July 14, 1970 F. W. CARROLL 3,520,783

METHOD OF ADJUSTING A RESISTOR BY ANODIZING

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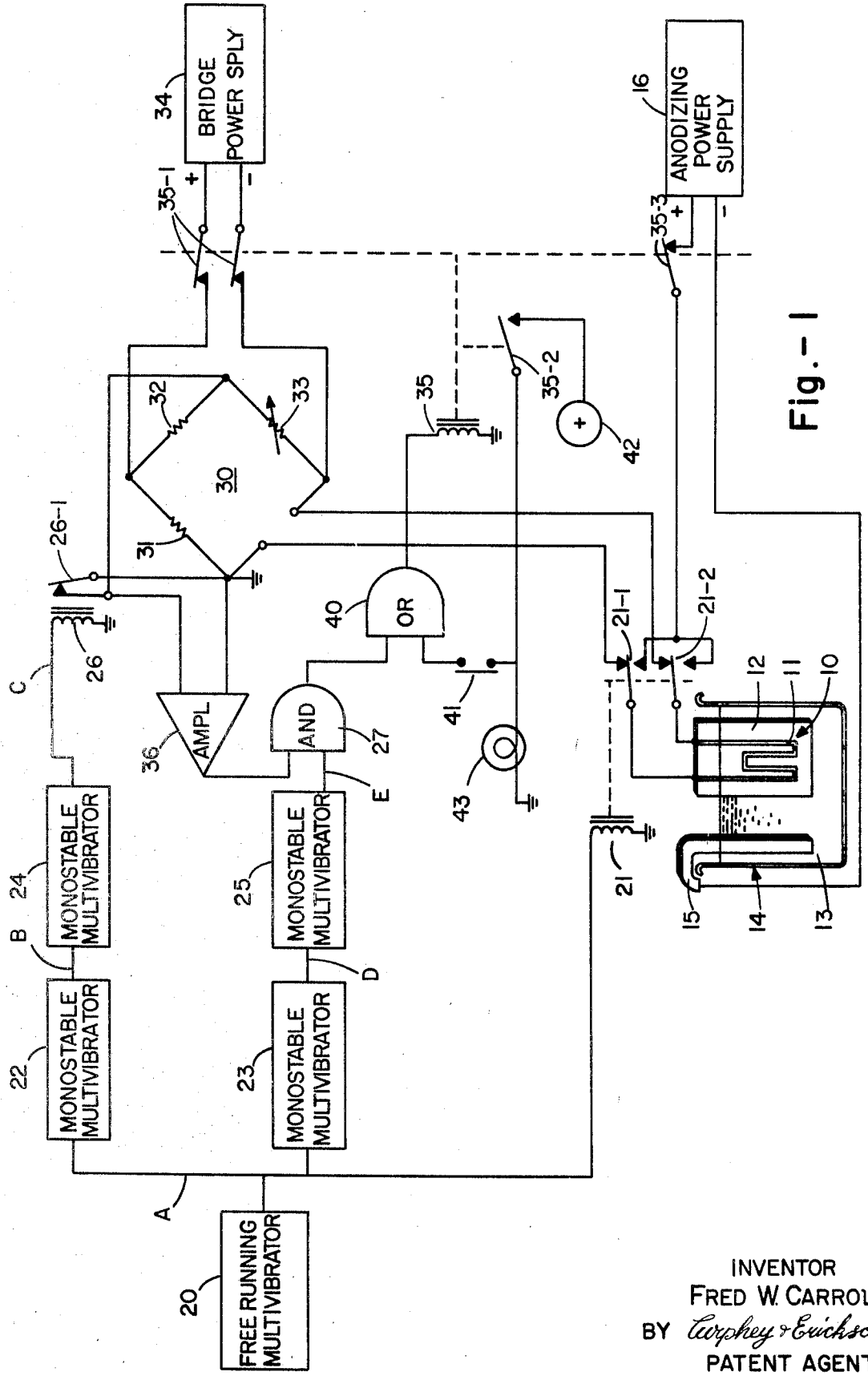


