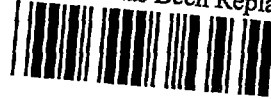


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H-196089

THICK FILM RESISTORField of the Invention

The present invention generally relates to thick film resistors used in hybrid electronic circuits. More particularly, this invention relates to an improved thick film resistor configuration, by which different resistance values for resistors formed of the same resistor composition can be readily achieved while forming the resistive portions of the resistors to be essentially identical in shape and size, such that packing density of the resistors can be increased.

10 Background of the Invention

Thick film resistors are employed in hybrid electronic circuits to provide a wide range of resistor values, generally between about 0.1 W and about 10 MW. Such resistors are printed on a ceramic substrate using thick film pastes, or inks, which are typically composed of an organic vehicle, a glass frit composition, an electrically conductive material, and various additives used to favorably affect the final electrical properties of the resistor.

Thick film conductors are employed to terminate the resistors of a hybrid circuit, and are typically formed prior to printing the resistor ink such that portions of the resistor ink overlies portions of the conductors. After printing, the resistor ink is dried and then sintered, or fired, to convert the ink into a suitable resistive film that adheres to the ceramic substrate and the underlying terminal portions of its conductors. After firing, part-to-part variations in resistance occur as a result of the difficulty in achieving consistent and uniform film thicknesses during printing of the resistor ink. Therefore, thick film resistors are typically printed to achieve a conservatively low resistance, and then trimmed to increase their resistance values to that required by their circuits. Trimming often entails using abrasive or laser techniques to form a cut into the thick film resistor, thereby increasing the resistor's effective electrical length, resulting in a corresponding increase in electrical resistance.

Thick film resistors typically have one of two basic configurations. The first employs a rectangular resistive film pattern between parallel conductors, as illustrated in Figures 1a-1d; the second configuration is known as a "top-hat" geometry, and includes a resistive film region
 5 projecting laterally from a rectangular base region of resistive film located between conductors. The former configuration is more widely used, though the top-hat configuration is advantageous where a wide trim range is desired.

Theoretically, a single ink composition could be used to create all resistors on a given circuit by forming the resistors to have appropriate
 10 lengths. However, severe space and size constraints typically dictate the use of different ink compositions within a given circuit. For this purpose, inks are commercially available in composition families referred to as end-members, which are formulated to produce resistors having sheet resistivities (R_s) in decade values from about 1 ohm per square ($W/$) to about 10
 15 megohms per square ($MW/$), (per 25 micrometers of dried thickness). Compositions having values that are one decade apart are referred to as adjacent end-members, which are blended to produce intermediate values of resistance. During sintering, the resistor ink is heated at a rate that is sufficiently slow to promote stability of the resistor and to allow the organic
 20 vehicle of the ink to burn off. Both physical and chemical changes occur within the thick film during sintering, by which the conduction network or microstructure of the resistor is formed. Various additives are typically used to achieve specific desired resistivity, stability and temperature characteristics.

The resistance of a thick film resistor can be theoretically
 25 determined by the following equation:

$$\text{Resistance (W)} = R_s \times L/W$$

where R_s is the sheet resistivity of the ink composition in ohms/square ($W/$),
 30 L is the electrical length of the resistor, and W is the electrical width of the

resistor. A resistor's length and width dimensions determine the surface area, or "footprint," required to accommodate the resistor on the surface of a circuit. The above equation is conventionally used to design thick film resistors for hybrid circuits, with the length (L) of the resistor often being the
5 final design characteristic manipulated to obtain the targeted resistance for a resistor in a circuit. In practice, the behavior defined by the above equation is non-ideal, with as-fired thick film resistors having resistances that can differ significantly from that predicted by the equation. In addition to resistance variations noted above as a result of the printing process, the sheet resistivity
10 value of a resistor generally decreases as the length of the resistor decreases due to metal ion (conductor) diffusion into the resistor during firing, such as when silver-bearing thick film conductors are employed to terminate the resistor on the circuit. The effect of conductor diffusion on sheet resistivity can be significant, yielding an "out of balance" resistor whose resistance is
15 below that required by its hybrid electronic circuit. Consequently, resistor trimming must also be performed to compensate for lower resistance values that occur due to conductor diffusion during firing.

While final resistance values of about $\pm 1\%$ can be achieved using abrasive or laser trimming techniques, the added processing step is
20 often undesirable from the standpoint of production costs and throughput. Furthermore, the degree to which the resistance value of a resistor can be corrected by trimming alone is complicated by the nonlinear relationship between length of cut and change in resistance, such that values outside a specified range may be inadvertently obtained, particularly if a relatively long
25 cut is required, resulting in scrappage of the circuit. An additional complication arising from longer trim cuts is resistor instability during operation, which has been correlated to material interactions that occur between the resistor and the underlying dielectric during trimming. Consequently, the ability to improve trimming precision or reduce or
30 eliminate the requirement for trimming would enhance the reliability of the

circuit and promote higher production rates.

