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(54) Abstract Title: **Microprocessor-controlled bias adjustment in a thermionic valve audio amplifier**

(57) The grid bias for the thermionic valves in a push-pull audio amplifier output stage is adjusted by a microprocessor in dependence on the cathode currents as sensed by small resistors. The quiescent valve currents can thus be stabilised without large power-wasting self-biasing cathode resistors and their bypass capacitors. The quiescent cathode currents may be reduced when the input audio level is low. The grid, anode, or heater voltages may be adjusted to match the outputs of the valves. Total harmonic distortion (THD), valve temperature, and amplifier hum also may be measured.

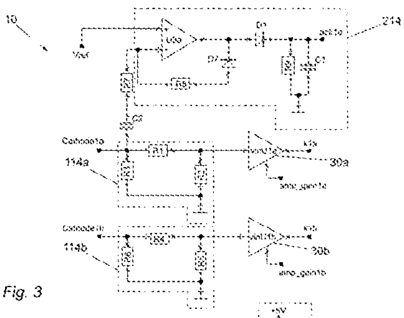

*Fig. 3*

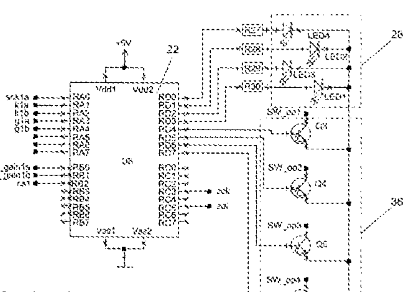

*Fig. 3 Continued*

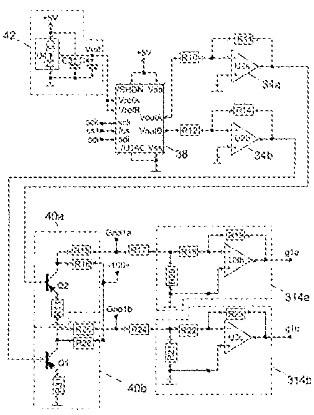

*Fig. 3 Continued*

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# Improved Amplifier Control Circuit

The present invention relates to an improved amplifier control circuit, in particular, an improved thermionic valve amplifier control circuit.

The present invention also relates to an amplifier incorporating a thermionic valve amplifier control circuit according to the invention.

Amplifiers known in the art generally come in one of two forms, a thermionic valve (also known as a thermionic tube) amplifier or a semiconductor amplifier. A hybrid form also exists which has a combination of thermionic valves and transistors in the ‘audio chain’.

Thermionic valves are very tolerant if their specified operating conditions are temporarily exceeded, unlike most semiconductors which tend to suffer from ‘catastrophic’ failure (defined as a failure mode which causes instantaneous and irreversible damage) if their operating conditions are exceeded.

Thermionic valves generally comprise a cathode, a heater, a grid and an anode all housed in an evacuated envelope, usually a glass envelope, and rely on extremely fine mechanical position of the electrodes for their operating characteristics. These are obviously subjected to manufacturing tolerances which affect various parameters. Unlike semiconductors, thermionic valve operating characteristics are highly dependent on the particular circuit in which they are used. Manufactures provide a large amount of tables, graphs and data on each thermionic valve to allow designers to use and exploit this trait.

In addition, unlike semiconductors, thermionic valves do, however, wear out which means that they have a finite operating life. Operating them under unfavourable conditions or beyond the manufacturers working specification, usually results in a reduced lifespan, although this may not be audibly apparent in their operation.

In audio applications, the majority of seriously damaging problems lie in the power output stages of the thermionic valve amplifier.

The majority of thermionic valve amplifiers use at least two thermionic output valves in a circuit configuration known as a “Push-Pull” circuit wherein an audio signal is spilt into two halves by preceding circuits. Each of the two “split” signals is used to drive one thermionic output valve. The signals then undergo power amplification by the thermionic output valves and are re-combined by a special audio grade transformer which also drives the loudspeaker.

A further configuration exists where a single or multiple parallel connected thermionic valves handle the entire signal without ‘phase splitting’ – this is known as ‘Single Ended’ operation.

A very important feature of any thermionic valve circuit is known as ‘biasing’ wherein a negative voltage is applied to the control grid of the thermionic valve in order to restrict or prevent current flowing between the anode and cathode of the thermionic valve. This ‘bias’ signal is used to control the amount of current which flows under ‘no-audio-signal’ conditions (quiescent conditions).

It is common practice to operate the power output stages of thermionic valve amplifiers in ‘Class AB’, where when no signal is present, a relatively small amount of D.C. current is allowed to flow in each valve to reduce distortion known as ‘crossover’ distortion of the amplified signal to a low level. However, thermionic valve amplifiers can also be operated in ‘Class A’ or ‘Class B’ modes.

The amount of quiescent current, that is current that flows in the thermionic valve when a drive signal is not applied, allowed to flow is very important to maintain optimum operating conditions. Too much current will cause harmonic distortion, increase heat dissipation in the anode, reduce audio output power and reduce the operational life of the thermionic valve. Too little current on the other hand will cause severe harmonic distortion and under extreme conditions could cause a condition known as ‘cathode poisoning’, which also reduces the effective operation life of the thermionic valve.

Conventional methods of biasing fall mainly into two categories, automatic (cathode) bias and fixed bias.

In cathode bias, a high power resistor is connected to the cathode circuit to signal ground and the grid is connected via a high value of resistance (usually 500k Ohms or greater) to earth or signal ground. The principle of operation is that when current starts to flow through the thermionic valve (and the cathode resistor), a volt drop proportional to the current will occur across the resistor. This will effectively make the cathode more positive than the signal ground (control grid potential) thus making the control grid more negative than the cathode. As a result, the grid will restrict the flow of current until equilibrium is obtained. The value of this current will be proportional to the value of cathode resistance. Any tendency for the current to increase or decrease due to aging or external conditions will be countered by the resultant change in control grid voltage.

A disadvantage of cathode biasing is that it is necessary to bypass the cathode resistor with a capacitor in order to preserve the audio amplifying properties of the thermionic valve. This capacitor is however in the audio signal path and therefore has a restricting effect on certain frequencies.

In addition, a significant amount of audio signal power is lost in the resistor, thereby reducing the audio output power for any given input power.

Furthermore, in high power amplifiers, the value of the cathode resistor must be made relatively large, which results in them needing to dissipate several Watts of heat, adding to the general heat dissipation within the amplifier chassis. As a result, high power amplifiers tend to use fixed bias due to the disadvantages of cathode biasing.

In fixed bias, an external negative supply is added to the grid which is controlled by a manually adjusted trimmer resistor. It is common practice to supply more than one of the thermionic valves from the same adjustment.

There are, however, also disadvantages associated with fixed biasing. For example, setting the bias conditions requires technical knowledge and skill and thus should be ideally performed by an audio technician.

In addition, frequent adjustments are necessary throughout the life of the thermionic valves.

The present invention provides a thermionic valve amplifier control circuit which overcomes or mitigates the disadvantages associated with known cathode and fixed biasing techniques.

According to a first aspect of the invention there is provided a thermionic valve amplifier control circuit for a thermionic valve amplifier comprising

at least one sensor devices adapted to measure an amplifier characteristic of the valve amplifier and produce a sensor signal in relation to the measured amplifier characteristic; and

a digital processing means connected to the or each sensor device,

wherein the digital processing means is adapted to receive the sensor signal produced by the at least one sensor device and to produce a control signal for adjusting a property of the thermionic valve amplifier in response to the received sensor signal.

A thermionic valve amplifier control circuit according to the invention provides the benefits associated with the cathode and fixed biasing techniques known in the art without any of the associated disadvantages.

The digital processing means allows a desired property of the thermionic valve amplifier, such as the applied bias, to be readily controlled and adjusted as required in response to a measured amplifier characteristic. This removes the need to bypass the cathode resistor with a capacitor in order to preserve the audio amplifying properties of the thermionic power valve as required in cathode biasing techniques.

The resultant control yields identical DC currents in each thermionic valve eliminating imbalance due to component tolerances and achieving a level of control not possible with cathode or fixed biasing methods. This eliminates the need to set up the DC conditions in the amplifier at the end of the manufacturing stage, or when new thermionic valves are fitted. It also removes the need for any external manual adjustment of the bias, which greatly reduces the risk of damage caused through maladjustment by inexperience.

In addition, since the adjustment of the properties of the thermionic valve amplifier, such as the bias conditions are performed by the digital processing means, the requirement of technical knowledge and skill in order to set the bias conditions of the thermionic valve so that they operate at optimum conditions is diminished.

Preferably the digital processing means comprises a microprocessor.

Preferably the thermionic valve amplifier control circuit further comprises an adjusting means adapted to receive the control signal and adjust a property of the thermionic valve amplifier in response to the received control signal.

Advantageously the thermionic valve amplifier control circuit further comprises a memory device adapted to store a value of the amplifier characteristic measured by the at least one sensor device.

Preferably the memory device comprises a reference value of the amplifier characteristic measured by the at least one sensor device.

The optimum values of current for different operating modes (Class A, Class B, or Class AB with fixed and also with cathode bias) are published by thermionic valve manufacturers. These values differ from type to type and even between variants of the same type. For example, it is possible to purchase the common Output Pentode type EL34 thermionic valve in several variants, each requiring different biasing voltages. The different variants are usually designated by a suffix, for example EL34B.

The reference value is preferably proportional to the manufacturer's published optimum value of current for the thermionic valve.