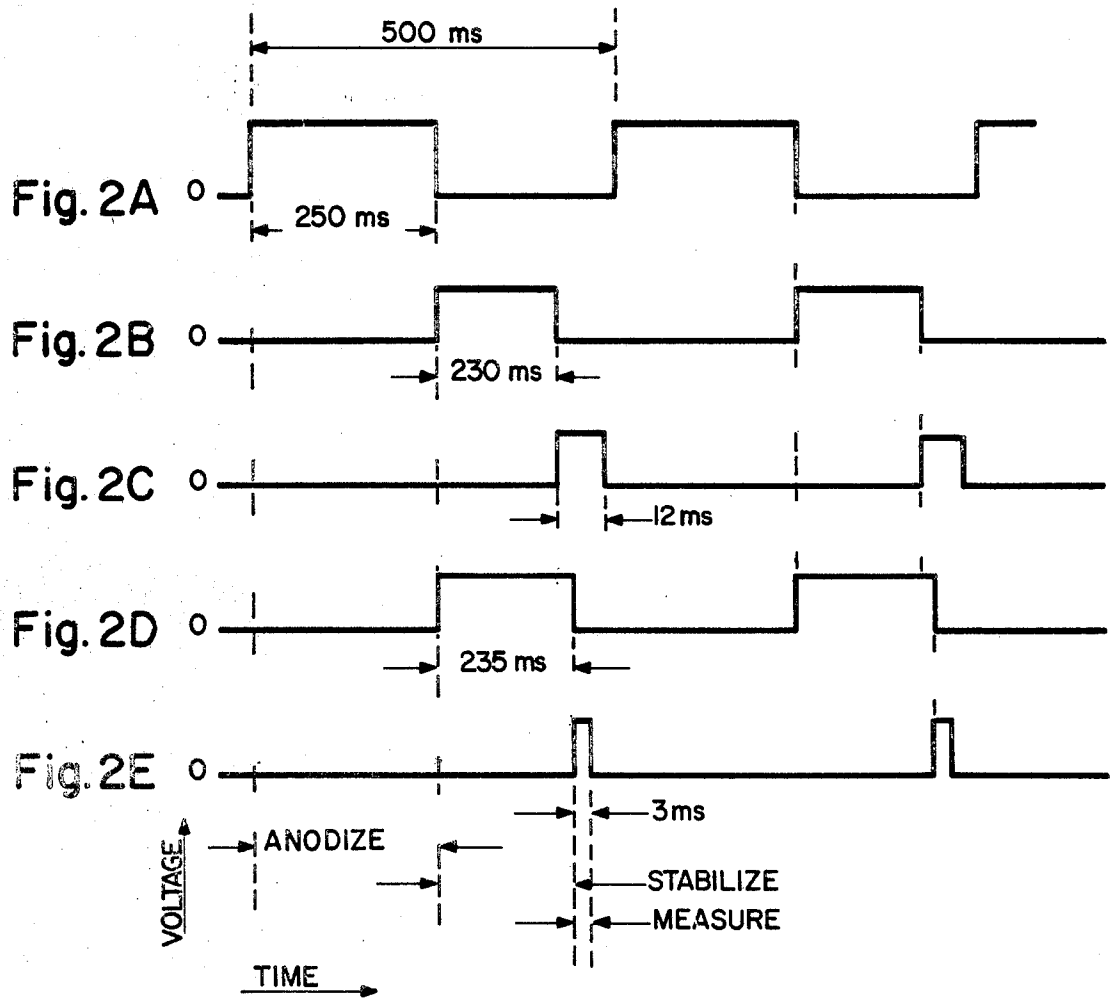
Fig. - 1

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METHOD OF ADJUSTING A RESISTOR BY ANODIZING

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METHOD OF ADJUSTING A RESISTOR BY ANODIZING

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U.S. Cl. 204—23 1 Claim

ABSTRACT OF THE DISCLOSURE

A circuit which is used to control the final adjustment of thin film resistors through alternate anodizing and measuring of the resistance, that provides a stabilizing period before the measuring interval, in order to allow any parasitic capacitance to charge, so as not to affect the accuracy of the measurement. Such a capacitance is formed across the resistor when immersed in the electrolyte with the anodized layer forming the dielectric between the conductive resistor and the electrolyte.

This invention relates to a method and apparatus for controlling the trimming of metal resistors by anodization, and is praticularly applicable for adjusting the value of thin film resistors during manufacture.

Thin film resistors may be produced by selective etching of a thin layer of metallic material which has been deposited upon an insulated substrate. As a practical matter, the accuracy of such a process yields resistors with a tolerance of approximately 10 percent. To improve upon this, and provide resistors having a tolerance of better than 1 percent, the metal film resistors have been subjected to an anodization process.