Another aspect of thick film resistor design is the desire to maximize the packing density of a resistor circuit or network, where the term "network" is taken to include the actual resistors as well as the conductive traces, probe pads, wirebond pads, interlayer conductor vias, surface mounted devices, etc., required for the circuit and which need to be placed in immediate proximity to the resistors. Although current resistor printing techniques achieve what are considered to be dense resistor networks, a large fraction of bare substrate is practically always present in the vicinity of the resistors. Notable reasons for the presence of these vacant surface regions include limitations of print definition, the practice of providing an open area along the edge of a resistor at which a trim cut is to be initiated, the wide range of resistor widths and lengths often required for resistors within a given network, and resistor balancing requirements. The latter is involved when it is desired to reduce the length of a trim cut for a resistor, necessitating a change in the resistor's length and/or width. To allow for such changes to occur after the circuit layout has been determined, sufficient substrate surface area in the vicinity of each resistor must be provided in order to permit the size of a resistor to be changed without affecting the layout of the remaining circuitry. Accordingly, optimum packing of a thick film circuit is rarely attainable due to the inevitable use of resistors having a wide variety of shapes and sizes, and the necessity to accommodate additional changes in resistor size as dictated by balancing.

From the above, those skilled in the art can appreciate the need for an improved thick film resistor configuration that enables the use of nearly identically-sized resistor portions (i.e., resistor portions having identical footprints) to promote denser resistor packing. In addition, it would be desirable if such a resistor configuration could completely eliminate the requirement for trimming under some circumstances, and promote the precision of the trimming operation under circumstances where trimming is

necessary. Availability of such a resistor configuration would allow more options for circuit packing of a thick film hybrid circuit having a number of thick film resistors when other circuit components are also present. For example, any number of resistor portions could be formed having essentially
5 identical footprints, the shape and size of which being tailored for a given resistor network to allow for greater flexibility when packing components and resistors together to optimize a given area of a circuit.

Summary of the Invention

10 It is an object of this invention to provide a thick film resistor configuration that enables the required electrical resistance of a thick film resistor to be achieved while simultaneously promoting denser resistor packing of a thick film hybrid circuit.

It is another object of this invention to provide a method for
15 fabricating thick film resistors having such a configuration.

It is still another object of this invention that such a resistor configuration and method reduce and potentially eliminate the requirement for trimming.

It is a further object of this invention that such a resistor
20 configuration enables thick film resistors of a given circuit to be produced from the same ink composition.

It is yet a further object of this invention that such a resistor configuration enables the use of shorter trim cuts and yields a more linear relationship between trim cut length and resistance.

25 In accordance with a preferred embodiment of this invention, these and other objects and advantages are accomplished as follows.

According to the present invention, there are provided a novel thick film resistor configuration and a method for fabricating thick film resistors, by which such resistors can be processed to achieve targeted
30 electrical resistances. More particularly, the configuration and method of this

invention involve creating thick film resistors for a hybrid circuit, in which the resistors of a given resistor network can be formed from the same resistor composition and have essentially the same footprint, yet may differ in resistance by a ratio of 20:1 or more. The resistors are characterized by
5 differences in their resistances being achieved through appropriate modifications to their conductor configurations. As a result, a standardized resistor size can be adopted for a given resistor network, thereby enabling optimal resistor packing for the network since subsequent modifications in resistor lengths and widths for resistor balancing need not be accommodated.

10 The invention further entails a conductor configuration that achieves a higher but more constant change in resistance relative to trim cut length by concentrating current flow at the intended start-of-trim site. The result is shorter and more accurate trim cuts, which significantly increase the speed and accuracy of the trimming process. An additional result is reduced
15 scrappage due to excessively long cuts and resistor instability, both of which are more likely to occur when relatively long trim cuts are required. Consequently, circuits employing thick film resistors configured and fabricated in accordance with this invention are characterized by enhanced production throughput, repeatability, and reliability.

20 Generally, a thick film resistor configured in accordance with this invention includes a pair of conductors having terminal portions that overlap (e.g., overlie or underlie) a resistive portion. The resistive portion is characterized by a footprint that can be essentially identical to that of other thick film resistors of the same hybrid circuit. As used herein, "footprint"
25 denotes the surface area required to accommodate the resistor as dictated by the resistor's size and shape (e.g., its outer dimensions and geometry). The terminal portions of the conductors are disposed at opposite edge portions of the resistive portion so as to be electrically interconnected through the resistive portion. As such, the terminal portions establish a current path
30 therebetween through the resistive portion, and therefore establish the

resistance value for the thick film resistor.

