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FEEDBACK CIRCUIT FOR ANODIZING THIN-FILM RESISTORS

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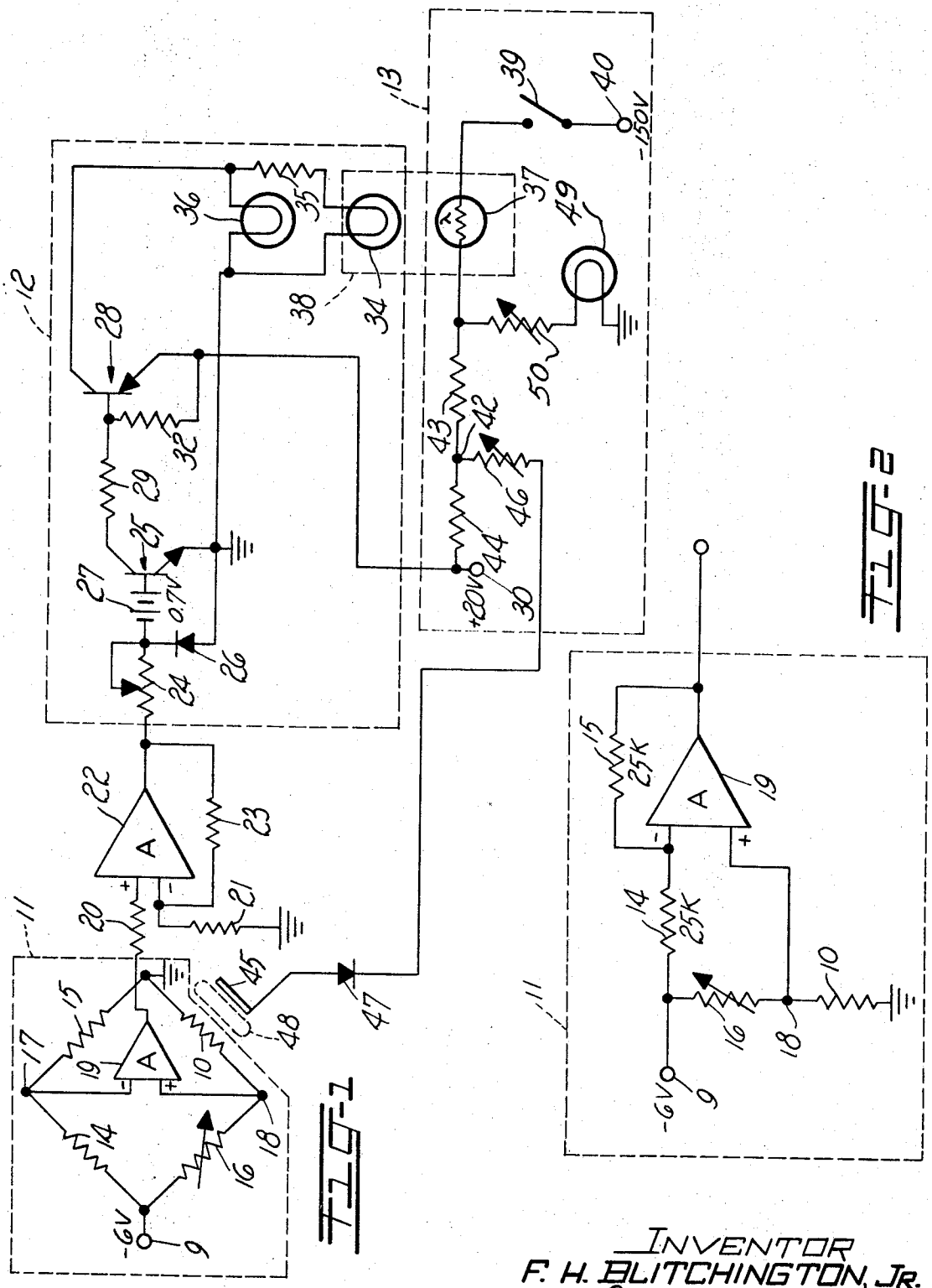