Preferably the control signal for adjusting the property of the thermionic valve amplifier is related to a difference between the measured value of the amplifier characteristic and the reference value of the amplifier characteristic.

Preferably the amplifier characteristic measured by at least one sensor device is a cathode current of a thermionic valve in the thermionic valve amplifier.

Unlike cathode biasing techniques, especially in high power amplifiers, where the value of the cathode resistor needs to be made relatively large, the present invention does not require a high value resistor nor for the value of the cathode resistor to be increased. The measurement of the cathode current may be simply carried out across a low value cathode circuit resistor.

The use of a low value cathode resistor, with a resistance of typically 1 ohm, means that several watts of heat dissipation can be eliminated as negligible power is dissipated in the resistor. In addition, extra audio output power from the resultant power saving can be provided without any additional overhead of input power from the mains supply.

The measurement of the cathode current can be effected by the at least one sensor device measuring a potential difference signal across a cathode circuit of a thermionic valve.

Where the amplifier control circuit comprises more than one sensor device, alternatively or in addition to the measurement of a potential difference signal across a cathode circuit by a sensor device, a sensor device could be adapted to measure a potential difference signal across an anode circuit and a sensor device could be adapted to measure a potential difference signal across a grid circuit of a thermionic valve. This allows the anode and screen grid currents, which the cathode current is a summation thereof, to be easily calculated.

The measurement of the potential difference across the anode and grid circuits may be achieved by the insertion of opto coupled sensors or hall effect sensors in both the anode and grid circuits in order to measure each of the anode circuit and screen grid circuit currents individually.

The measurement of the anode and the screen grid circuit currents separately provides a more accurate indication of the operating conditions than measuring the cathode circuit current. This is especially advantageous in multi-grid thermionic valves such as Tetrodes, Beam Tetrodes and Pentodes.

Preferably the control signal is a bias signal adapted to be applied to the thermionic valve amplifier and the bias signal is related to a difference between the measured cathode current and a reference cathode current value.

The thermionic valve amplifier control circuit may further comprise an operational amplifier adapted to amplify the cathode current signal.

Conveniently the thermionic valve amplifier control circuit additionally comprises at least one analogue to digital convertor connected to the operational amplifier adapted to convert a signal received from the operational amplifier from an analogue signal into a digital signal.

Preferably the amplifier characteristic measured by the at least one sensor device is a dynamic amplitude of a drive signal to a grid of a thermionic valve of the thermionic valve amplifier and the control signal is adapted to effect a change in the effective gain of the thermionic valve in response to the amplitude of the drive signal.

The adjustment of the gain of the thermionic valve in response to the amplitude of the drive signal would have a similar effect to almost perfect matching of the output values of the thermionic valves even if the thermionic valves were completely unmatched in their gain characteristics.

In order to ensure that both halves of the split signal are amplified by the same amount, it is known for manufacturers to use pairs (also ‘quartets’ and ‘octets’ depending on the power output required) of thermionic valves having the same characteristics. Identifying a ‘matched’ pair, quartet or octet of thermionic valves is a laborious and costly process as each manufactured thermionic valve has to be tested and its properties recorded so that a suitable pair, quartet or octet can be found when needed. Furthermore, there is no guarantee that a thermionic valve would be able to be matched with another thermionic valve at a later stage.

Even in so called matched pairs, quartets or octets of thermionic valves no two thermionic valves will be exactly the same, thus likely that each of the thermionic valves will amplify the signal by a slightly different amount. If in the preceding stages these thermionic valves amplify the two halves of the ‘split’ signal by unequal amounts due to component tolerances and thermionic valve aging, the resultant drive signals will also be amplified unequally by the thermionic valves (even if they were perfectly matched). This unequal amplitude would constitute harmonic distortion of the waveform when re-combined at the output transformer.

This problem will be overcome by the present invention as each individual thermionic valve can be adjusted as required such that the resultant drive signals are amplified equally by the thermionic valves, thus reducing the requirement for providing matched pairs, quartets or octets of thermionic valves having very similar or identical characteristics.

The control signal may effect a change in the effective gain of the thermionic valve in one of a number of ways.  For example the control signal could alter one or more of the following thermionic valve properties in order to effect the change in the gain – grid bias, anode voltage, or heater supply to individual thermionic valves.

Alternatively, the adjusting means may comprise a shunt regulator in or a variable amplifier that is positioned in series with an output signal path of the grid in order to effect a change in the gain of the thermionic valve.

Preferably the amplifier characteristic measured by the at least one sensor device is an input power of the amplifier and the property of the thermionic valve amplifier adjusted the control signal is a quiescent current supply to the thermionic valve when no audio power is detected.

It is generally not possible to reduce the power consumption of a thermionic valve amplifier which uses standard biasing methods, as the quiescent currents in each thermionic valve are set either by a component value or a manual adjustment. The present invention however makes it possible for the power consumption to be reduced as required through the alteration of the quiescent current supply. This is because the alteration of the quiescent current by the control signal will have the same effect as altering the power consumption of the thermionic valve amplifier.

The amplifier control circuit of the invention allows the detection of periods where no audio power has been delivered and adjustment of the bias to the thermionic valves to reduce the quiescent current to a low but safe level, thus effectively creates a low power standby condition without invoking cathode poisoning.

Preferably the amplifier characteristic measured by the at least one sensor device is a conductance in a thermionic valve and the property of the thermionic valve amplifier adjusted by the control signal is a voltage supply to an anode of the thermionic valve in response to a drop of conductance in the thermionic valve or if the current exceeds a pre-set maximum value.

The measurement of the conductance of the thermionic valve allows the integrity of the evacuated envelope of the thermionic valve to be monitored. If the evacuated envelope is broken, the resultant loss of vacuum would cause immediate loss of conduction in that thermionic valve. The anode structure of a thermionic power valve may be at a potential of around 500 volts, a failure in the integrity of the evacuated envelope will allow the ingress of gases which could potentially damage other components of the thermionic valve amplifier. The adjusting means would remove the high voltage supply from the thermionic valve amplifier or just the individual thermionic valve thus making the protruding electrodes electrically safe.

Preferably the amplifier characteristic measured by the at least one sensor device is a bulb temperature of a thermionic valve.

It is a know fact that the life of any thermionic valve is considerably shortened by the electrode structure and glass bulb becoming too hot. Even if the cooling arrangements are adequate for normal operation, abnormal heating can be caused by several conditions including, mechanical cooling by radiation and convection due to blocked ventilation slots, thermionic valves overdriven by excessive input signals or short circuit load, peripheral component failure such as a leaky grid coupling capacitor causing excessive DC current in the thermionic valve.

Due to the fact that the bulb temperature is measured, the measured bulb temperature can be fed to the digital processing means which would monitor the temperature. The digital processing means can thus issue a warning and/or automatically reduce the drive conditions to the thermionic valve(s) affected by over temperature conditions and hence conserve the life of the thermionic valve(s).

The sensor device may be any suitable sensor, for example it could be in the form of a temperature sensor adapted to be coupled to the glass bulb, the base or a pin of the thermionic valve, or may be in the form of radiation detector adapted to detected infra red radiation from the bulb.

Preferably the amplifier characteristic measured by the at least one sensor device is a hum in an output voltage of the thermionic valve amplifier and the control signal is adapted to alter the phase of an output signal of the thermionic valve amplifier.

It is a known fact that line (50 or 60 Hz) currents present within the amplifier chassis can introduce noise and distortion into the amplification chain. The most audible effect of this is to an audible 50/60Hz hum derived from the mains line current or a 100/120Hz hum sourced from the full wave mains rectification circuits. It is standard practice to introduce a very small anti-phase version of the line current into the audio chain in an attempt to neutralise the 50/60Hz hum. This technique is successful up to a point, but it is a little understood fact that, because each thermionic valve in the chain is likely to be contributing only a portion of the total hum voltage, and that because of the very complex phase relationships between the hum components, changing one thermionic valve in the audio chain can increase the total hum voltage present at the output.

The present invention allows the total hum present in the output stage to be detected and measured by the sensor device and feed to the digital processing means which produces a control signal which will inject the signal to the preceding stage in order to neutralise the output low frequency noise.

Preferably the amplifier control circuit further comprises a control element adapted to receive the control signal and to alter the phase of the output signal of the valve amplifier in response to the received control signal.

The control element may be adapted to inject an anti-phase signal into the output signal path of the thermionic valve amplifier or alternatively inject a phase shift signal into the output signal path.

Conveniently the at least one sensor device comprises a narrow band pass software filter.

Preferably the thermionic valve amplifier control circuit further comprises a transmitting means for transferring information from the digital processing means to an external device.

The present invention allows the continuous monitoring of certain properties of the thermionic valve amplifier. This continuous monitoring process enables the digital processing means to detect and in a lot of cases diagnose fault conditions at their outset before they become serious, for example the existence of leaky coupling capacitors, faulty resistors etc.

With the transferring means, the information gather by the digital processing means can be transferred to an external device to aid diagnosis of the amplifier and to alert a user of possible failure of the amplifier. Thus allowing the information to be used, if needed, for remote diagnosis of fault conditions.

The transmitting means may be a USB port or equivalent device.

It may instead be in the from of an LED or a transmitter adapted to transmit a signal selected from a group comprising an infrared signal or a radio frequency signal, such as a Bluetooth or a WiFi (wireless networking) signal, to the external device.

The valve amplifier control circuit may further comprise one or more LEDs to indicate to a user the status of the thermionic valve amplifier or the status of a component of a thermionic valve.

According to a second aspect of the invention there is provided a thermionic valve amplifier comprising an amplifier control circuit according to the first aspect of the invention.