According to the invention, the current path of the thick film resistor can have a different length than current paths of other thick film resistors on the same circuit by sole virtue of its terminal portions having a different shape and/or size that those of the other resistors. As a result, the resistance value of the thick film resistor can be significantly different from the resistance values of the other resistors of the same circuit, though the resistors have resistive portions with essentially identical footprints. As a result, denser packing can be achieved with this invention because resistor placement and excess substrate surface space surrounding each resistor are not required to accommodate a network of resistors having a wide variety of sizes and shapes. At the same time, multiple resistor networks may be present in a single hybrid circuit, with each network employing resistor and terminal portions that differ from those of the other resistor networks in order to uniquely accommodate additional circuit components or any other particular circuit requirements. Denser resistor packing is also promoted because surplus substrate space is not required around each resistor to accommodate possible changes in resistor size after circuit layout is completed due to a subsequent resistor balancing of the circuit.

According to one embodiment of the invention, the terminal portions of a resistor are formed to have opposing tapered edges that diverge relative to each other. As such, the resistor's current path is established between the tapered edges, and the lengths of the tapered edges determine the length and flux pattern of the current path, which in turn affects the resistance value of the thick film resistor. In addition, it has been determined that the diverging tapered edges of the terminal portions create a nonuniform current density through the resistor portion. By configuring the terminal and resistor portions to concentrate current flow at the intended start-of-trim site, a significant increase is achieved for the ratio and linearity between the change in resistance and the length of a trim cut made in the resistive portion. As a

result, the invention promotes the ability to accurately trim a resistor, promotes the speed at which a trim cut can be made, and enables a shorter trim cut which leads to greater resistor stability.

5 Other objects and advantages of this invention will be better appreciated from the following detailed description.

Brief Description of the Drawings

 The above and other advantages of this invention will become
10 more apparent from the following description taken in conjunction with the accompanying drawings, in which:

 Figures 1a-1d show the current flux pattern of a thick film resistor configured in accordance with the prior art;

 Figures 2a-2d show the current flux pattern of a thick film
15 resistor configured in accordance with one embodiment of the present invention;

 Figure 3 contrasts the relationships between change in resistance and length of trim cut for the prior art resistor of Figures 1a-1d and the inventive resistor of Figures 2a-2d; and

20 Figures 4 through 5 represent thick film resistors configured in accordance with second and third embodiments of the present invention.

Detailed Description of the Invention

 Figures 2a-d, 4a-b and 5a-b represent thick film resistors
25 configured and processed in accordance with this invention. For contrast, a thick film resistor 10 configured in accordance with prior art practices is shown in Figures 1a-d. The prior art resistor 10 is shown as including a pair of parallel conductors 12 that extend along opposite edges of a resistive film 14, through which current flows between the conductors 12. In Figure 1a,
30 the current path through the resistive film 14 is represented by a number of

essentially parallel flux lines 16. Figures 1b-d show the progressive effect of longer trim cuts 18 in the resistive film 14, and particularly the relatively greater affect that the cut 18 has on those flux lines 16 nearest the cut 18.

Figure 3 graphically illustrates the affect of a progressively
5 longer trim cut 18 and the resulting resistance value of the resistor 10, with "Relative Resistance" denoting the ratio of the resistance value after the cut (e.g., corresponding to Figures 1b-d) to the original resistance value of the resistor 10 (corresponding to Figure 1a). As shown, the relationship between resistance and trim cut length is far from linear, with the ratio being rather
10 low for the shorter trim lengths of 50 percent and less. Consequently, relatively long cuts are often required, and the precision with which a desired resistance value can be obtained becomes increasingly complicated by the nonlinear relationship as longer trim cuts become necessary. Further complicating this situation is the greater likelihood of resistor instability as a
15 result of a relatively long trim cut.

Figures 2a-d illustrate a resistor 110 configured in accordance with a first embodiment of this invention, and by which significant improvements in the resistance-trim cut relationship are achieved. The resistor 110 includes a pair of conductors 112 and a resistive film 114 through
20 which current flows between the conductors 112. Though the conductors 112 are shown as extending substantially collinear to each other in a direction transverse to the opposite edges of the resistive film 114, it is equally foreseeable that the conductors 112 could extend parallel to each other along the opposite edges of the resistive film 114. Notably, the opposing ends of
25 the conductors 112 are tapered to form opposing edges 120 that diverge relative to each other, i.e., they diverge in a direction corresponding to a line equidistant from the edges 120. Also shown is a breach in the resistive film 114 between the conductors 112. The breach forms a short slot 122 that extends into the otherwise rectangularly-shaped perimeter of the resistive film
30 114. According to the invention, the slot 122 eliminates the requirement to

start a trim cut, such as the trim cuts 118 shown in Figures 2b-2d, outside the rectangular perimeter of the resistive film 114.

