can suggest, that the confinement of gases occurred in the pores of the baked paste. A drop in the sintering rate accompanies the phenomenon being described. Another cause inhibiting the sintering process can be the homogenization of the paste, causing nonuniform contraction within the limits of the film.

2.3 Investigations of Test Systems (Circuits)

A topological diagram of a system (circuit), with the aid of which the process of the heat treating of films is checked, is presented in Fig. 3. The conducting track in the f/f system (circuit) /containing 189 squares/ was used for resistance measurements; contacts with dimensions of 1.6 x 1.8 mm were used for investigating the adhesion of the films baked at different temperatures.

A test system (circuit) was made on alundum plates with dimensions of 20 x 30 mm, and a thickness of 0.55-0.65 mm. The viscosity of the paste used for the printing of the paste at a temperature of 27° C was 272 kcp /measurement was made of a Brookfield viscosimeter of the RVT type at a T-B spindle rate of 1.0 r/min. The printings were carried out on a screen-printer of the Sprague firm in a way making it possible to obtain films with a thickness of 13 and 26 um.The parameters of the screen printing are: overall pressure - 3 atm; squeegee pressure - 1.4 atm. Moreover the printings of the DP 9061 paste were carried out enriched in DP 8399 glaze. The films intended for the investigation of resistance were protected in the final stage of the process with DP 8185 glaze. The films were baked in a tunnel furnace of the BTU firm. The maximum baking temperatures were: 800°, 850°, and 900° C. The temperatures distributions in the furnace during the bakings are presented in Figs. 4, 5, 6, and 7.

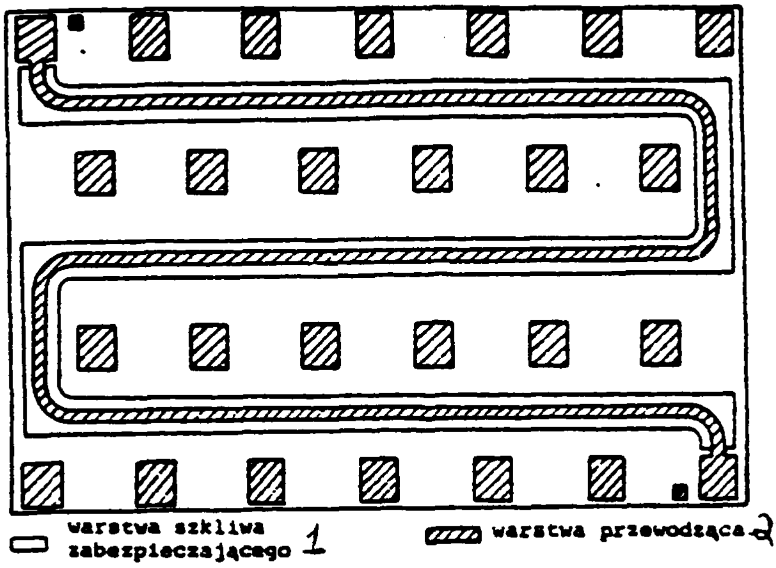


Fig. 3. The topology of the test system (circuit).

KEY: 1 - protective glaze film; 2 - conductive film.

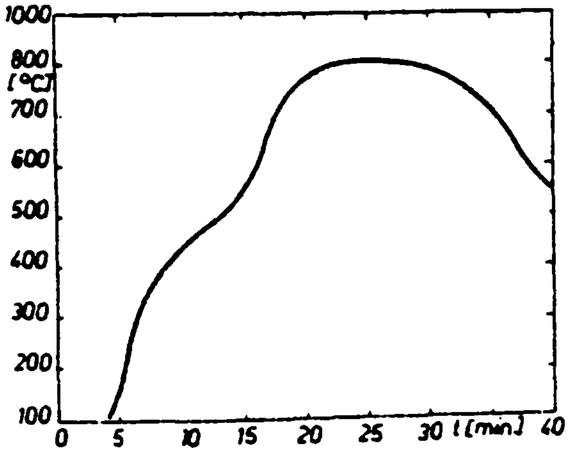


Fig. 4. The temperature distribution in the furnace for DP 9061 paste. A max. temperature of T_p=800° C over a time period of T_p=5 min.

<u>The measurements of the initial resistance</u> were carried out directly after the baking of the films. The purpose of the measurements was to determine the effect of the film baking temperature on the value of

the resistance. The results /the average values of resistance from 10 measurements/ are located in Table 2. A small fall off in the resistance of the films baked at a higher temperature is perceptible.