Preferably the thermionic valve amplifier comprises a controllable valve heater power supply unit.

According to a third aspect of the invention there is provided a method of controlling a thermionic valve amplifier comprising the steps of

measuring an amplifier characteristic of the valve amplifier using at least one sensor device; and

adjusting a property of the thermionic valve amplifier in response to the measured amplifier characteristic via a digital processing means connected to the at least one sensor device.

According to a fourth aspect of the invention there is provided a method for matching two or more thermionic valves of a thermionic valve amplifier comprising the steps of

measuring the total harmonic distortion produced by the valve amplifier;

measuring a dynamic amplitude of a drive signal to the grid of each thermionic valve; and

individually adjusting the gain of the driver stages of at least one thermionic valve to minimise the total harmonic distortion produced by the valve amplifier.

According to a fifth aspect of the invention there is provided a method for performing an in-circuit test of a thermionic valve amplifier, comprising the steps of:

a) calculating the mutual conductance of each thermionic valve of the thermionic valve amplifier;
b) comparing the calculated value with a reference mutual conductance value for the respective thermionic valve;
c) calculating a decline in the life of the thermionic valve.

A common requirement for thermionic valve amplifiers used for professional and stage purposes is that there should be a high percentage of confidence that one or more thermionic valves will not fail during the performance. Thermionic valves are often thought of in the same manner as light bulbs, in that they are most likely to fail catastrophically at switch on. This means that the moment just after the switch on point constitute the most stressful and potentially damaging periods in the life of the equipment.

In an attempt to guard against this possibility, it is common practice to do one of two things on a regular basis:

a) regularly remove the thermionic valves and have them commercially tested;
b) replace the thermionic valves with new stock on a regular basis.

These two methods however have certain drawbacks.

It is a known fact that the removal of a thermionic valve from its socket results in a number of potentially damaging mechanical stresses on the metal to glass seals around the pins. Each insertion of an all glass thermionic valve will cause micro-cracking of the glass around the pin. This will invariably cause a small leakage of air into the thermionic valve, causing ‘gassing’ and eventually leading to its demise.

Removal for testing will also break the intimate contact between the holder and the thermionic valve contact pin resulting in a poorer contact on re-insertion.

Furthermore, many thermionic valve testers apply unreasonable electrical stresses to the thermionic valve internal electrodes and it is not uncommon for a known good valve to be damaged during the test.

Thermionic valve testers can also give erroneous results depending on the way they perform the test, possibly allowing faulty thermionic valves to show ‘good’ and the good thermionic valves to be rejected as ‘bad’.

The method of blanket replacement with new stock on a regular basis can also lead to problems. If the failure distribution curve for thermionic valves is analysed, it can be seen to follow the classic ‘bathtub’ failure curve. This inevitably means that an amplifier which is regularly re-valved will inevitably be considerably more likely to fail during the first hundred hours of service than one which has been left untouched.

The performance of an in-circuit test mitigates the problems mentioned above. As the test is carried out in-circuit, it is not necessary to remove the thermionic valves and thus the detrimental effects to the thermionic valve and amplifier cause by thermionic valve removal are avoided. In addition, replacement of the thermionic valves will only be required when needed, rather than on a regular basis, as a user would have an indication of the decay in the life of the thermionic valve.

Preferably the method further comprises the step of storing the calculated conductance value in a memory device.

Preferably the reference mutual conductance value used in step (b) is a previously calculated mutual conductance value stored in the memory device.

Preferably the method further comprises the step of predicting the remaining life span of the thermionic valve.

Preferably the method further comprises the step of increasing a power supply to a heater of the thermionic valve in response to the predicted life span of the thermionic valve.

The increase in the power supply to the heater of the thermionic valve will result in an increase in the cathode emission. This in effect will give extra life to the thermionic valve and will give a user more time to replace the thermionic valve.

According to a sixth aspect of the invention there is provided a method of retrofitting a thermionic valve amplifier with a thermionic valve amplifier control circuit comprising the steps of connecting a thermionic valve amplifier control circuit according to the first aspect of the invention to a thermionic valve of the thermionic valve amplifier.

The invention will now be described by way of non-limiting example, with reference to the accompanying drawings in which:

Figure 1 is a block diagram of an embodiment of a thermionic valve amplifier control circuit according to an aspect of the invention;

Figure 2 is a circuit diagram of an embodiment of a thermionic valve amplifier according to an aspect of the invention;

Figure 3 is an internal circuit diagram of the components of an embodiment of a thermionic valve amplifier control circuit according to the invention;

Figure 4 is a flow chart of an example of a biasing method using a thermionic valve amplifier control circuit according to the invention;

Figures 5a and 5b are a flow chart of an embodiment of a method of operation of the thermionic valve amplifier control circuit according to the invention.

Referring to Figures 1 and 2, a block diagram and circuit diagram of the set up of a thermionic valve amplifier control circuit **(10)** with a thermionic valve amplifier **(12)** is shown.

For ease of clarity, a thermionic valve amplifier **(12)** comprising a pair of thermionic output valves **(16a, 16b)** is shown. It should be readily apparent to a person skilled in the art that the invention can be used with thermionic valve amplifiers comprising more than two thermionic valves.

The thermionic valve amplifier **(12)** further comprises at least one transformer **(18)** and at least one loud speaker **(20)**. The components and arrangement of the components of the valve amplifier **(12)** are known in the art and will therefore not been described in any further detail.

The thermionic valve amplifier control circuit **(10)** comprises one or more sensor devices **(14)**, which in number correspond at least to the number of thermionic valves of the thermionic valve amplifier **(12)**, each connected to a respective thermionic output valve **(16a, 16b)** and adapted to measure a characteristic of the thermionic valve amplifier.

The thermionic valve amplifier control circuit **(10)** further comprises a digital processing means in the form of a microprocessor **(22)** connected to each of the sensor devices **(14)**, a memory device **(24)** connected to the microprocessor **(22)**, one or more operational amplifiers, at least one analogue to digital convertor connected to the operational amplifier(s), at least one digital to analogue convertor, transmitting means **(26)** for transferring information from the microprocessor **(22)** to an external device, and one or more LEDs **(28)** for indicating to a user the status of the thermionic valve amplifier **(12)** or the status of a component of a thermionic valve **(16)**.

The microprocessor **(22)** comprises at least one electronic circuit adapted to produce a control signal for adjusting a property of the thermionic valve amplifier in response to the measured characteristic obtained by the sensor device(s) **(14)**.

The microprocessor **(22)** comprises at least one electronic circuit adapted to produce a control signal for adjusting a property of the thermionic valve amplifier in response to the measured characteristic obtained by the sensor device(s)

The thermionic valve amplifier control circuit **(10)** further comprises an adjusting means (not shown) adapted to receive the control signal and adjust a property of the thermionic valve amplifier in response to the received control signal.

Referring to Figure 3, a circuit diagram of an embodiment of the thermionic valve amplifier control circuit **(10)** is shown.

The control circuit **(10)** includes a pair of first sensors **(114a, 114b)** with one of the first sensors **(114a, 114b)** connected to the cathode of one of the thermionic valves. The first sensors **(114a, 114b)** are adapted to measure a potential difference signal **(Cathode1a, Cathode1b)** across the cathode circuit of the respective thermionic valve **(16a, 16b)** to which they are connected and produce a corresponding cathode current signal.

An operational amplifier **(30a, 30b)** is connected to each of the first sensors **(114a, 114b)** to amplify the measured cathode current signal before the amplified signal **(k1a, k1b)** is received by the microprocessor **(22)**.

A pair of second sensors **(214)** adapted to measure the input power of the valve amplifier are also connected to the cathode of a respective thermionic valve. Only one of the second sensors **(214)** is shown in Figure 3 for clarity.

The second sensors **(214)** are each connected to the microprocessor **(22)** and the input power signal **(ack1)** produced by each of the second sensors **(214)** is received by the microprocessor **(22)**.

The control circuit **(10)** further includes a pair of third sensors **(314a, 314b)**, each connected to a grid of one of the thermionic valves. The third sensors **(314a, 314b)** are each adapted to measure a grid voltage and a dynamic amplitude of a drive signal to the grid of the thermionic valve. Each third sensors **(314a, 314b)** produces a gain signal **(g1a, g1b)** in relation to the measured grid voltage and dynamic amplitude.

The third sensors **(314a, 314b)** are each connected to the microprocessor **(22)** and the gain signal **(g1a, g1b)** produced by each of the third sensors **(314a, 314b)** is received by the microprocessor **(22)**.

The microprocessor **(22)** comprises at least one analogue to digital convertor (not shown) for converting the received amplified signals **(k1a, k1b)**, the input power signals **(ack1)** and the gain signals **(g1a, g1b)** from an analogue signal to a digital signal. It is to be understood that it is not necessary for the analogue to digital convertor(s) to be integral with the microprocessor **(22)**, the analogue to digital convertor(s) could instead be separate from the microprocessor **(22)**.

The microprocessor uses the data it has received from the sensor devices **(114, 214, 314)** to calculate various properties of the thermionic valves and the valve amplifier, as discussed in more detail below.

A plurality of LEDs **(28)** are coupled to the microprocessor and are adapted to indicate to a user a status of the thermionic valve amplifier or a status of a component of a thermionic valve based on the properties calculated by the microprocessor **(22)**.

A plurality of control switches **(36)** are also connected to the microprocessor **(22)** and are adapted to control the drive relay of the valve amplifier such that the microprocessor can switch on/off the valve amplifier as required.