As with the prior art resistor 10 of Figures 1a-d, a current path through the resistive film 114 is represented by a number of current flux lines 116. Figures 2b-d show the progressive effect of a longer trim cut 118 in the resistive film 114, with increasing lengths having an increasingly greater affect on the length of the current path and therefore the resistance value of the resistor 110. Notably, the tapered edges 120 of the conductors 112 alter the flux field through the resistive film 114, concentrating the current flow near the slot 122 where the trim cut 118 is initiated. This effect on current flow density remains apparent regardless of the length of the cut 118. Furthermore, as schematically depicted by Figures 2a-d, the length of the cut 118 has a significant effect on all of the flux lines 116, including those furthest from the cut 118. An advantageous result arising from the above-noted aspects can be seen in the change in resistance of the resistor 110 relative to the length of the trim cut 118, which is illustrated in Figure 3. As is apparent, the resistance ratio for the resistor 110 of this invention is significantly more consistent than that for the resistor 10 of the prior art.

Furthermore, Figure 3 shows that the ratio between resistance and trim cut length for the resistor 110 is roughly twice that for the prior art resistor 10 at trim lengths up to about 75 percent. Consequently, significantly shorter cuts 118 can be employed to achieve the same change in resistance, and the more constant resistance-cut length ratio promotes the precision with which a desired resistance value is obtained. An important advantage resulting from this aspect of the invention is that the resistor 110 of Figures 2a-d is more stable than the resistor 10 of Figures 1a-d, and is therefore more tolerant of subsequent processing. Consequently, the resistor 110 is highly suitable as a buried resistor of a multilayer thick film hybrid circuit, in which a dielectric layer overlies the resistor 110. In this role, deposition and firing of the overlying dielectric layer has minimal effect on the resistance of the

resistor 110 due to the enhanced stability of the resistor configuration of this invention. In contrast, the resistance value of the resistor 10 shown in Figures 1a-d could be expected to change significantly during subsequent processing of a multilayer circuit, an undesirable result that could not be
5 corrected by trimming due to the presence of the dielectric layer.

Yet another advantage of the resistor configuration shown in Figures 2a-d is that the power handling capability of the resistor remains relatively constant and may even increase as the length of the trim cut 118 increases. For a conventional resistor cut as shown in Figures 1a-d, the
10 resistive portion 14 nearest the trim cut 18 does not carry a significant amount of current; this area is effectively lost for the purpose of heat dissipation, resulting in a decrease in power handling capacity for the resistor 10. The tapered edges 120 of the conductors 112 shown in Figures 2a-d significantly reduce this effect since current flows through an increasingly larger region of
15 the resistive portion 114 as the length of the trim cut 118 increases. As a result, power resistors equipped with tapered conductors in accordance with this invention can be made smaller and more easily trimmed as compared to prior art resistors of the type shown in Figures 1a-d.

The above advantages noted with the resistor configuration of
20 Figures 2a-d are largely attributable to the tapered edges 120 of the conductors 112, the size of the conductors 112 and their orientation relative to the resistive film 114. Notably, the resistive film 114 and a portion, herein referred to as a terminal 112a, of each conductor 112 overlap each other, such that the size and shape of the terminals 112a directly affect the current path
25 and therefore the resistance of the resistor 110. For illustrative purposes, the terminals 112a are shown in Figures 2a-d as those portions of the conductors 112 that overlie the resistive film 114, though it is more conventional that the resistive film 114 would be deposited after formation of the conductors 112, such that the terminals 112a are defined as those portions of the conductors
30 112 that lie beneath the resistive film 114.

With reference to Figures 4a and 4b, which illustrate thick film resistors 210 according to a second embodiment of this invention, altering only the size of the terminals 212a of the resistor's conductors 212 can have a marked effect on the current path through the resistive film 214, and therefore the resistance value of the resistor 210. Again, the resistive portion 214 is shown as having a rectangular shape, with a slot 218 formed to eliminate the prior art requirement for initiating a trim cut (not shown) outside of the rectangular pattern of the resistive film 214. The conductors 212 are shown as being oriented collinear to each other, though they could extend parallel to each other as depicted in Figures 2a-d. Finally, the terminals 212a are shown to have differing lengths in the direction along the opposite edges of the resistive film 214, such that the resistance values of the resistors 210 of Figures 4a and 4b will correspondingly differ.

As Figures 4a and 4b are intended to illustrate the use of different conductor configurations to form otherwise identical resistors, the material used to form the resistive films 214 would be the same. Nonetheless, the resistance value for the resistor 210 shown in Figure 4a has been experimentally determined to be roughly one-half that of its counterpart in Figure 4b, an effect derived solely from the differing lengths of their terminals 212a in conjunction with the presence of the opposing tapered edges 220. Again, the footprint of the resistive film 214 is identical for each resistor 210, and therefore is not a contributing factor in the different resistance values obtained.