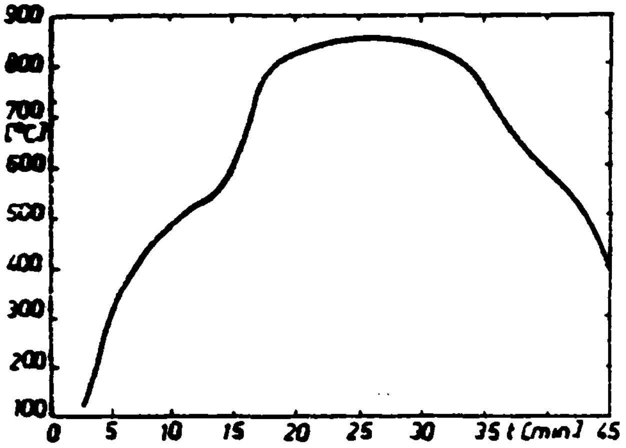
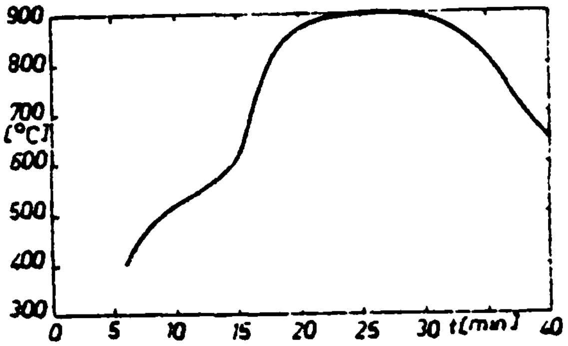


Fig. 5. The temperature distribution in the furnace for the DP 9061 paste. The max. temperature $T_p=850^\circ$ C over a time period of $t_p=6$ min.

Fig. 6. The temperature distribution in the furnace for the DP 9061 paste. The max. temperature $T_p=900^\circ$ C over a time period of $t_p=6$ min.



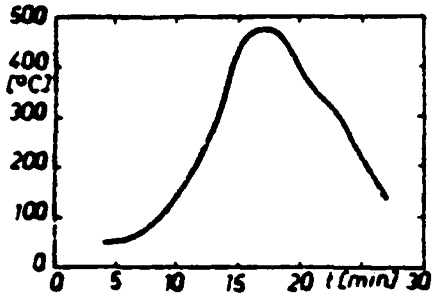


Fig. 7. The temperature distribution in the furnace for the DP 8185 paste. The max. temperature $T_p=470^\circ$ C over a time period of $t_p=2$ min.

Table 2

The dependence of film resistance on baking temperature

Domieszka szkliwa DP 8399 [%] 1	Grubość warstwy [μm] 2	Rezystancja warstwy R/□ [mΩ/□] 3		
		Temperatura wypalania [°C] 4		
		800	850	900
0	13	27,2	25,9	26,0
0	26	23,1	22,2	22,6
5	26	13,3	13,3	12,7
10	26	14,4	13,8	13,5
20	26	17,7	12,4	16,6

Key: 1 - Addition of DP 8399 glaze; 2 - Film thickness; 3 - Film resistance; 4 - Baking temperature.

Table 3

Percentage change in film resistance with time

Domieszka szkliwa DP 8399 [%] 1	Grubość warstwy [μm] 2	Czas trwania badania [h] 3	$\left[\frac{\Delta R}{R}\right]$ [%]		
			4 Temperatura wypalania [°C]		
			800	850	900
0	13	250	+0,03 ·	+0,12	-0,14
		500	+0,15	-0,26	-0,30
		1000	-0,02 ·	+0,10	-0,13
0	26	250	+0,21 ·*	-5,91 ·*	-5,90 *
		500	+0,14 ·	-4,88 ·	-6,12
		1000	+0,23 ·	-5,95 ·	-6,19
5	26	250	-5,62	-0,57 ·*	-0,38
		500	-5,90	-0,59	-0,53
		1000	-5,84	-0,69	-0,41
10	26	250	-5,18 *	-3,90	+0,35
		500	-5,42 ·	-4,48	+0,18 ·
		1000	-5,25 ·	-3,86	+0,15 ·
20	26	250	+0,20	-4,51 *	-4,47 *
		500	-0,08 ·	-4,59	-4,88
		1000	-0,04 ·	-4,59	-4,22

Note: (·) - value spread 60%

(*) - the results take into account in this series only the values of the max. or of min $\frac{\Delta R}{R}$

KEY: 1 - Addition of DP 8399 glaze; 2 - Film thickness; 3 - Duration of the investigation; 4 - Baking temperature.