FIG-1

FIG-2

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FEEDBACK CIRCUIT FOR ANODIZING THIN-FILM RESISTORS

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ABSTRACT OF THE DISCLOSURE

A thin-film resistor, which is to be anodized to increase its resistance to a preselected value is connected to one arm of a bridge circuit. As the resistor is being anodized, an imbalance in the bridge drives a monitor circuit which controls a variable resistance in series with a supply of anodizing voltage. As the thin-film resistor being anodized approaches the preselected value, the bridge becomes more nearly balanced and the variable resistor increases in value to interrupt the flow of anodizing current.

CROSS-REFERENCE TO RELATED APPLICATION

This application is related to an application filed in the name of A. R. Gerhard on May 9, 1968, Ser. No. 727,972.

BACKGROUND OF THE INVENTION

(1) Field of the invention

The invention relates to a control circuit for anodizing thin-film resistors. One problem encountered in anodizing resistors is that precise resistor values cannot be attained if the resistance is not monitored during the anodization process. Further, in anodizing resistors on a production basis, it is desirable to apply a high anodizing current at first and then reduce the current as the value of the resistor approaches the desired resistance, in order to decrease the total time required for anodization.

(2) Description of the prior art

In the past, a number of different circuits have been developed in which the resistance of a resistor being anodized is monitored by a bridge circuit to stop the flow of anodizing current when the bridge is balanced. Such anodization control circuit may, additionally, decrease the anodizing current as the resistor approaches a desired value. However, in these prior circuits the resistor is alternately connected to the monitoring and anodizing circuits, so that part of the time the resistance is being measured and the remaining time the resistor is being anodized. Since the resistor is only anodized during part of the time, the total process of anodization takes longer. Further, the resistance of the resistor being anodized may pass through the desired value during the last cycle of anodization and be outside the desired tolerance range. Finally, if the resistance of the resistor being anodized is continuously monitored during anodization, such as by a Wheatstone bridge, the anodizing current flowing in the resistor disturbs the operation of the bridge and results in errors.

SUMMARY OF THE INVENTION

The object of the invention is a new and improved anodizing control circuit. In one embodiment of the circuit, a resistor to be anodized is continuously connected to a monitor circuit that produces a control voltage signal which is in proportion to the deviation of the resistor from a desired value. A source of anodizing current is connected to the resistor via an electrolyte to continuously anodize it and increase its resistance. A control circuit, which is connected to the source of anodizing current, operates in response to the control voltage from the monitor circuit to interrupt the anodizing current when the resistance of the resistor reaches the desired value.

BRIEF DESCRIPTION OF THE DRAWING

The nature of the present invention and its various advantages will appear more fully by referring to the following detailed description in conjunction with the appended drawing, in which:

FIG. 1 is a schematic drawing of a feedback anodizing circuit constructed in accordance with the invention; and

FIG. 2 is a schematic drawing of an alternate embodiment of the resistance sensing circuit constructed in accordance with the invention.

DETAILED DESCRIPTION

Referring to FIG. 1, a thin-film resistor **10** is connected into one arm of a bridge circuit **11**. The resistor **10** may comprise a resistive pattern of tantalum which has been sputtered onto an insulative substrate. The resistance of the resistor **10** is to be increased to a preselected value by anodizing the tantalum film to reduce the cross section of conductive material and thereby increase its resistivity. The output of the bridge circuit **11** is connected to a monitor circuit **12** which controls the rate at which anodizing current is delivered by a current supply circuit **13**.