Figures 5a and 5b illustrate yet another embodiment of this invention, in which the size and shape of the terminals 312a are modified to affect the current path through a resistive film 314, and therefore the resistance value through a thick film resistor 310 formed by the resistive film 314 and the terminals 312a. As with the embodiment of Figures 4a and 4b, the resistive film 314 is shown as having a slot 318, and a pair of conductors 312 forming the terminals 312a are shown as being oriented collinear to each

other, though again they could be shown as being parallel to each other. Notably, the terminals 312a are not shown to have opposing tapered edges, so as to eliminate the influence that diverging terminals would have on the resistance values of the resistors 310. The resistive film 314 again has a rectangular footprint, though notably altered by an extension 322 through
5 which any trim cut (not shown) would extend from the slot 318. Advantageously, the extension 322 provides for a wide trimmable range for the resistors 310.

As with Figures 4a and 4b, the resistor embodiment of Figures
10 5a and 5b is intended to illustrate the effect that different conductor configurations have on otherwise identical resistors, i.e., same resistive film material and footprint. Nonetheless, the resistance value of the resistor 310 of Figure 5a has been experimentally determined to be roughly six-tenths that of its counterpart in Figure 5b, an effect derived solely from the differing sizes
15 of their terminals 312a. Again, the footprint of the resistive film 314 is the same for each resistor 310, and therefore is not a contributing factor in the different resistance values obtained.

According to the invention, generally conventional processing techniques can be employed to fabricate a thick film hybrid circuit having a
20 resistor network composed of thick film resistors configured according to this invention, such as one or more of those shown in Figures 2a-d, 4a-b and 5a-b.

The thick film materials for the resistive films and conductors may be chosen from those commercially available. Prior to printing the resistive films and conductors, the present invention enables the physical dimensions of the
25 resistor films to be predicated on optimizing the resistor packing density of the circuit, in view of generally broad limitations established by the targeted resistive values. With this invention, it is foreseeable that all resistors of a given resistor network will employ resistive films whose shape and outer dimensions are the same and optimized to promote the density of the network.
30 For example, each of the resistive films 114, 214 and 314 of the resistors

110, 210 and 310 have a rectangular footprint and may have the same overall size, though their specific shapes and conductor patterns might differ. Most notably, the present invention avoids the conventional requirement to determine a unique aspect ratio (length/width) for each individual resistor in order to roughly obtain the desired resistance value for each resistor after firing. As is conventional, the resistance value of each thick film resistor required by the circuit may dictate the use of a particular resistor ink composition to provide a suitable initial sheet resistivity.

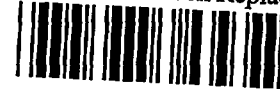
The next step in configuring the resistors is to determine the conductor configuration, or more accurately the shape and size of the terminals of the conductors, including whether or not the terminals should be formed to have tapered opposing edges as depicted by the embodiments of Figures 2a-d and 4a-b. The decision to form the terminals with opposing tapered edges may take into consideration the extent to which trimming is anticipated in order to achieve an appropriate resistor balance for the circuit. Any suitable printing process can then be employed to deposit the thick film materials, such as a screen printing technique. The resistive films are preferably printed, dried and fired after printing and firing the conductors, such that the resistive films overlay and adhere to the conductors and the circuit's substrate.

After firing, conventional resistor balancing procedures may be followed to more precisely attain the resistances required by the circuit. Importantly, trimming of resistors configured according to this invention can be performed more readily in view of the more linear relationship achieved between the change in resistance and trim cut length, as illustrated by Figure 3. Furthermore, the slots formed in the resistive films also facilitate the trimming operation, since trim cuts need not be initiated outside of the resistive film area.

From the above, it can be appreciated that a significant advantage of this invention is that a hybrid thick film circuit having thick film

resistors configured in accordance with this invention can achieve dense resistor packing through adoption of an optimal standard size and shape for the resistive film of each resistor in a given resistor network, and then uniquely configuring the conductors of each resistor to approximately obtain the desired resistance value for each resistor of the circuit. After firing, trimming can be performed to more closely obtain the desired target resistances for each resistor. Notably, a wide range of resistances, generally on the order of about 20:1, can be attained using the same ink composition for all resistors of a circuit, though it is within the scope of this invention that different resistive inks could be used. In some circumstances, it is foreseeable that thick film resistors could be fabricated without requiring a post-firing trimming operation. Otherwise, it is anticipated that a significantly reduced amount of trimming would be necessary to bring a resistor within the tolerance range permitted by a circuit as a result of uniquely configuring the conductors for each resistor, as well as the reduced amount of trimming necessary as a result of the higher resistance change-to-cut length ratio achieved by the use of tapered terminals. In summary, the present invention provides a novel thick film resistor configuration and a method for fabricating thick film resistors characterized by enhanced production throughput, repeatability, and reliability.