This involves initially constructing the resistor to have a value lower than the desired value. The resistor is then anodized in an electrolytic cell thus forming an insulating oxide on the surface thereof. This reduces the cross-sectional area of the resistor which, in turn, results in an increase in its resistance. The anodization process is continued until the resistance has increased to a desired value. One method of trimming such resistors is described in the U.S. Pat. No. 3,148,129, issued Sept. 8, 1964 and invented by H. Basseches et al. The process described in this patent involves continuously monitoring the resistance of the resistor while the anodization is taking place. This process is complicated by the fact that the flow of current resulting from the anodization must be taken into account when determining the actual resistance value otherwise inaccurate values will result.

In order to overcome this problem, a further improvement has been made in which the resistor is alternately anodized and then measured immediately thereafter until the desired resistance value is obtained, whereupon the anodization process is automatically terminated. During the measuring step, current flow fom the resistor to the electrolyte and back into the resistor is prevented by the formation of the oxide coating over the surface. This coating may be obtained by a preliminary anodization carried out before the final adjusting process. This process has performed satisfactorily for producing resistors with a tolerance of 1 percent or better up to a value of about 10 kilohms. However, when it was attempted to produce resistors having a value higher than this, it was found very difficult to maintain the tolerance within the desired 1 percent. Thus, even though the source of anodization current had been disconnected from the electrolytic cell prior to measuring the value of the resistor, the measurement and could not be accurately made.

It has been discovered that this resulted from the

formation of a parasitic capacitance wherein the conductive portion of the resistor and the electrolyte form the two conductors with the anodized layer acting as the dielectric. This provides an effective capacity shunting the terminal ends of the resistor. The parasitic capacitance does not appreciably affect low value resistors since the capacitive reactance is not low enough to alter the measured value of the resistor. However, when trimming high resistances, applicant has found that the charging time of this parasitic capacitance must be taken into account or erroneous measurements will be obtained. Thus, the shunting reactance of the capacitor results in an impedance measurement which is lower than the actual resistance value thereby prolonging the anodizing process. This ultimately results in the thin film resistance having a value higher than that desired.

Applicant has found that by providing a waiting or stabilizing period between the application of the measuring voltage and the monitoring of that voltage (so that the parasitic capacitance may charge), that this process may be extended to high value resistors without obtaining erroneous measurements. Such a process is then only limited by the leakage current which exists through the anodized layer and the electrolyte resulting from the potential impressed across the resistor during the measuring step.

In accordance with the present invention there is provided a method of adjusting the resistance of a metal resistor by anodizing in an electrolyte which comprises the steps of applying an anodizing current between the resistor and a spaced electrode immersed in the electrolyte so as to anodize the resistor and progressively increase its resistance. Thence, removing the anodizing current and applying a measuring voltage across the resistor. Monitoring the measuring voltage a predetermined period of time after its application to determine the resistance of the resistor. The predetermined period of time being sufficient to allow any parasitic capacity between the resistor and the electrolyte to charge to the measuring voltage. Thence, repeating the previous steps if the measured resistance is below a desired value, or terminating the anodizing when the measured resistance reaches the desired value.

An example embodiment of the invention will now be described with reference to the accompanying drawings in which:

FIG. 1 illustrates a schematic diagram partly in block form of an anodization control circuit is accordance with the present invention; and

FIGS. 2A, 2B, 2C, 2D, and 2E illustrate voltage waveforms at various reference points in the circuit illustrated in FIG. 1.

Referring to FIG. 1, there is shown a metal resistor in the form of a thin film tantalum resistor generally **10**, having a conductive strip **11** deposited on an insulated substrate **12**. The resistor **10** is shown immersed in an electrolyte **13** of an electrolytic cell, generally **14**, and functions as an anode electrode during the anodizing process. Also immersed in the electrolyte **13** is a cathode electrode **15** which is spaced from the thin film resistor **10**. An anodizing power supply **16** provides a constant source of anodizing current during the anodizing process as hereinafter explained. The anodization control circuit comprises a control means in the form of a free-running multivibrator **20**, an output of which is used to drive a relay coil **21**. In addition to driving the relay coil **21**, the multivibrator **20** drives two monstable multivibrators **22** and **23** which in turn control two additional monostable multivibrators **24** and **25** respectively. The output of the monostable multivibrator **24** drives a relay coil **26**, while the output of the monostable multivibrator **25** is connected to one input of an AND gate **27**. The

anodization control circuit also comprises a measuring means which includes a resistance bridge, generally **30**, in which the thin film resistor **10** forms one arm. The other three arms are formed by two fixed resistors **31** and **32** and a variable resistor **33**. The measuring current for the bridge **30** is supplied by a D-C bridge power supply **34** which is connected across opposing ends of the bridge **30** through normally closed control contacts **35–1** of a relay coil **35**. The other two ends of the bridge **30** are connected to a D-C amplifier **36**, the output of which is connected to a second input of the AND gate **27**. Connected across the input of the D-C amplifier **36** are normally closed shorting contacts **26–1** which are controlled by the relay coil **26**.