The bridge circuit **11** includes a first resistive arm **14** and a second resistive arm **15** connected in series between ground potential and a negative 6 volt power supply **9**. The bridge is completed by a third resistive arm **16** connected in series with the thin-film resistor **10**. A first operational amplifier **19** is connected between points **28** and **18** of the bridge and acts as a null detector to indicate the degree of deviation of the bridge from a balanced condition. The amplifier **19** has a very high input impedance to avoid loading the bridge circuit and provides essentially unity gain. The positive output signal of the detector amplifier **19** is connected to a first input resistor **20** of a second non-inverting operational amplifier **22**. The negative input terminal of the amplifier **22** is grounded through a second input resistor **21**. The amplifier **22** has a feedback resistor **23** connected from its output to its input to provide a large voltage gain due to the large ratio of the feedback resistor, which is in the range of 1 megohm, to the input resistor, which may be aproximately 3K ohms.

The second amplifier **22** couples the bridge circuit **11** to the monitor circuit **12** in that its output is connected by an input resistor **24** to the base of a first transistor **25**. A diode **26** is connected between the base and emitter electrodes of the transistor **25** to protect the transistor base-emitter junction from excessive negative voltages. The emitter of the transistor **25** is grounded. A biasing battery **27** is included to hold the base voltage of the transistor **25** approximately 0.7 v. positive with respect to the emitter to overcome the base emitter voltage drop which is characteristic of conventional silicon transistors. The battery **27** will allow the transistor to begin and cease conduction when the bridge is balanced and the amplifier **22** produces a zero output voltage. The collector of the first transistor **25** is connected to a second transistor **28** through a current limiting resistor **29**. A biasing resistor **32** is provided between the base and emitter electrode of the second transistor **28**. The emitter of the second transistor **28** is biased by a positive 20 volt source **30**.

The output of the second transistor **28** is connected to drive a first lamp **34** through a load resistor **35**. A second monitor lamp **36** is also connected across the output of the second transistor **28** to provide an indication to the operator of whether the circuit is anodizing. For the operating voltages herein described, the lamps are preferably of the type rated at 26 volts. The first

lamp **34** is in optical communication with a photo-resistor **37**; both of which are sealed in a light-tight enclosure **38**. As the illumination intensity of the lamp **34** increases the resistance of the photo-resistor **37** decreases. Although a number of different photo-resistors could be used, one similar to the type LDR 25 photocell manufactured by the Delco Corporation is preferred. This type of photo-resistor has a resistance which varies from greater than one megohm when dark to approximately 500 ohms when illuminated by the **26** volt lamp **34** operating at 20 volts. Further, the photo-resistor is rated at maximum operating values of 200 volts, 1 ampere and 25 watts power dissipation.

The photo-resistor **37** is connected in series with a negative 150-volt power supply **40** through an anodizing switch **39**. The photo-resistor **37** is also connected to a summing point **42** through a first voltage dividing resistor **43**. The summing point **42** is in turn connected to the positive 20-volt power supply **30** through a second voltage dividing resistor **44**. The summing point **42** serves to deliver anodizing current to a cathode electrode **45** through a current control potentiometer **46** and a diode **47**. The cathode electrode **45** is in electrical anodizing contact with the thin-film resistor **10** through a body of electrolyte **48** which may be composed of a viscous solution of 0.01% citric acid. An incandescent lamp **49** having a tungsten filament and a load resistor **50** are series connected from between the resistor **43** and the photo-resistor **37** to ground. The lamp and resistor provide a suitable high resistance load for the power supply under normal anodizing conditions and, because of the characteristics of the tungsten, also serve to shunt the small value of anodizing current near the end of the anodization process.

In operation, the variable resistor **16** of the bridge circuit **11** is set equal to the final desired resistance of the thin-film resistor **10** and the anodizing current switch **39** is closed. When the thin-film resistor **10** is anodized to equal the variable resistor **16** the bridge is balanced and the potential at points **17** and **18** will be equal. Initially, the bridge is unbalanced, because the resistance of the thin-film resistor **10** is too low, and there is a potential difference between points **17** and **18** which is proportional to the degree of deviation of the thin-film resistor **10** from the standard resistor **16**. The detector amplifier **19** connected across points **17** and **18** produces an output voltage which is indicative of the degree of imbalance in the bridge. The power amplifier **22** delivers current to drive the transistors **25** and **28** which deliver an output voltage to illuminate the lamps **34** and **36**. The intensity of illumination of the lamps **34** and **36** vary in direct proportion to the degree of imbalance in the bridge circuit **11**.