While our invention has been described in terms of a preferred embodiment, it is apparent that other forms could be adopted by one skilled in the art. For example, different materials and resistor configurations could be used other than those noted and shown, and processing techniques and processing orders other than those noted could be employed. Accordingly, the scope of our invention is to be limited only by the following claims.



CLAIMS

1. A method for forming thick film resistors, the method comprising the steps of: forming each of a pair of thick film resistors to have a resistive portion and a pair of conductors, each of the conductors having a terminal portion, the resistive portions of each of the thick film resistors
5 having approximately equal footprints and formed from substantially identical resistive materials; and for each of the thick film resistors, forming the terminal portions and opposite edge portions of the resistive portion to overlap such that the terminal portions establish a current path therebetween through the resistive portion, the terminal portions being sized and shaped to
10 determine a length for the current path and thereby affect a resistance value for the thick film resistor, the resistance value for a first of the thick film resistors differing from the resistance value of a second of the thick film resistors as a result of the terminal portions of the one thick film resistor differing in size and shape from the terminal portions of the second thick film
15 resistor.

2. The thick film resistors formed by the method recited in claim 1.

3. The thick film resistors as recited in claim 2, wherein the thick film resistors are buried resistors of a multilayer thick film hybrid circuit.

4. A method as recited in claim 1, further comprising the step of forming at least one of the thick film resistors to have a breach formed at an edge of the resistive portion between the terminal portions.

5. A method as recited in claim 1, further comprising the step



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of trimming at least one of the thick film resistors by forming a trim cut in the resistive portion at an edge thereof between the terminal portions, the trim cut being formed to have a length sufficient to increase the length of the current
5 path and therefore the resistance value of the at least one thick film resistor.

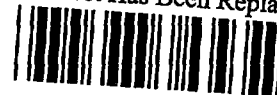
6. A method as recited in claim 1, wherein the terminal portions of at least one of the thick film resistors are formed to extend substantially parallel to each other along the opposite edge portions of the resistive portion.

7. A method as recited in claim 1, wherein the terminal portions of at least one of the thick film resistors are formed to extend substantially collinear to each other in a direction substantially transverse to the opposite edge portions of the resistive portion.

8. A method as recited in claim 1 further comprising the step of forming the terminal portions of at least one of the thick film resistors to have opposing tapered edges that diverge relative to each other so as to affect the length of the current path and the resistance value of the at least one thick
5 film resistor, the tapered edges promoting a linear relationship between the length of the current path and the resistance value of the at least one thick film resistor.

9. A method as recited in claim 1 further comprising the step of forming the terminal portions of each of the thick film resistors to have opposing tapered edges that diverge relative to each other so as to affect the length of the current path and the resistance value of their corresponding thick
5 film resistor, the resistance value for a first of the thick film resistors differing from the resistance value of a second of the thick film resistors as a result of the terminal portions of the one thick film resistor having a different length





along the tapered edges from the terminal portions of the second thick film resistor.

10. The thick film resistors formed by the method recited in claim 8.

11. The thick film resistors as recited in claim 10, wherein the thick film resistors are buried resistors of a multilayer thick film hybrid circuit.

12. A method for forming a thick film resistor, the method comprising the steps of: forming a resistive portion and a pair of conductors, each of the conductors having a terminal portion, the terminal portions and opposite edge portions of the resistive portion overlapping such that the
5 terminal portions establish a current path therebetween through the resistive portion; and forming the terminal portions to have opposing tapered edges that diverge relative to each other, the current path being established between the tapered edges such that the tapered edges determine a length for the current path and thereby affect a resistance value for the thick film resistor.

13. A method as recited in claim 12, wherein the terminal portions are formed to extend substantially parallel to each other along the opposite edge portions of the resistive portion.

14. A method as recited in claim 12, wherein the terminal portions are formed to extend substantially collinear to each other in a direction substantially transverse to the opposite edge portions of the resistive portion.

15. A method as recited in claim 12, further comprising the



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step of forming a breach in the resistive portion at an edge thereof and between the terminal portions.

16. The thick film resistor formed by the method recited in claim 12.

17. The thick film resistor as recited in claim 16, wherein the thick film resistor is a buried resistor of a multilayer thick film hybrid circuit.

18. A method as recited in claim 12, further comprising the step of trimming the thick film resistor by forming a trim cut in the resistive portion at an edge thereof between the terminal portions, the trim cut being formed to have a length sufficient to increase the length of the current path
5 and therefore the resistance value of the thick film resistor, the tapered edges of the terminal portions promoting a linear relationship between the length of the breach and the resistance value of the thick film resistor.