The investigation of the resistivity of the films was carried out over a period of 1,000 hours. The current loading for particular series was calculated assuming, that the power emitted on the plate amounts to 1.5 W. The percentage change in the resistance of the films with time is presented in Table 3 /given in the table are the average values from 10 measurements/. Films with a thickness of 13 µm baked at a temperature of 850° C and 900° C manifested the greatest stability. A thicker overprint and the addition of DP 8399 glaze caused the deterioration of the resistive stability of the films.

The effect of multiple baking on the resistance was checked on films 13 um thick subjected to a cycle of bakings during the creation of a simple 3-film circuit. The maximum baking temperatures were: 850° C /during a period of 45 min/, 700° C /during a period of 45 min/, and 470° C /during a period of 20 min/. The initial resistance of the films baked in the f/f process was 24.2 mΩ/□ ,whereas the percentage change in resistance after 1,000 hours was - 0.113.

The effect of the baking temperature on the adhesion of the films to the substrate was investigated on films immersed in solder with a percentage composition of 62 Sn /35 Pb/ 3 Ag and at a temp. of 215° C over a period of 2 s., to which was manually added silver-plated Cu wire with a Ø 0.5 mm. Evaluation of the adhesion was carried out by the method of scarifying the wire ends at an angle of 90° with the aid of a spring-actuated dynamometer. The results of the measurements /the average values for 40 specimens in each series/ are set down in Table 4.

Table 4

Measurements of the Adhesion of a Film to the Substrate

Domieszka szkliwa DP 8399 1	Grubość warstwy [µm] 2	3 Przyczepność [kG/cm²]		
		4 Temperatura wypalania [°C]		
		800	850	900
0	13	0,49	0,71	0,69
0	26	0,52	0,69	0,69
5	26	0,52	0,69	0,69
10	26	0,52	0,69	0,69
20	26	0,52	0,69	0,69

KEY: 1 - Addition of DP 8399 glaze; 2 - Film thickness; 3 - Adhesion; 4 - Baking temperature.

The optimum adhesion to the substrate was ascertained for films 13 μm thick baked at a max. temperature of 850° C. Analogously, the adhesion of films 13 um thick subjected to 3-fold baking /850° C, 760° C, 470° C/ was checked, did not undergo change and amounted to 0.73 kg/mm^2.

2.4. The Effect of Baking Temperature on Film Structure

The investigation of the structure of the films was carried out by observing the pattern of the secondary electrons on a JSM-35 scanning electron microscope. Observation of the films was carried out at a magnification of 3,600x, Photo 3.

In the dried DP 9061 film there is evident a nonuniform distribution of PdAg with a grain size of from 0.3 to 20 μm. The contact of the grains with each other is evident in the baked films /Photos 3a and b/. Increasing the baking temperature from 800° to 850° C caused the growth of grains of about 1 μm /Table 5/, as a result of which the value of R/□ decreased /which was found to be higher in the course of the measurements of the R/□ /. In films made from a composition of conductive and dielectric pastes inhibition of the growth of the metal grains is evident during the sintering /and thereby the increase in the R/□ of the film/.

3. Conclusions

The conducted investigations made it possible to study the phenomena taking place during the heat treating of the DP 9061 films and to quantitatively determine the dependence between the sintering temperature and the value of R/□ and the size of the PdAg grains in f/f films. An additional effect of the work was the determination of the role of the glaze contained in the paste /mainly Bi$_2$O$_3$/ as the agent binding the film to the alundum substrate and responsible for its adhesion to the ceramics. On the bases of the works it is possible to ascertain, that:

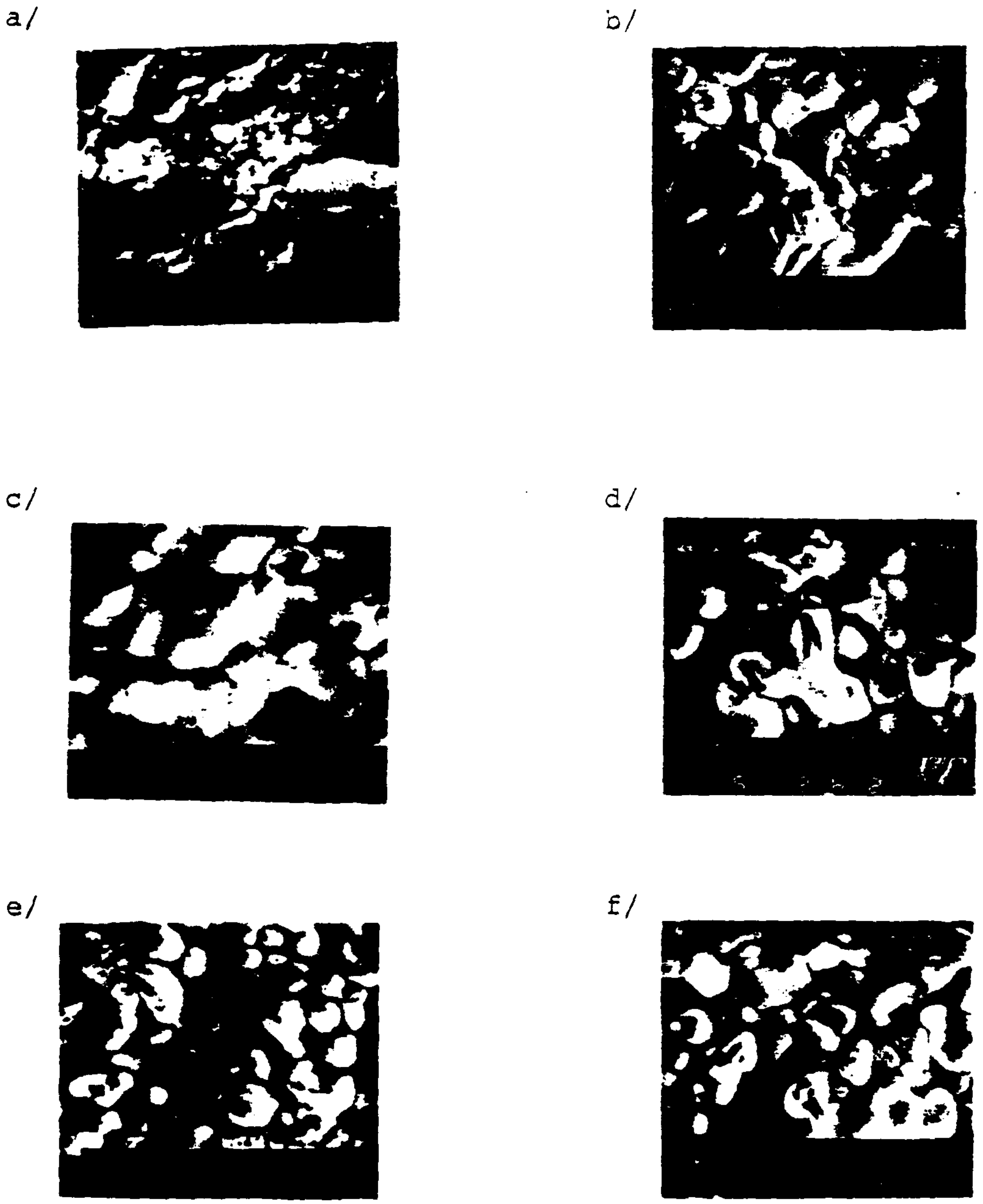
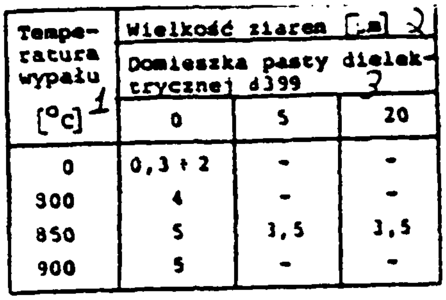


Photo 3

a/ a picture of an unbaked DP 9061 conducting film; b/ a picture of a DP 9061 conducting film baked at a temperature of 800° C; c/ a picture of a DP 9061 conducting film baked at a temperature of 850° C; d/ a picture of a DP 9061 conducting film baked at a temp. of 900° C; e/ a picture of a film baked from a composition of of DP 9061 conducting paste /95%/ and a DP 8399 dielectric paste /5%/ baked at a temperature of 850° C; f/ a picture of a film baked from a composition of DP 9061 conducting paste /80%/ an a DP 8399 dielectric paste /20%/ baked at a temperature of 850° C.

Table 5.

The dependence of the grain size of PdAg occurring in DP 9061 paste on the baking temperature and the addition of glaze to the f/f paste



Temperatura wypału [°C] 1	Wielkość ziaren [μm] 2		
	Domieszka pasty dielektrycznej 8399 3		
	0	5	20
0	0,3 ÷ 2	-	-
300	4	-	-
850	5	3,5	3,5
900	5	-	-

KEY: 1 - Baking temperature; 2 - Grain size; 3 - Addition of 8399 dielectric paste

- The resistance /R/□ / of DP 9061 film approximately 13 μm thick baked at a temperature of 850° C is about 25.9 mΩ/□. A change in the baking temperature of about ±80° C causes a change in R/□ of ±1%. Films baked at T_p=850° C display the optimum stability of resistance in time /+0.1%/.