The output of the AND gate **27** is connected to one input of an OR gate **40**, the output of which is used to drive the relay coil **35**. In addition to controlling the normally closed contacts **35–1**, the relay coil **35** also controls normally open lock-up contacts **35–2** and normally closed contacts **35–3**. The normally open contacts **35–2** are connected in series with a reset switch **41** between a second input to the OR gate **40** and a source of voltage **42**. To indicate when the anodization process is completed, an indicating lamp **43** is powered from the source of voltage **42** through the normally opened contacts **35–2**.

The measuring arm of the bridge **30** is coupled across the thin film resistor **10** through connecting means which in the present embodiment comprise normally closed contacts of break before make transfer contacts **21–1** and **21-2** that are actuated by the relay coil **21**. The negative terminal of the anodizing power supply **16** is connected directly to the cathode electrode **15**. The positive terminal of the supply **16** is connected through the normally closed contacts **35–3** and normally open contacts of transfer contacts **21–1** and **21–2** to the thin film resistor **10**.

Referring generally to FIGS. 1 and 2, the voltage output of the free-running multivibrator **20**, reference point A of FIG. 1, is illustrated graphically in FIG. 2A. As shown, the output is a square wave having a total period of 500 milliseconds. The voltage at reference point A is used to drive the monostable multivibrator **22** which produces at its output, reference point B of FIG. 1, a pulse of 230 milliseconds as shown in FIG. 2B. This in turn is used to drive the monostable multivibrator **24** which produces at its output, reference point C of FIG. 1, a driving pulse of 12 milliseconds as shown in FIG. 2C.

The voltage output at reference point A is also used to drive the monostable multivibrator **23** which produces at its output, reference point D of FIG. 1, a pulse of 235 milliseconds as shown in FIG. 2D. This in turn drives the monostable multivibrator **25** which produces at its output, reference point E of FIG. 1, a gating pulse of 3 milliseconds as shown in FIG. 2E.

During operation, the voltage output at reference point A, from the multivibrator **20**, actuates the relay coil **21**. This in turn transfers the thin film resistor **10** from the bridge **30** to the positive terminal of the anodizing power supply **16** by actuation of the transfer contacts **21–1** and **21–2**. With the anodizing supply **16** connected across the electrolytic cell **14**, anodization of the tantalum thin film resistor **10** takes place for a time interval of 250 milliseconds. This converts part of the conductive portion of the strip **11**, consisting of tantalum nitride, to tantalum pentoxide which is an insulator. This slightly reduces the cross-sectional area of the resistor **10** thereby increasing its overall resistance.

At the end of the 250 millisecond interval, the relay coil **21** is de-energized which in turn disconnects the anodizing power supply **16** and reconnects the thin film resistor **10** to the measuring arm of the bridge **30**. The bridge power supply **34** which, at this point, is connected across the bridge **30** through the normally closed contacts **35–1**, applies a voltage across the thin film resistor **10**. Because, at this point, the contacts **26-1** are closed, any unbalance in the bridge **30** will not be immediately coupled to the amplifier **36**. Hence, current flow, resulting from the charging of any parasitic capacitance, will not affect a true reading of the resistor **10**. After a stabilizing period of 230 milliseconds, the pulse signal voltage at reference point C energizes the relay coil **26** thereby removing the shorting contacts **26–1** and allowing any unbalance voltage from the bridge **30** to be applied to the D-C amplifier **36** for a period of 12 milliseconds. This voltage is amplified and the output coupled to one input of the AND gate **27**. Five milliseconds after the removal of the shorting contacts **26–1**, the pulse at reference point E is applied to the second input of the AND gate **27** for a period of 3 milliseconds. If the resistance value of the thin film resistor **10** is below the desired value, the output of the D–C amplifier **36** will be opposed to that at reference point E and no output signal will be coupled from the AND gate **27**. As a result, when the control signal at reference point A reactuates the relay coil **21**, the bridge **30** will again be disconnected from the resistor **10** and anodizing power supply **16** will be reconnected across the cell **14**.