19. A method as recited in claim 18 wherein the forming steps entail forming a plurality of resistive portions and a corresponding plurality of pairs of conductors to form a corresponding plurality of thick film resistors, the resistive portions being formed from substantially identical resistive
5 materials to have approximately equal footprints, and wherein the trimming step yields at least one of the thick film resistors having a different resistance value than another of the thick film resistors as a result of the trim cut of the at least one thick film resistor having a different length than the other thick film resistor.

20. The thick film resistor formed by the method recited in claim 18.



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21. The thick film resistor as recited in claim 20, wherein the thick film resistor is a buried resistor of a multilayer thick film hybrid circuit.

22. A method as recited in claim 12 wherein the forming step entails forming the terminal portions to have lengths in a direction along the tapered edges so as to substantially achieve the resistance value for the thick film resistor.

23. A method as recited in claim 22 wherein the thick film resistor is a first thick film resistor and the forming steps entail forming a second resistive portion and a second pair of conductors to form a second thick film resistor, the second resistive portion being formed from a
5 substantially identical resistive material and to have an approximately equal footprint as that of the first thick film resistor, the terminal portions of the second thick film resistor being formed to have opposing tapered edges that diverge relative to each other, the second thick film resistors having a different resistance value than the first thick film resistors as a result of the
10 terminal portions of the second thick film resistor being longer than the terminal portions of the first thick film resistor.

24. The thick film resistor formed by the method recited in claim 22.

25. The thick film resistor as recited in claim 24, wherein the thick film resistor is a buried resistor of a multilayer thick film hybrid circuit.

26. A thick film hybrid circuit comprising a resistor network that comprises a pair of thick film resistors, each of the thick film resistors comprising: a pair of conductors spaced apart on a substrate; and a resistive portion overlying terminal portions of the pair of conductors, the resistive
5 portion characterized by a footprint, the terminal portions being disposed





beneath opposite edge portions of the resistive portion so as to be electrically interconnected through the resistive portion, the terminal portions establishing a current path therebetween through the resistive portion which determines a resistance value for the thick film resistor; wherein the footprints of the resistive portions of the thick film resistors are approximately equal and the resistive portions are formed from a single resistive material, yet the terminal portions of the first and second thick film resistors differ such that the resistance value of the first thick film resistor is greater than the resistance value of the second thick film resistor.

27. A thick film hybrid circuit as recited in claim 26, wherein each of the first and second thick film resistors further comprises a trim cut between the terminal portions thereof and extending into the resistive portion thereof from an edge thereof, the resistance value of the first thick film resistor being increased relative to the resistance value of the second thick film resistor as a result of the trim cut of the first thick film resistor being longer than the trim cut of the second thick film resistor.

28. A thick film hybrid circuit as recited in claim 26, wherein the terminal portions of each thick film resistor extend along the opposite edges of their respective resistive portions, the resistance value of the first thick film resistor being greater than the resistance value of the second thick film resistor as a result of the terminal portions of the first thick film resistor being shorter than the terminal portions of the second thick film resistor.

29. A thick film hybrid circuit as recited in claim 26, wherein the pair of terminals of at least one of the thick film resistors has opposing edges, the edges diverging from each other so as to increase a distance between the edges and thereby affect the resistance value of the at least one thick film resistor.





30. A thick film hybrid circuit as recited in claim 26, wherein the resistive portions of the first and second thick film resistors are substantially identical in shape and size.

31. A thick film hybrid circuit as recited in claim 26, wherein at least one of the thick film resistors has a breach formed at an edge of the resistive portion between the terminal portions.

32. A thick film hybrid circuit as recited in claim 26, wherein the terminal portions of at least one of the thick film resistors are formed to extend substantially parallel to each other along the opposite edge portions of the resistive portion.

33. A thick film hybrid circuit as recited in claim 26, wherein the terminal portions of at least one of the thick film resistors are formed to extend substantially collinear to each other in a direction substantially transverse to the opposite edge portions of the resistive portion.

34. A thick film hybrid circuit as recited in claim 26, wherein the thick film hybrid circuit is a multilayer circuit and the thick film resistors are buried resistors.



THICK FILM RESISTORAbstract:

A thick film resistor configuration and a method for fabricating thick film resistors, by which such resistors can be processed to achieve targeted electrical resistances. The configuration and method of this invention involve creating thick film resistors for a given hybrid circuit, in which the

5 resistors can be formed from the same resistor composition and have essentially the same peripheral shape and exterior dimensions, yet may differ in resistance by a ratio of 20:1 or more. The resistors are characterized by differences in their resistances being achieved through appropriate modifications to their conductor configurations. As a result, a standardized

10 resistor size can be adopted for a given resistor network, thereby enabling optimal resistor packing for the network since subsequent modifications in resistor lengths and widths for resistor balancing need not be accommodated.