The memory device (not shown) is contained within the microprocessor and comprises a reference value of the amplifier characteristic to be measured by each of the sensor devices **(114, 214, 314)** of the amplifier control circuit **(10)**. The reference value is proportional to the optimum value of current for the different operating modes published by the thermionic valve manufacturer for each thermionic valve.

The reference data is used by the microprocessor **(22)** to generate the control signal adapted to adjust a property of the valve amplifier **(12)** in response to the measured amplifier characteristic by a value related to a difference between the measured value of the amplifier characteristic and the reference value of the amplifier characteristic.

The microprocessor **(22)** generates of one or more control signals, which may for example be in the form of an error signal, which are applied to a signal path of a component of the valve amplifier **(12)**.

The control signals generated by the microprocessor **(22)** are converted into serial data **(sdi)** and are forwarded to a digital to analogue convertor **(38)** adapted to convert the serial data **(sdi)** from a digital to analogue form.

The microprocessor **(22)** further comprises a quiescent condition timer comprising a counter and information from the timer **(sck)** is also forwarded to the digital to analogue convertor **(38)**.

The control circuit **(10)** further comprises a voltage regulator circuit **(42)** which provides a reference voltage **(Vref)** for the amplifier control circuit **(10)**.

The reference voltage **(Vref)** is provided to both the digital to analogue convertor **(38)** and the second sensor devices **(214)**.

A modified voltage signal **(VoutA, VoutB)** proportional to the reference voltage **(Vref)** and the serial data **(sdi)** is forwarded by the analogue to digital convertor **(38)** to a respective operational amplifier **(34a, 34b)** which in turn inverts the polarity of the modified voltage signal **(VoutA, VoutB)** so as to create a bias signal **(Grid1a, Grid1b)** to be applied to the control grid of a respective thermionic valve **(16a, 16b)**.

An adjusting means in the form of a shunt regulator circuit **(40a, 40b)** is provided in the output signal path of the grid and is adapted to effect a change in the effective gain of the thermionic valve **(16a, 16b)** in response to the amplitude of the drive signal i.e. the bias signal applied to the thermionic valve **(16a, 16b)**.

Each bias signal **(Grid1a, Grid1b)** in addition to being fed to the grid of a respective thermionic valve **(16a, 16b)** is fed to a respective third sensor device **(314a, 314b)**.

The amplifier control circuit **(10)** further comprises one or more fourth sensor devices (not shown) capable of attachment to a thermionic valve, each adapted to measure a bulb temperature of the thermionic valve.

The amplifier control circuit **(10)** also further comprises one or more fifth sensor devices (not shown) capable of measuring a conductance in each of the thermionic valves.

The control and adjustment of the bias conditions of the thermionic valve amplifier **(12)** by the thermionic valve amplifier control circuit **(10)** will now be described with reference to Figure 4.

The first sensor devices are first used to measure the cathode current of each thermionic valve in the amplifier **(502)**.

The measured low level signal from each thermionic valve cathode is then amplified using the operational amplifiers **(504)** before being forwarded to one of the several analogue to digital converters contained within the microprocessor.

The amplified signals are subsequently converted to an analogue value into an equivalent digital value by the operational amplifiers **(506)**.

The microprocessor is used to carefully control the quality, linearity and internal noise produced by the convertor, and a software algorithm may be used to determine when no audio signal is present.

The digital value is then compared with a reference value held in the memory device **(508)**.

An error signal proportional to the difference between the measured and reference values is then generated by microprocessor **(510)** and used to adjust the bias voltage to each thermionic valve individually to maintain a zero error signal **(512)**.

The thermionic valve control circuit **(10)** in addition to monitoring and controlling the bias of the thermionic valve amplifier **(12)** can be set up to constantly monitor other properties of the amplifier and adjust the characteristics of the thermionic valves **(16)** or other components of the thermionic valve amplifier **(12)** to ensure that the thermionic valves **(16)** and the amplifier **(12)** are working at the optimum conditions.

A flow chart **(600)** of the operation of an embodiment of a thermionic valve amplifier control circuit is shown in Figures 5a and 5b.

On start up **(602)** following initial 'warm up' **(604)**, the high tension (H.T.) supply is applied to each of the valves **(606)**. The thermionic valve control circuit then calibrates the amplifier by conducting an in-circuit test of each of the thermionic valves of the amplifier.

In order to carry out the test, the microprocessor will first measure and store the value of the cathode/anode current **(608)** before adjusting the grid bias **(610)**. The grid bias is adjusted in fixed steps for a set number of increments and the cathode/anode current in each thermionic valve is measured and stored for each grid bias value. Once the maximum number of iterations have been completed **(612)**, the measured values are then tabulated and used to calculate the mutual conductance of each thermionic valve **(614)**.

The calculated value is then compared with a reference value for the mutual conductance of the respective thermionic valve stored in the memory device and the difference between the two values is used by the microprocessor to calculate the decay in emission since the last test **(616)**.

The microprocessor then uses this information to calculate a predicted life span of each thermionic valve and informs the user of the status of each thermionic valve via one of the LEDs or via the transmitting means **(620)**.

Each of the thermionic valve's calculated conductance value is then subsequently stored the values in a memory device to be used as the reference value for the next circuit test.

If a thermionic valve is approaching the end of it's life and a user does not have sufficient time to replace the thermionic valve before use of the amplifier, the user can instruct the microprocessor to increase the power supply to the heater of the thermionic valve in order to increase the resultant cathode emission and hence the life of thermionic valve.

Following the in-circuit test, a stabilisation process is carried out **(622)**. The dynamic amplitude of the drive signal to each grid of each thermionic valve is measured by a third sensor device in order to match the thermionic valves. The microprocessor calculates the total harmonic distortion produced by the amplifier and adjusts the gain of the driver stages of each thermionic valve individually as required in order to minimise the total harmonic distortion.

The adjustment in the gain of the driver stages is effected via the shunt regulators positioned in the output signal path of the grid of a respective thermionic valve.

In alternative embodiment, the microprocessor adjusts the gain of the driver stages of by adjusting a property of the thermionic valve such as the grid bias, the anode voltage or the heater supply to the thermionic valve.

In yet another alternative embodiment, the thermionic valve control circuit comprises a variable amplifier positioned in series in the output signal path of the grid of the thermionic valve which is adjusted by microprocessor to effect a change in the gain of the driver stages.

Following the matching process, the previously stored bias value for each individual thermionic valve is applied to the thermionic valve **(624)**.

After the previously stored bias is applied to the thermionic valves, the cathode/anode current of each thermionic valve is measured and stored **(626)**. The measured value is then compared to a normal/reference value **(628)** for the cathode/anode current. If the measured value is much greater than or much less than the normal value, a fault has occurred in the amplifier and the microprocessor reports the fault to a user via one of the LEDs or via the transmitting means **(630)**. Following notification of the fault, the microprocessor switches off the valve amplifier **(632)**.

If no fault is detected, the microprocessor checks to see if the cathode/anode current is static **(634)**. If the cathode/anode current is not static, the control circuit repeats steps 626, 628 and 634 until a static current is determined.

During this process, the microprocessor also monitors the amplifier input power via the input current applied to the thermionic valves.

Once a static current is determined, the quiescent condition timer is cleared and the counter of the quiescent condition timer is set to zero **(636)**.

Biasing as previously described is then applied to each thermionic valve as appropriate. In summary, the process involves the steps of measuring the current applied to the cathode of each thermionic valve **(638)**, comparing the measured current with the optimum stored value for the desired operating classification and calculating an error value **(640)**, and increasing or decreasing the bias applied to the grid of each of the thermionic valves as required in order to reduce the error value **(644)** if the error value is not zero.

If the error value is zero, the microprocessor checks the status of the input power of the amplifier. If no audio power is detected, the microprocessor will increment the value of the quiescent condition timer counter and check whether the counter has exceeded a specified value proportional to a predetermined length of time **(646)**.

If the current value of the counter has not exceeded the specified value, steps 638, 640 and 642 are repeated.

When the counter has exceeded the specified value, the microprocessor initiates an energy saving feature by reducing the quiescent current applied to the thermionic valves by adjusting the bias to the valves **(648)**.

The microprocessor continues to monitor the audio power input and continually checks whether a dynamic grid signal is present in amplifier **(650)**. If a dynamic grid signal is not detected, the microprocessor will increment the value of the counter and repeat steps 648 and 650. If the quiescent condition continues for a prolonged predetermined period of time, the microprocessor may power down the amplifier.

When a dynamic grid signal is detected, step 626 is initiated by the microprocessor and the monitoring and controlling process reinitiated.

In a further embodiment, wherein the thermionic valve amplifier control circuit **(10)** is adapted to measure a hum in an output voltage of the thermionic valve amplifier **(12)**, at least one of the sensor devices is in the form of a narrow band pass software filter. The narrow band pass software filter is used to measure the hum present at the output at the end of the audio chain of the amplifier **(12)**.

When an unwanted hum is detected, the microprocessor **(22)** generates a control signal in response to the hum and injects the control signal into the output signal path of the amplifier in order to alter the phase of the signal.

The amplifier control circuit **(10)** may further comprise a control element adapted to receive the control signal and alter the phase of the output signal of the valve amplifier.

The control signal generated by the microprocessor **(22)** could be an anti-phase signal or a phase shift signal.

While the invention has been described with reference to use with a thermionic valve amplifier, it is to be understood the invention is not limited thereto and can readily be used with hybrid type amplifiers incorporating a thermionic valve.