- The drop in the resistance of a film with an increase in the sintering temperature occurs as a result of PdAg grain growth /the contact surface of the grains increases/.

- Multiple baking /at temperatures of 850° C; 760° C; 470° C/ in comparison with baking at a temperature of 850° C causes a change in R/□ from 25.9 mΩ/□ to 24.2 mΩ/□ /6.6%/ and a change in stability over a period of 1,000 hours from +0.1% to -0.1%. The value of the adhesion did not undergo change.

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THICK-FILM STABILIZED POWER SUPPLY GL-033

Jerzy Turozak, Janusz Kawa

This report describes the hybrid stabilized power supply system with the possibility of regulating the output voltage within 10 to 12 V at a current of 2 A which was developed at the Industrial Institute of Electronics. The system was created using thick-film technology with uncovered high-power semiconductor elements. The supply is intended for general-purpose equipment: radio receivers, televisions, electroacoustic equipment, etc.

1. Introduction

An important advantage of thick-film technology over thin-film and monolithic technology is the possibility of creating medium- and high-power systems. The possibility of using uncovered semiconductor elements - in particular, high-power - means that the cost of hybrid thick-film systems is comparable to that of discrete systems, with a very great decrease in size. A stabilized power supply with a power output of 25 W, as well as a power loss of 15 W, was developed and built using the above capabilities.

2. Technical Parameters of System

Stabilized thick-film power supply type GL-033 was designed using semiconductor elements: BZP 611C5V1, BYP 401-100, BCP 157, and BD 135 in glass and plastic housings, as well as uncovered high-power transistor type 2N3055.

A miniature monolithic capacitor with a capacitance of 2.2 nF was used in the system which was constructed [Tr. Note: translation of last word uncertain; Polish is przeciwzbudzeniowym]. The stabilizer is protected by a housing made of an artificial material (Fig. 1) with an aluminum base, through which the heat is transferred to the external radiator. The system works correctly as long as the temperature of the aluminum part of the housing does not exceed 35°C.

As an example, at an ambient temperature of 70°C, when the stabilizer is loaded with a current of 1.6 A and an output voltage of 10 V, as well as a supply voltage of 17 V, 50 Hz, it is necessary to have a radiator made of an aluminum black plate with a surface area of 250 cm^2 and thickness of 4 mm, onto which the system is screwed with screws M3 (after first coating the surface of the joint with silicon paste).

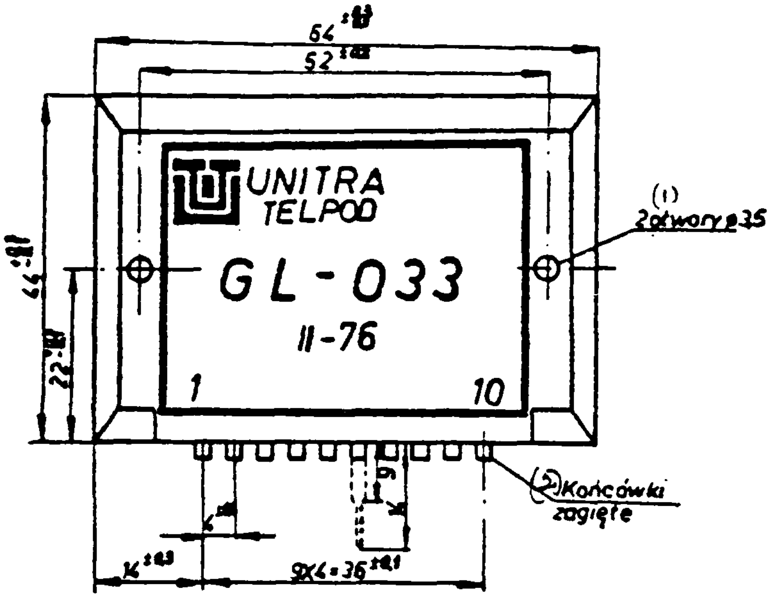

Fig. 1. Design and dimensions of housing of thick-film power supply GL-033.
KEY: (1) Holes. (2) Bent terminals.

The system has an output voltage (set by an external potentiometer) within 10-12 V, as well as a current of 1.9 A. The pulsating voltage is lower than 10 mV_{SK}. The stabilizer has overload protection set at a maximum value of 2.7 A. When the value of the overload resistance decreases (e.g., before short circuiting), the system is cut off, and it can remain in this state for a rather long period of time.