The variation in illuminating intensity of the lamp **34** will cause the resistance of the photo-resistor **37** to vary in the same proportion. The variation in resistance of the photo-resistor **37** varies the voltage drop across the resistor and therefore, the potential at the summing point **42**. Thus, when the lamp **34** is at maximum intensity, the resistance of the photo-resistor **37** is small and a large negative voltage due to the negative 150 volt source is applied to point **42**. A negative voltage at point **42** produces an anodizing current which flows through the cathode electrode **45** and anodizes the thin-film resistor **10** to increase its value. As the bridge moves toward balance, the lamp **34** becomes darker, the resistance of the photo-resistor **37** increases, the voltage at point **42** becomes less negative, and a smaller amount of anodizing current is delivered to the cathode electrode **45** so that the rate of anodization is decreased.

When the resistor **10** reaches the desired value the bridge is balanced and the lamp **34** is dark because the transistors **25** and **28** have ceased to conduct. At this point, the resistance of the photo-resistor **37** is very large and the potential at the summing point **42** has become slightly positive due to the voltage divider resistors **44** and **43** and the positive 20-volt source **30**. This positive voltage back-biases the diode **47** and insures that no more anodizing current can flow to the cathode electrode **45**.

A characteristic of the bridge and monitor circuits **11** and **12** is that as the bridge approaches balance, the anodizing current becomes very small. This means that the last small increments of change in value of the resistor **10** takes place very slowly. For this reason, it is desirable to stop the anodizing current altogether when it is so small that its effect on the resistor **10** is negligible. For this purpose the incandescent lamp **49** is connected from ground through a variable resistor **50** to a point between the photo-resistor **37** and the summing point **42**, to act as a voltage-dependent resistance device. That is, as the voltage across the lamp becomes very low the current which the lamp draws increases. Since the tungsten filament of the lamp **49** is hot, when the voltage at the summing point **42** is large, the resistance of the filament is high. As the voltage at the summing point **42** becomes comparatively low, the filament begins to cool and its resistance decreases rapidly. The lower resistance tends to shunt the remaining amount of anodizing current to ground. This effect serves to stop the flow of anodizing current as the value becomes negligible.

Another significant feature of the circuit resides in the manner in which anodizing current is applied to the thin-film resistor **10** without appreciably affecting current flow in the bridge circuit. When the bridge is unbalanced as the anodization process begins, point **17** is typically at a potential of minus 3 volts while point **18** is at a potential of approximately minus 2 volts. As the negative cathode **45** applies anodizing current to the resistor **10**, the current flow therethrough creates a voltage drop and point **18** tends to become slightly more negative. That is, the flow of anodizing current tends to create a negative feedback effect and drives the bridge towards a balanced condition. It is this effect which allows a resistor in a bridge circuit to be measured and anodized simultaneously.

The gain of the amplifier **22** and the driving current resistor **24** may be adjusted so the amplifier and the transistors **25** and **28** operate in a condition of saturation until the bridge is very nearly balanced. This condition results in maximum anodizing current flow and enables the total anodization time to be reduced. As balance is closely approached, the components come out of saturation and reduce the anodizing current. Since part of the appearance of bridge balance is due to a voltage drop in the resistor **10** resulting from anodizing current, the bridge will move slightly away from balance as the anodizing current is reduced. The small remaining portion of anodization will take place in the conventional manner described above. The relatively long response time of the photo-resistor **37**, that is, between an illumination change and a corresponding change in resistance, prevents the entire circuit from going into oscillation during the slightly unstable condition as the bridge nears balance.