## CLAIMS

1. A thermionic valve amplifier control circuit for a thermionic valve amplifier comprising

at least one sensor device adapted to measure an amplifier characteristic of a valve amplifier and produce a sensor signal in relation to the measured amplifier characteristic; and

a digital processing means connected to the at least one sensor device, wherein the digital processing means is adapted to receive the sensor signal produced by the at least one sensor device and to produce a control signal for adjusting a property of the thermionic valve amplifier in response to the received sensor signal.

2. A valve amplifier control circuit as claimed in claim 1 wherein the digital processing means comprises a microprocessor.

3. A valve amplifier control circuit as claimed in claim 1 or 2 further comprising an adjusting means adapted to receive the control signal and adjust a property of the thermionic valve amplifier in response to the received control signal.

4. A valve amplifier control circuit as claimed in claim 1 to 3 further comprising a memory device adapted to store a value of the amplifier characteristic measured by the at least one sensor device.

5. A valve amplifier control circuit as claimed in claim 4 wherein the memory device comprises a reference value of the amplifier characteristic measured by the at least one sensor device.

6. A valve amplifier control circuit as claimed in claim 5 wherein control signal for adjusting the property of the thermionic valve amplifier is related to a difference between the measured value of the amplifier characteristic and the reference value of the amplifier characteristic.

7. A valve amplifier control circuit as claimed in any one of the preceding claims wherein the amplifier characteristic measured by at least one sensor device is a cathode current of a thermionic valve in the thermionic valve amplifier.

8. A valve amplifier control circuit as claimed in claim 7 wherein the control signal is a bias signal adapted to be applied to the thermionic valve amplifier and the bias signal is related to a difference between the measured cathode current and a reference cathode current value.

9. A valve amplifier control circuit as claimed in claim 7 or 8 further comprising an operational amplifier adapted to amplify the cathode current signal.

10. A valve amplifier control circuit as claimed in claim 9 further comprising at least one analogue to digital convertor connected to the operational amplifier adapted to convert a signal received from the operational amplifier from an analogue signal into a digital signal.

11. A valve amplifier control circuit as claimed in claims 1 to 7 wherein the amplifier characteristic measured by the at least one sensor device is a dynamic amplitude of a drive signal to a grid of a valve of the thermionic valve amplifier and the control signal is adapted to effect a change in the effective gain of the thermionic valve in response to the amplitude of the drive signal.

12. A valve amplifier control circuit as claimed in claim 11 wherein the property of the thermionic valve adjusted by the control signal is the grid bias of the thermionic valve.

13. A valve amplifier control circuit as claimed in claim 11 wherein the property of the thermionic valve adjusted by the control signal is the anode voltage of the thermionic valve.

14. A valve amplifier control circuit as claimed in claim 11 wherein the property of the thermionic valve adjusted by the control signal is a property of a heater supply of the thermionic valve.

15. A valve amplifier control circuit as claimed in claim 11 when dependent on claim 3 wherein the adjusting means comprises a shunt regulator in an output signal path of the grid.

16. A valve amplifier control circuit as claimed in claim 11 when dependent on claim 3 wherein the adjusting means comprises a variable semiconductor amplifier in series with an output signal path of the grid.

17. A valve amplifier control circuit as claimed in claims 1 to 7 wherein the amplifier characteristic measured by the at least one sensor device is an input power of the amplifier and the property of the thermionic valve amplifier adjusted by the control signal is a quiescent current supply to the thermionic valve when no audio power is detected.

18. A valve amplifier control circuit as claimed in claims 1 to 7 wherein the amplifier characteristic measured by the at least one sensor device is a conductance in a thermionic valve and the property of the thermionic valve

amplifier adjusted by the control signal is a voltage supply to an anode of the thermionic valve in response to a drop in conductance.

19. A valve amplifier control circuit as claimed in claims 1 to 7 wherein the amplifier characteristic measured by the at least one sensor device is a bulb temperature of a thermionic valve.

20. A valve amplifier control circuit as claimed in claims 1 to 7 wherein the amplifier characteristic measured by the at least one sensor device is a hum in an output voltage of the thermionic valve amplifier and the control signal is adapted to alter the phase of an output signal of the thermionic valve amplifier.

21. A valve amplifier control circuit as claimed in claim 20 further comprising a control element adapted to receive the control signal and to alter the phase of the output signal of the valve amplifier in response to the received control signal.

22. A valve amplifier control circuit as claimed in claim 21 wherein the control element is adapted to inject an anti-phase signal into the output signal path of the thermionic valve amplifier.

23. A valve amplifier control circuit as claimed in claim 21 wherein the control element is adapted to inject a phase shift signal into the output signal path of the thermionic valve amplifier.

24. A valve amplifier control circuit as claimed in any one of claims 20 to 23 wherein the at least one sensor device comprises a narrow band pass software filter.

25. A valve amplifier control circuit as claimed in claims 1 to 7 comprising two or more sensor devices as claimed in one or more of the following groups: claims 7 to 10, claims 11 to 16, claim 17, claim 18, claim 19 and claims 20 to 24.

26. A valve amplifier control circuit as claimed in anyone of the preceding claims further comprising a transmitting means for transferring information from the digital processing means to an external device.

27. A valve amplifier control circuit as claimed in claim 26 wherein the transmitting means is a USB port.

28. A valve amplifier control circuit as claimed in claim 26 wherein the transmitting means is transmitter adapted to transmit a signal selected from a group comprising an infrared signal, a radio signal, such as a Bluetooth signal or a WiFi signal, to the external device.

29. A thermionic valve amplifier comprising an amplifier control circuit according to any one of claims 1 to 28.

30. A thermionic valve amplifier according to claim 29 further comprising a controllable valve heater power supply unit.

31. A method of controlling a thermionic valve amplifier comprising the steps of

measuring an amplifier characteristic of the valve amplifier using at least one sensor device; and

adjusting a property of the thermionic valve amplifier in response to the measured amplifier characteristic via a digital processing means connected to the at least one sensor device.

32. A method for matching two or more thermionic valves of a thermionic valve amplifier comprising the steps of

measuring the total harmonic distortion produced by the valve amplifier;

measuring a dynamic amplitude of a drive signal to the grid of each thermionic valve; and

individually adjusting the gain of the driver stages of at least one thermionic valve to minimise the total harmonic distortion produced by the valve amplifier.

33. A method for performing an in-circuit test of a thermionic valve amplifier, comprising the steps of:

a) calculating the mutual conductance of each thermionic valve of the valve amplifier;

b) comparing the calculated value with a reference mutual conductance value for the respective thermionic valve; and

c) calculating a decline in the life of the thermionic valve.

34. A method according to claim 33 further comprising the step of storing the calculated conductance value in a memory device.

35. A method according to claim 33 or 34 further comprising the step of predicting a life span of each thermionic valve.

36. A method according to any one of claim 35 further comprising the step of increasing a power supply to a heater of a thermionic valve in response to the predicted life span of the thermionic valve.

37. A method of retrofitting a thermionic valve amplifier with a valve amplifier control circuit comprising the steps of connecting a thermionic valve amplifier control circuit as claimed in any one of claims 1 to 28 to an output of a thermionic valve.

38. A thermionic valve amplifier control circuit as hereinbefore described with reference to and/or illustrated in the accompanying drawings.

39. A method for performing an in-circuit test of a thermionic valve amplifier as hereinbefore described with reference to and/or illustrated in the accompanying drawings.