The receiver can also be supplied through stabilizer GL-033 from a battery, whereupon:

- if the battery voltage is higher than the required voltage, the stabilizer lowers it accordingly;
- if it is lower, the stabilizer system does not work, and the battery voltage decreased by a value of around 0.5 V on a series-connected transistor is present on the receiver.

In the case of supply from a battery, the following systems also operate: anti-overload and anti-short-circuit. The rest of the parameters of stabilizer GL-033 are as follows:

- stabilization factor of 8 mV/V
- output impedance of 100 m
- temperature coefficient of 2.5 mV/°C
- minimum voltage drop of 0.5 V.

3. Description of Electronic System

Stabilized supply GL-033 is composed of a rectifier, as well as the appropriate stabilizer (circuit diagram in Fig. 2). The rectifier consists of two independent two-diode units which can be combined into a Graetz bridge system, or else one of them can be used when a transformer with a double secondary winding is available. In this case, the other part of the rectifier can be used for other purposes. - The supply is made as a series-type system with an additional input stage that depends on the transistor which

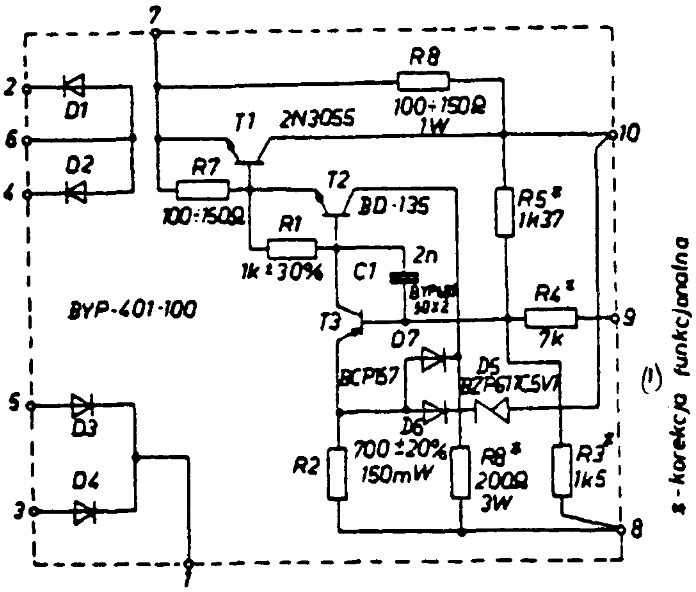

Fig. 2. Circuit diagram of thick-film supply GL-033.
KEY: (1) Functional correction.

was constructed. These connections ensure that the system is protected against short circuiting, for in the event of a short circuit of the output, all of the transistors are closed, and the short-circuit current flows exclusively through resistor R6, bypassing the power transistor.

Considering the shortage of p-n-p power transistor structures in the home market, the stabilizer system in which the output and input voltages are negative relative to a common terminal was accepted. The use of the easily accessible transistor structures 2N3055 in the stabilizer system in question permitted this.

The series transistor (T1) is controlled from the transistor emitter (T2) BD 135. Resistor R8, which limits the base current of T1, is located in collector circuit T2. Resistor R7 is connected between the base and emitter T1, improving the conditions of the operation of T1 during closing (e.g., during output shorting). This is especially important for the hybrid system, in which the unmeasured [?] transistor structure (unsegregated with regard to the maximum collector-emitter voltage) is used as T1. When the output is shorted, the entire input voltage (e.g., 27 V) is applied to closed transistor T1. The transistor base T2 is controlled from collector T3. Resistor R1, which is used to boost current T3, is connected between the base and emitter T2. This increases the amplification of the system, which contributes to reducing the output impedance of the supply. Moreover, R1 plays a similar role with respect to transistor T2 as R7 does with respect to transistor T1. The system for connecting transistors T1 and T2 which was used permitted transistor T1 to become saturated, which decreases the minimum voltage drop on the stabilizer.