An alternate measuring circuit **11** which may be substituted for the bridge circuit **11** of FIG. 1 is shown in FIG. 2. A negative 6-volt power supply **9** is connected across the variable standard value of resistance **16** and the thin-film resistor **10** to be anodized. The negative input of the operational amplifier **19** is connected to the negative 6-volt source through a 25K ohm input resistor **14**. A 25K ohm feedback resistor **15** is connected from the output to the negative input of the amplifier **19** to give unity gain. The positive input terminal of the amplifier **19** is connected to point **18** between the standard resistor **16** and the thin-film resistor **10**. The output of the amplifier **19** is to be connected to the input resistor **20** (FIG. 1) of the second amplifier **22**.

A characteristic of the operation amplifier **19** is that it produces an output voltage which, through its feedback resistor **15**, tends to make the voltage on the positive and negative input terminals equal. For example, when the value of the thin-film resistor **10** is less than

the standard resistor **16**, the potential at point **18** is less than one-half of −6 volts. Assuming point **18** is at −2 volts, the output voltage of the amplifier **19** must go to +2 volts in order to make both the positive and negative input terminals both equal to −2 volts. The positive output voltage drives the monitor circuit **12** (FIG. 1) to control the anodization current. Similarly, when the thin-film resistor **10** is equal to the standard resistor **16** the potential at point **18** will be −3 volts. Since the positive input terminal of the amplifier **19** is −3 volts, the output potential must go to zero volts so that the negative input terminal will also be −3 volts. Thus, the amplifier output voltage of the amplifier is zero when anodization is to cease.

It is to be understood that the above described embodiments are simply illustrative of the invention and that many other embodiments can be devised without departing from the scope and spirit of the invention.

What is claimed is:

1. A circuit for controlling the rate at which a thin-film resistor is anodized to increase the resistance of said resistor to a preselected value, comprising:

a Wheatstone bridge having said thin-film resistor connected as a first arm, a resistor equal to said preselected value connected as a second arm, and means for producing an output signal which is proportional to the difference between said first and second arms;

a control lamp connected to the detector of said bridge having an illumination intensity which is proportional to the output signal of the detector;

a source of anodizing voltage;

means, including a cathode electrode, for applying anodizing current from said source to said thin-film resistor to anodize said resistor and increase its resistance; and

a photo-sensitive resistor connected between said voltage source and said means for applying anodizing current, said photo-sensitive resistor being optically connected to said control lamp to increase its resistance and limit the anodizing current in response to a decrease in illumination intensity of said control lamp.

2. A circuit as set forth in claim **1** which also includes:

voltage-dependent resistance means connected from between said photo-sensitive resistor and said means for applying anodizing current, to ground, said voltage-dependent resistance means having a high resistance when the voltage thereacross is large, said resistance decreasing to shunt the flow of anodizing current as the voltage thereacross decreases.

3. A circuit as set forth in claim **1** which also includes:

an incandescent lamp connected from between said photo-sensitive resistor and said means for applying anodizing current, to ground, said lamp including a filament having a high resistance when heated which filament cools and decreases in resistance to shunt the flow of anodizing current as the resistance of the photo-sensitive resistor becomes very large.

4. A circuit for controlling the rate at which a thin-film resistor is anodized to increase the resistance of said resistor to a preselected value, comprising:

means for producing a control signal which is indicative of the difference between the resistance of said thin-film resistor and said preselected value;

means responsive to said control signal producing means for producing radiation having an intensity which is dependent upon the value of said control signal;

a source of anodizing current;

means for applying anodizing current from said source to said thin-film resistor to anodize said resistor and increase its resistance; and

means responsive to the radiation produced by said radiation producing means for varying the anodizing current delivered to said current applying means by said current source.

5. A circuit for controlling the anodization of a thin-film resistor, as set forth in claim **4**, in which:

said radiation responsive means includes radiation sensitive resistance means connected between said current source and said means for applying anodizing current, said radiation sensitive resistance means being coupled to said radiation producing means to increase the value of said radiation sensitive resistance and limit the anodizing current in response to a corresponding change in radiation intensity.

6. A circuit for controlling the anodization of a thin-film resistor, as set forth in claim **5**, in which:

said radiation producing means is a control lamp; and said radiation sensitive resistance means is sensitive to visible light.

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