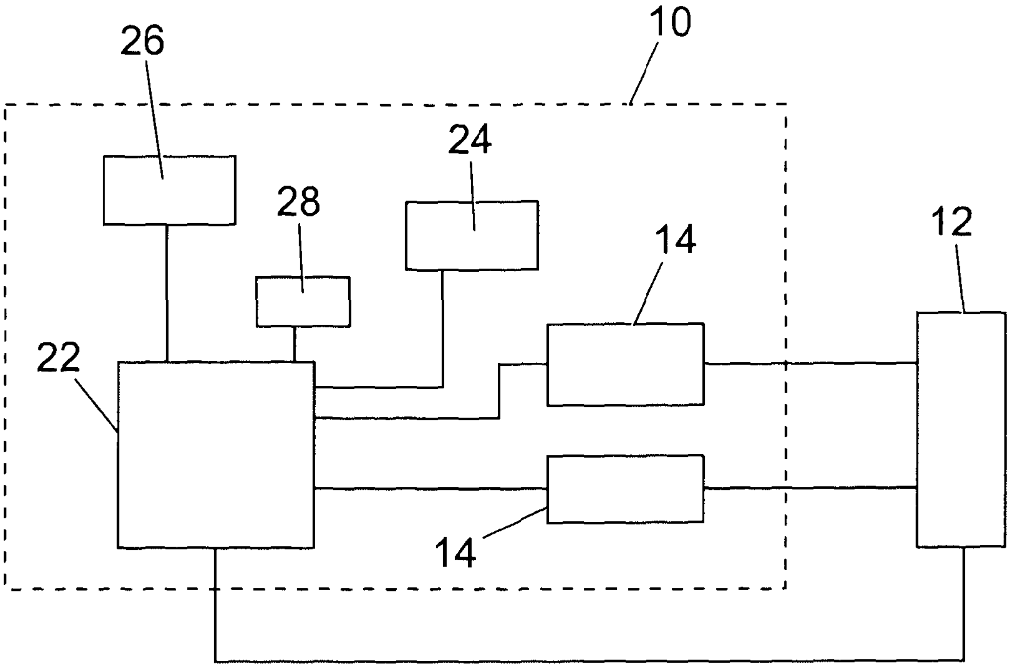



Fig. 1

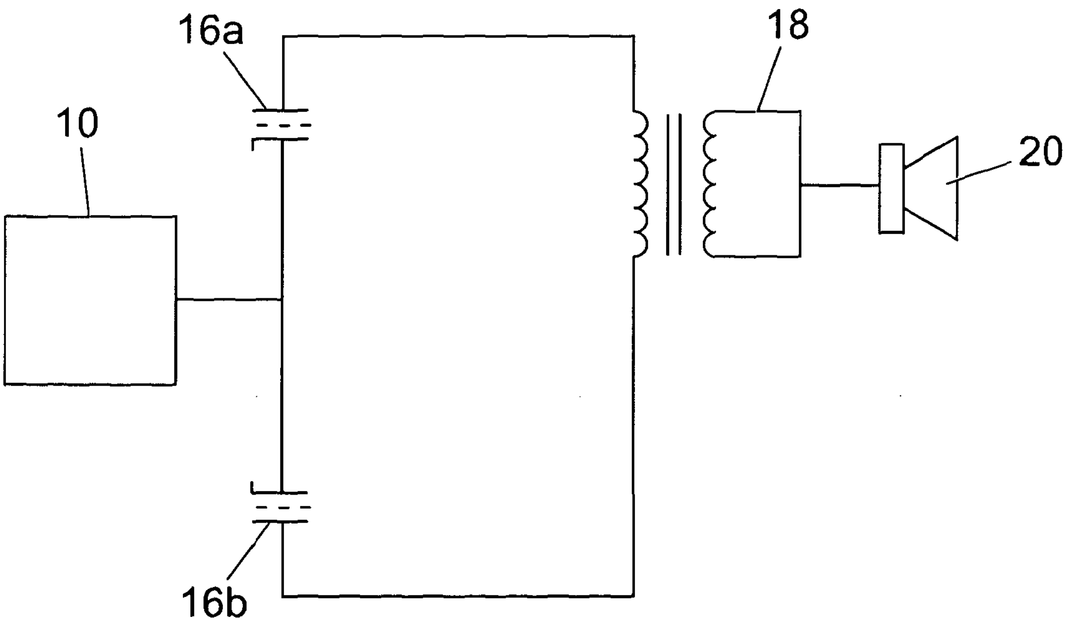



Fig. 2

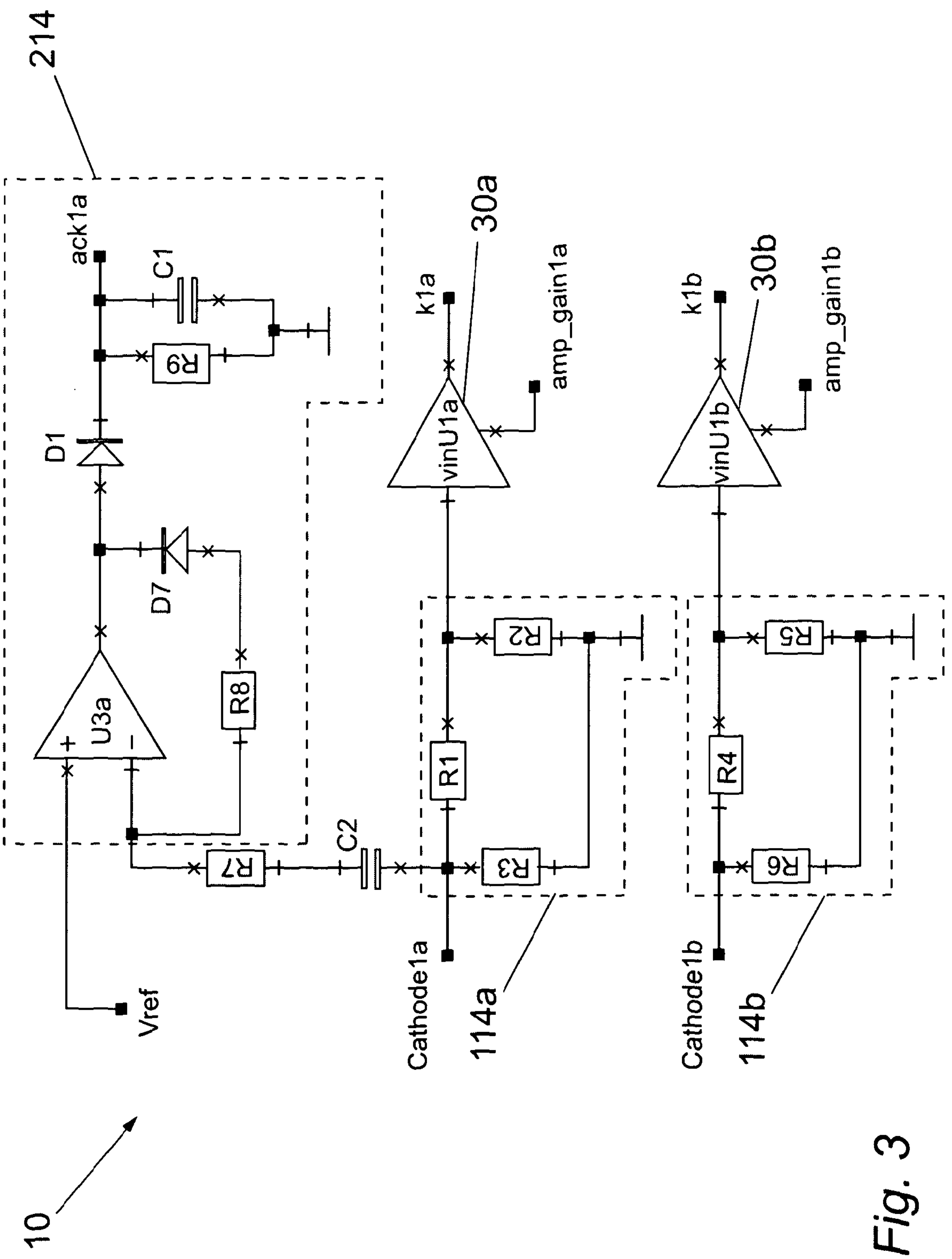

214
ack1a
C1
R9
D1
D7
R8
U3a
+
-
Vref
R7
C2
30a
k1a
amp_gain1a
vinU1a
R2
R1
R3
Cathode1a
114a
30b
k1b
amp_gain1b
vinU1b
R5
R4
R6
Cathode1b
114b
10