A divider composed of Zener diode D5 and resistor R2 is connected in the emitter circuit of transistor T1. Compensation diode D6 is connected in series with the Zener diode in order to compensate for the heat coefficient of emitter-base T3. A divider of resistors R5 and R3, used for setting the output voltage, is located in the base circuit of transistor T1. Additional resistor R4, connected to the divider of R5, R3, is used to slightly alter the output voltage by means of an external potentiometer, which is connected to the output terminals of the stabilizer, and its contact is connected to any lead of R4. Diode D7 is connected between collector T2 and emitter T3 in order to make the operational threshold for limiting the output current independent of the input voltage. The system for limiting the output current operates as follows: an increase in the output current causes an increase in the base current of T2, which causes an increase in the voltage drop on resistor R8. When the voltage on resistor R8 exceeds the voltage on resistor R2, diode D7 begins to conduct, causing transistor T3 to be closed. This causes (with the further loading of the stabilizer) a drop in the output voltage and a decrease in the current flowing through the Zener diode D5, until it is closed. Then the reduction in the output voltage causes a decrease in the output current through a reduction in the voltage on the base T3, which results in the current-versus-voltage characteristic shown in Fig. 3.

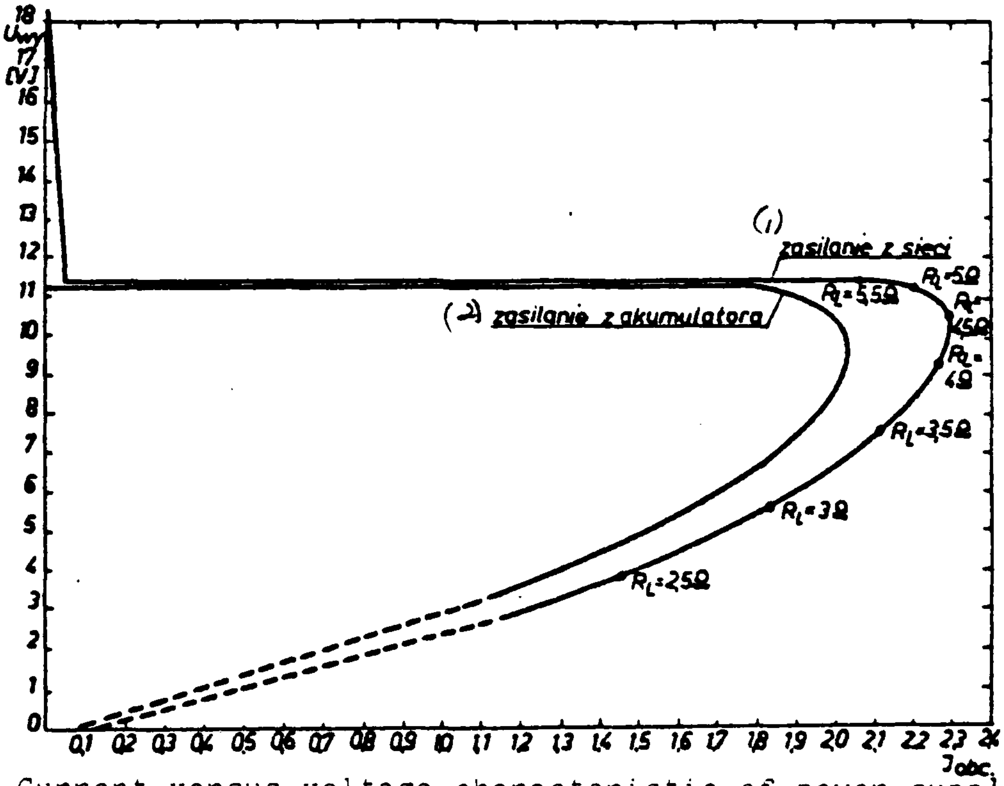

Fig. 3. Current-versus-voltage characteristic of power supply GL-033.
KEY: (1) Supply from network. (2) Supply from battery.

This characteristic is favorable when the power losses on the stabilizer to limiting the current within a small range are only slightly greater than the losses under nominal conditions and characteristic loading, while they decrease with further loading of the stabilizer. As soon as the output voltage drops below around 3 V, the stabilizer is closed, and only a small, limited short-circuit current flows through resistor R6.

A capacitor used to eliminate the high-frequency excitation of the system is connected between the base and collector T3. Before starting the system, it is necessary for the voltage at which T3 begins to conduct (around 2 V) to be present at the output. Resistor R6 is used to create this voltage. The value of resistor R6 made it possible for the system to be started up under the most unfavorable conditions (supply voltage of 11 V), with loading by the receiver, which draws a current of around 20-30 mA with a voltage of 2 V.

4. Description of Applied System

Figure 4 shows the applied system of thick-film voltage stabilizer GL-033.