With the power supply **16** reconnected, the anodization process continues with further conversion of the outer layer of the conductive portion of the thin film resistor **10** to an insulator. This is turn further decreases the cross-sectional area of the resistor **10** thereby resulting in an additional increase in its overall resistance.

This alternate anodizing and measuring process continues until the resistance of the thin film resistor **10** has risen to a value where the bridge **30** passes through its null or balance point. As a result, the polarity of the output voltage connected to the D–C amplifier **36** is reversed during the time interval that the contacts **26–1** are open. Hence an output signal from the amplifier **36** is coupled to the AND gate **27** that is in phase with that of reference point E thereby opening the gate **27**. This in turn opens the OR gate **40** which provides a drive signal for the relay coil **35**. Actuation of the relay **35** closes the lockup contacts **35–2** which in conjunction with the reset switch **41** applies a holding voltage from the source **42** to the OR gate. Actuation of the relay **35** prevents further anodization and measurement of the thin film resistor **10** by disconnecting the power supplies **16** and **34** through opening of the contacts **35–3** and **35–1** respectively. The adjusting process is now terminated as indicated by the control lamp **43** which receives its voltage from the source **42** through the contacts **35–2**.

A new thin film resistor may now replace the resistor **10** and the adjusting process restarted by depressing the reset switch **41**. The process then continues in a like manner as described above until the value of the new resistor reaches the desired level whereupon the process will again be terminated.

The gain of the D–C amplifier **36** and the sensitivity of the AND gate **27** are designed so that a resistance value for the thin film resistor **10** of about 0.05 percent above the desired value provides sufficient voltage to open the AND gate **27** during the 3 millisecond time interval that the pulse appears at reference point E. In addition, the anodizing time as determined by the free-running multivibrator **20** and the current from the anodizing power supply **16** are adjusted so that the total change in resistance value during each anodizing cycle is held to 0.2 percent.

It has been found that a parasitic capacitance in the order of 0.1 microfarads can be formed across the thin film resistor **10** with the conductive portion of the resistor and the ionized electrolyte **13** acting as the two conductors and the anodized layer on the thin film resistor **10** acting as the dielectric. Thus, when adjusting a resistor for a final value of 200 kilohms to 1 percent accuracy, applicant found that a stabilizing period of 230 milliseconds, as determined by the output from the mono-

stable multivibrator **22**, was required to allow adequate time for the parasitic capacitance, resulting from the application of voltage from the D-C bridge power supply **34**, to charge before the contacts **26–1** are opened and the resultant voltage from the bridge **30** is connected to the D-C amplifier **36**. Appreciable variations in the value of the parasitic capacitance may be found depending upon the geometry and configuration of the resistor **10** and the thickness of the anodized layer thereon. Hence, it may be necessary to use longer stabilizing periods depending upon the final value of the resistor and the accuracy required.

This system permits the trimming of high value thin film resistors in the megohm range within 1 percent tolerances or better. The upper limiting factor for the system will be limited by the leakage current through the oxide into the electrolyte **13** which results in an impedance shunting the thin film resistor **10**. The lower limit for trimming resistors by this method is primarily dictated by the contact resistance of the anodization control circuit. Additionally, to prevent appreciable anodizing during the measuring step due to the bridge power supply **34**, the voltage therefrom is chosen to be well below that supplied by the anodizing power supply **16** during the anodizing interval.

While the anodizing process has been described for trimming thin film resistors made of tantalum nitride, it can be readily extended to resistors made of any other suitable material which will anodize and for which it is desired to adjust the resistance value thereof.

What is claimed is:

1. A method of adjusting the resistance of a metal resistor by anodizing in an electrolyte comprising the steps of:

(a) applying an anodizing current between the resistor and a spaced electrode immersed in the electrolyte for a first period of time to anodize the resistor and thereby progressively increase the resistance thereof, the anodization resulting in a capacitance being formed between the resistor and the electrolyte;

(b) removing the anodizing current and applying a direct current measuring voltage across the resistor for a second period of time;

(c) allowing the resultant direct current to flow until the charge across the capacitance reaches equilibrium;

(d) after said equilibrium is reached, feeding the measuring voltage to a monitoring circuit to determine the resistance of the resistor;

(e) repeating steps (a), (b), (c) and (d) if the measured resistance is below a desired value; and

(f) terminating the anodizing when the measured resistance reaches the desired value.

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