*Fig. 3*

15 10 03

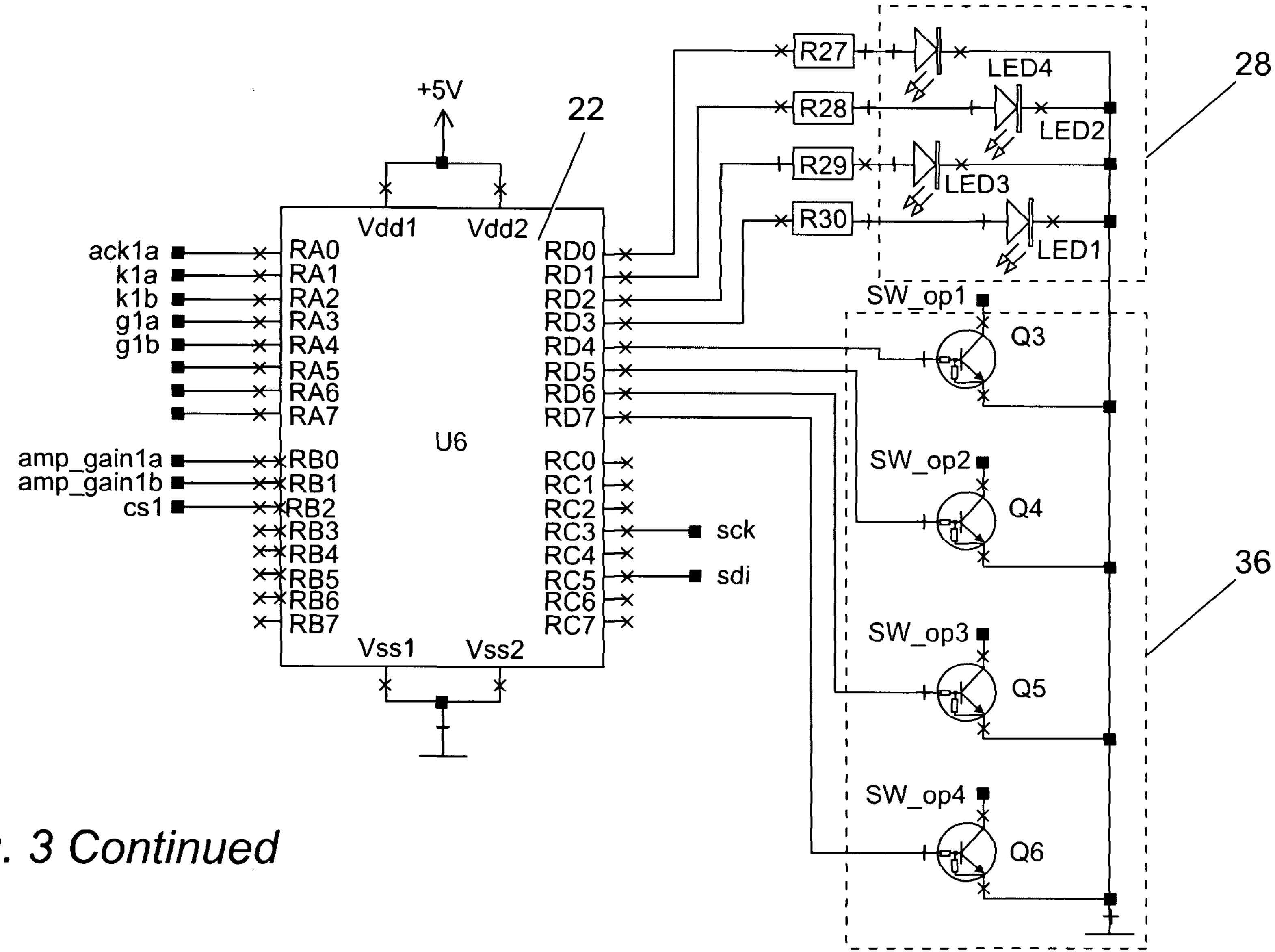



*Fig. 3 Continued*

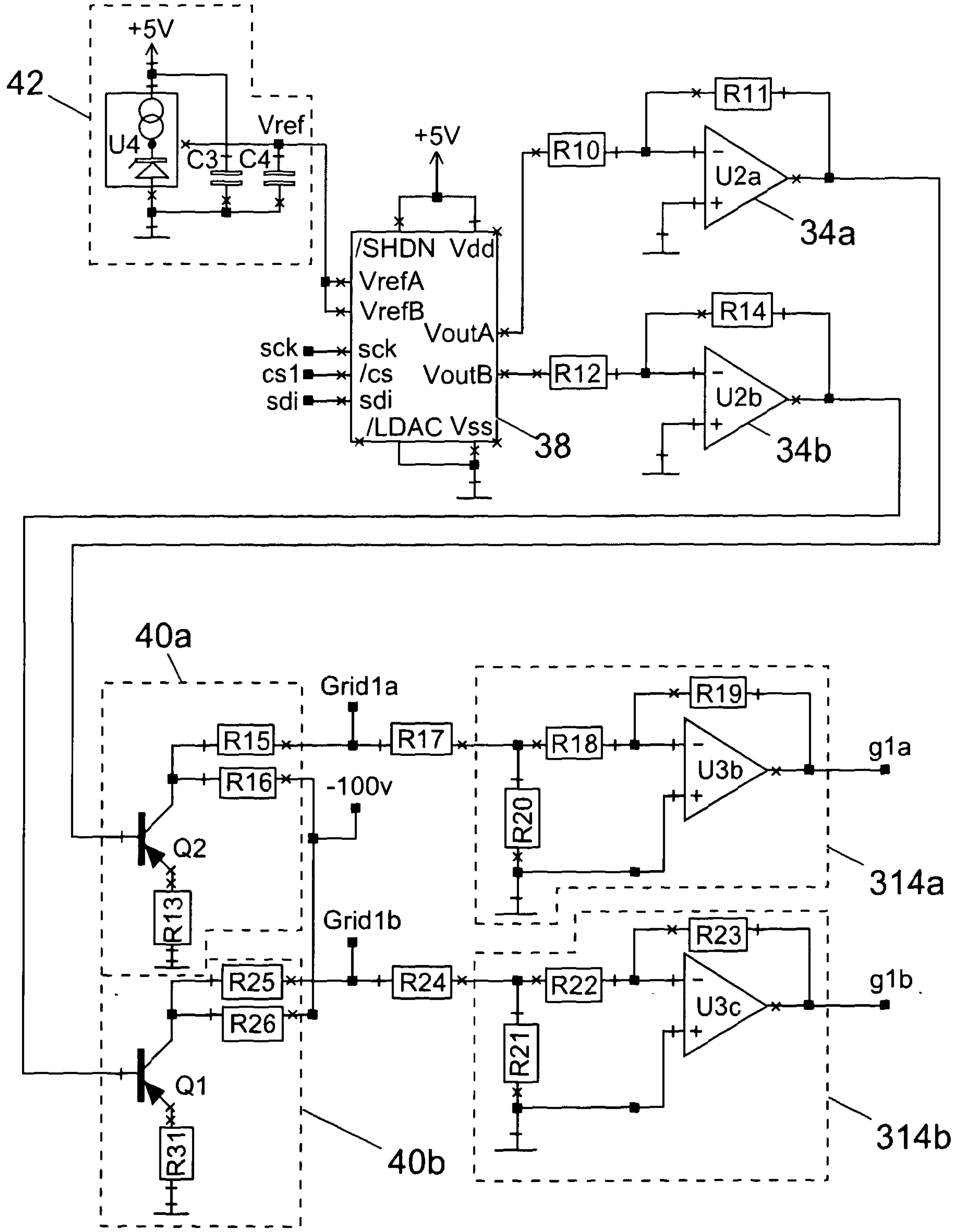



*Fig. 3 Continued*

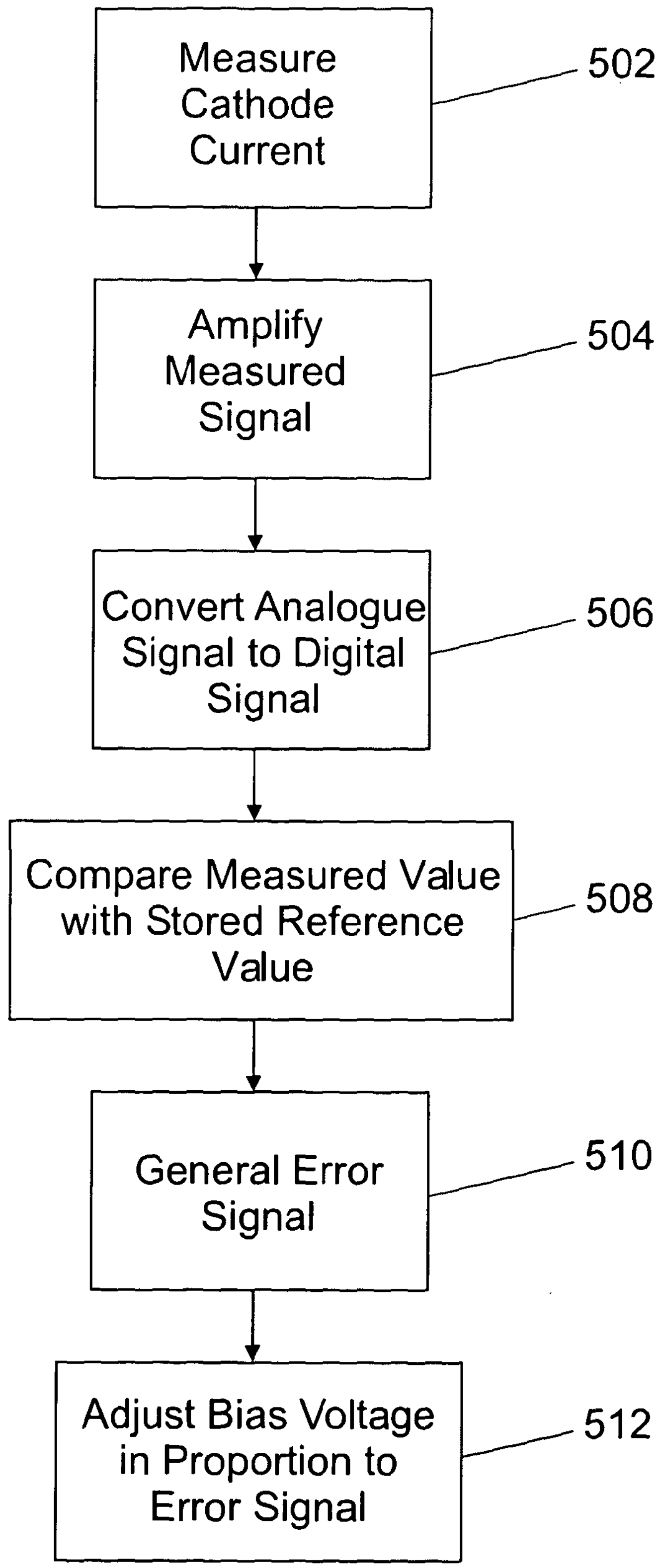

Measure Cathode Current
502
Amplify Measured Signal
504
Convert Analogue Signal to Digital Signal
506
Compare Measured Value with Stored Reference Value
508
General Error Signal
510
Adjust Bias Voltage in Proportion to Error Signal
512