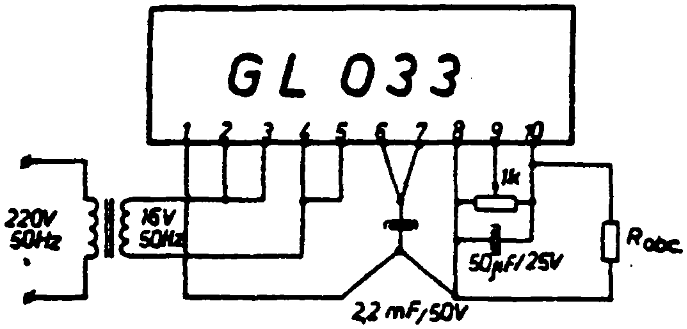

Fig. 4. Diagram of applied system of thick-film power supply GL-033.

Alternating-current voltage of 50 Hz from the network transformer with a maximum value of 17 V is fed to terminals 2-3 and 4-5 of the stabilizer. A capacitor of 2.2-4.7 mF should be connected by special leads to terminals 1 and 8 (plus), as well as 6 and 7 (minus) - four leads altogether. This prevents the pulsating voltage created on the resistors of the leads, through which the current of several dozen amperes for charging the electrolytic capacitor flows, from reaching the stabilizer system. The load should be connected to terminals 8 and 10. An electrolytic capacitor of around 50 mF should be connected parallel to it; this capacitor prevents the high-frequency excitation of the stabilizer system when the output is loaded by a capacitance on the order of 0.1 μF. A linear potentiometer of 1-5 kohms (with the potentiometer contact on terminal 9) can be connected to terminals 8, 9 and 10; it is used to regulate the stabilized output voltage within 10-12 V. When the receiver is supplied from a battery, the rectifier system should be eliminated, directly connecting the "minus" electrode of the battery to terminal 7, and the "plus" - to terminal 8.

5. Results of Measurements and Conclusions

In order to compare the dependences of the pulsating voltage on the stabilizer load on the capacitance of the electrolytic capacitor used in the supply filter, measurements were made on a batch of ten GL-033 systems. For the first set of measurements, a capacitor with capacitance of 2.2 mF was used, and for the second - 4.7 mF. The results are given in Tables 1 and 2.

Table 1. Pulsating voltage with connection of 2.2 mF electrolytic capacitor.

Numer układu (1)	1	2	3	4	5	6	7	8	9	10
nap. tętn. (2) [mV]$_{sk}$	7,5	7,2	6,9	6,9	7,5	8,6	7,5	6,9	6,2	7,5

KEY: (1) System No. (2) Pulsating voltage.

Table 2. Pulsating voltage with connection of 4.7 mF electrolytic capacitor.

Numer (1) układu	1	2	3	4	5	6	7	8	9	10
nap. tętn. (2) [mV]$_{sk}$	4,8	4,8	4,5	4,5	4,7	4,9	4,7	4,4	4,1	5,1

KEY: (1) System No. (2) Pulsating voltage.

As the circuit diagram of the stabilizer (Fig. 2) shows, the initially corrected functionally maximum current is directly affected by the gain of the series-connected transistor T1, which varies in the course of operation. This transistor is installed in the form of a structure without a housing, secured only by an elastic compound.

As the system operates, this structure ages, and different types of contamination can also get into the connection. Even when the most careful technological cleanliness is observed, it is impossible to eliminate the impurities which affect the parameters (primarily, gain) of the transistor. Table 3 shows the variation in the maximum output current during 200 hours of operation of the power supply under aggravated conditions of accelerated aging.

Table 3. Variation in maximum breaking current of stabilizer system GL-033 under the effect of aging.

Numer (1) układu	(3) Prąd maksymalny [A]							
czas (2) [godz] :	0	18	32	56	80	100	150	200
1	2,58	2,57	2,55	2,56	2,55	2,55	2,54	2,55
2	2,65	2,62	2,66	2,66	2,63	2,62	2,63	2,63
3	2,19	2,20	2,29	2,22	2,25	2,25	2,28	2,26
4	2,57	2,57	2,51	2,55	2,52	2,55	2,50	2,53
5	2,66	2,61	2,66	2,60	2,60	2,61	2,62	2,61

KEY: (1) System No. (2) Time (hours). (3) Maximum current.

Stabilizer GL-033 is the electrical correspondent to system BW5111 of the Sanyo company. Admittedly, the latter has a better ripple factor (the Japanese system provides 4 mV_{sk}), but this parameter can be considerably improved by using a high-capacitance electrolytic capacitor (see Tables 1 and 2). Besides, system GL-033 makes it possible for the receiver to be supplied from a network (through a transformer) and a battery, whereas BW5111 can only be supplied from a network.

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