*Fig. 4*

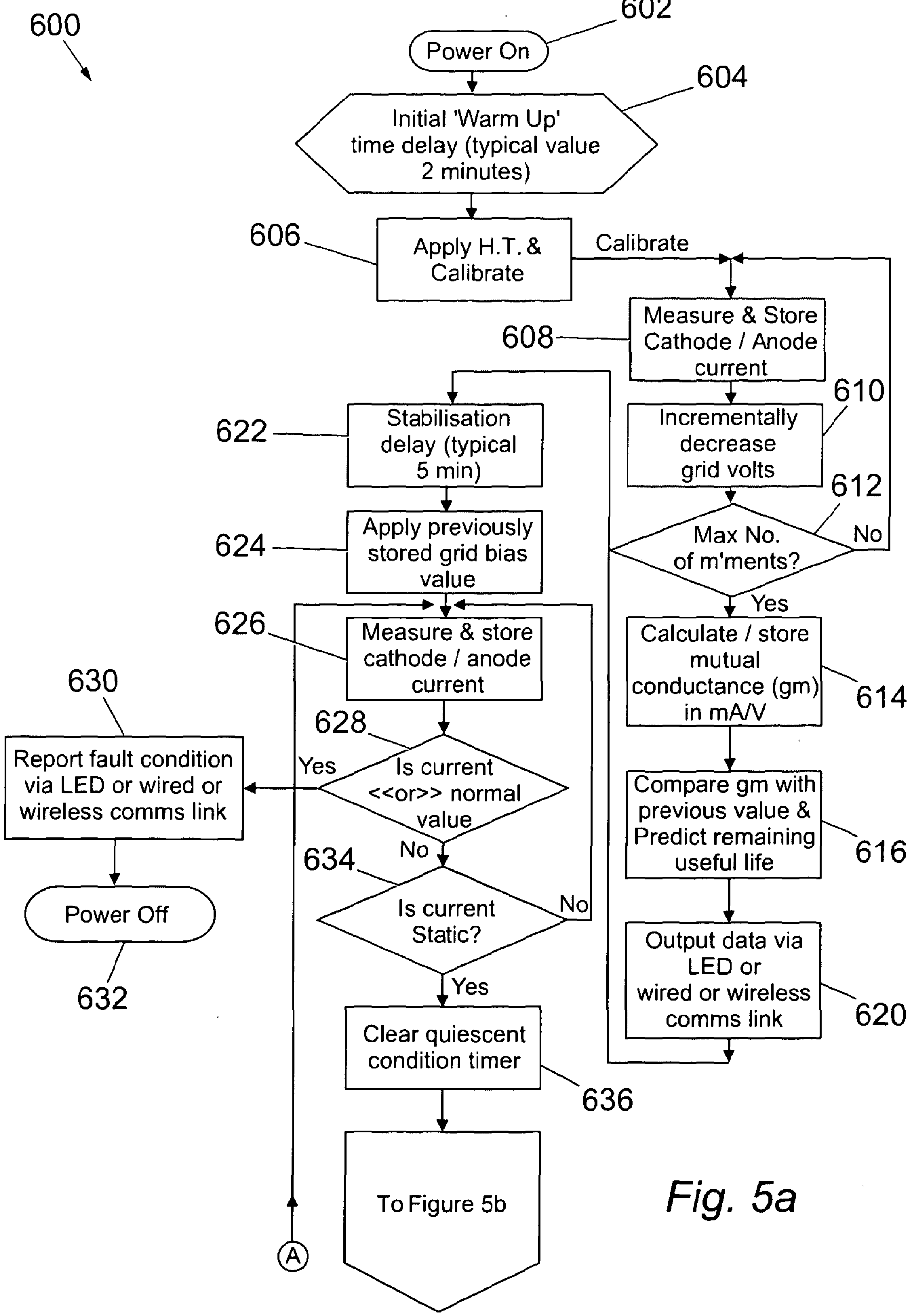
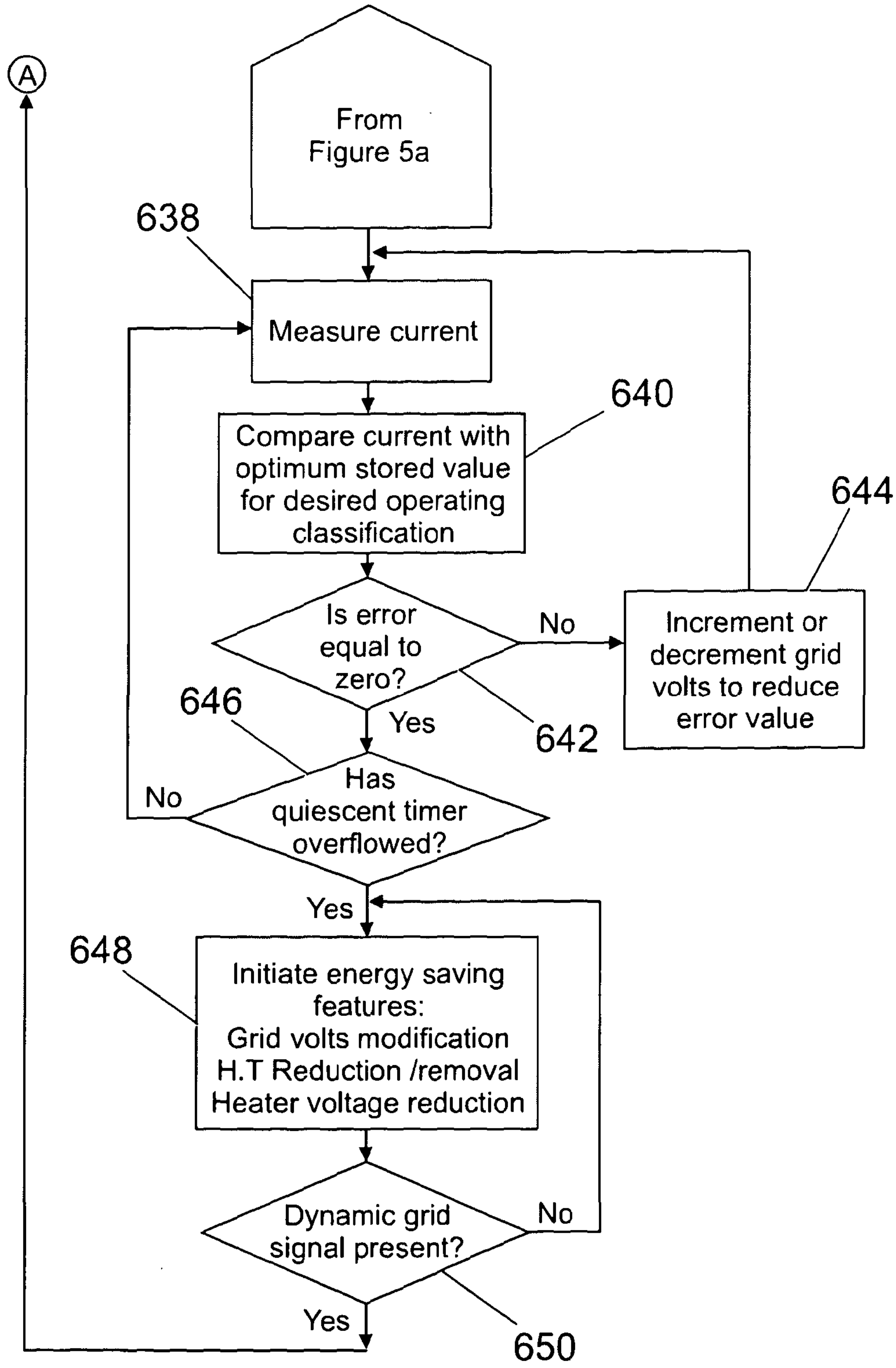

600
602
Power On
604
Initial 'Warm Up' time delay (typical value 2 minutes)
606
Apply H.T. & Calibrate
Calibrate
608
Measure & Store Cathode / Anode current
610
Incrementally decrease grid volts
612
Max No. of m'ments?
No
Yes
Calculate / store mutual conductance (gm) in mA/V
614
Compare gm with previous value & Predict remaining useful life
616
Output data via LED or wired or wireless comms link
620
622
Stabilisation delay (typical 5 min)
624
Apply previously stored grid bias value
626
Measure & store cathode / anode current
628
Is current <<or>> normal value
Yes
No
630
Report fault condition via LED or wired or wireless comms link
Power Off
632
634
Is current Static?
No
Yes
Clear quiescent condition timer
636
To Figure 5b
A

Fig. 5a

600



A
From Figure 5a
638
Measure current
640
Compare current with optimum stored value for desired operating classification
644
Is error equal to zero?
No
Increment or decrement grid volts to reduce error value
Yes
642
646
No
Has quiescent timer overflowed?
Yes
648
Initiate energy saving features:
Grid volts modification
H.T Reduction /removal
Heater voltage reduction
Dynamic grid signal present?
No
Yes
650


*Fig. 5b*

**Application No:** GB0814382.8 **Examiner:** Mr K Sylvan
**Claims searched:** 1-31 and 37 **Date of search:** 30 September 2008

## Patents Act 1977: Search Report under Section 17

**Documents considered to be relevant:**

| Category | Relevant to claims | Identity of document and passage or figure of particular relevance |
|---|---|---|
| X | 1-10,26-29, 31 and 37 | GB1162046 A C.I.T. See figure 2, page 2 line 92 to page 3 line 74 and page 4 lines 22-46. |
| X,Y | X: 1-5,7,9,10,25,29,31,37; Y: 17 | GB2410142 A Scott. See figures 4-6, page 3 lines 3-6 and claim 5. |
| Y | 17 | GB2344237 A Smith. See claim 1 line 2 and the penultimate "bullet point" on page 8. |
| X | 1-5,17,29,31,37 | JP11027055 A Kenwood. See the figures and the JAPIO abstract. |
| X | 1-5,19,29,31,37 | JP11027056 A Kenwood. See the figures and the JAPIO abstract. |

Categories:

| | | | |
|---|---|---|---|
| X | Document indicating lack of novelty or inventive step | A | Document indicating technological background and/or state of the art. |
| Y | Document indicating lack of inventive step if combined with one or more other documents of same category. | P | Document published on or after the declared priority date but before the filing date of this invention. |
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**Field of Search:**

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC$^{X}$ :

H3W

Worldwide search of patent documents classified in the following areas of the IPC

H03F

The following online and other databases have been used in the preparation of this search report

WPI,EPODOC,TXTE

**International Classification:**

| Subclass | Subgroup | Valid From |
|---|---|---|

| Subclass | Subgroup | Valid From |
|---|---|---|
| H03F | 0001/04 | 01/01/2006 |
| H03F | 0001/30 | 01/01/2006 |
| H03F | 0003/28 | 01/01/2006 |