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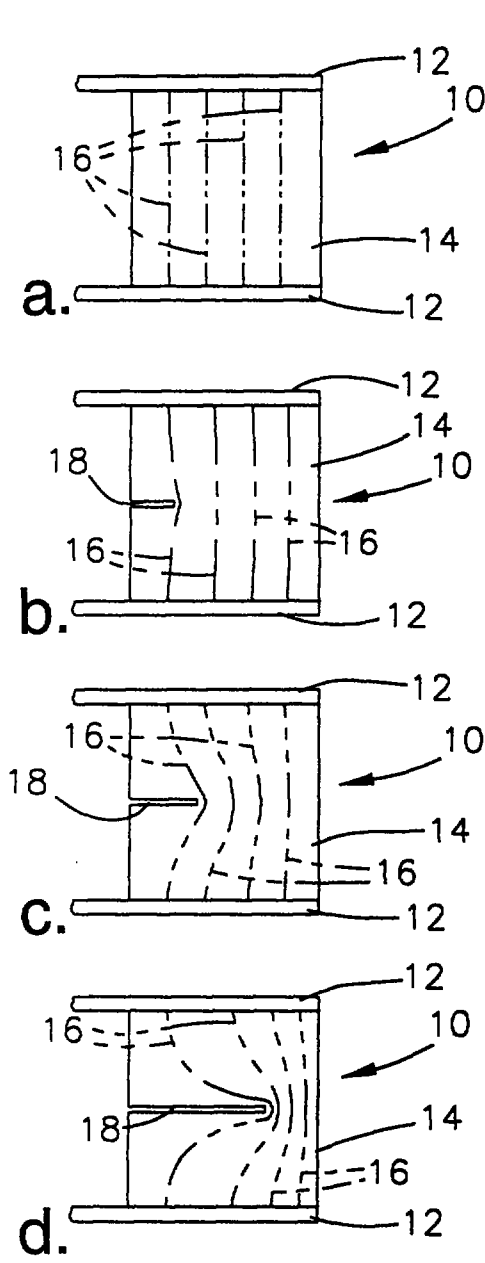


Fig. 1.

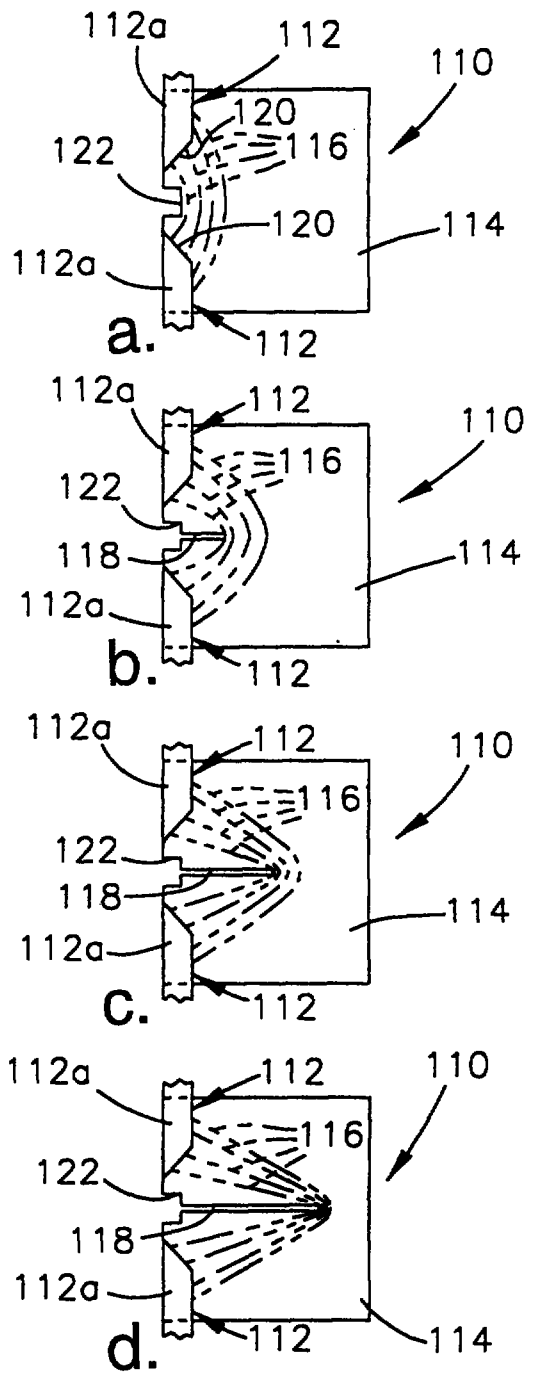
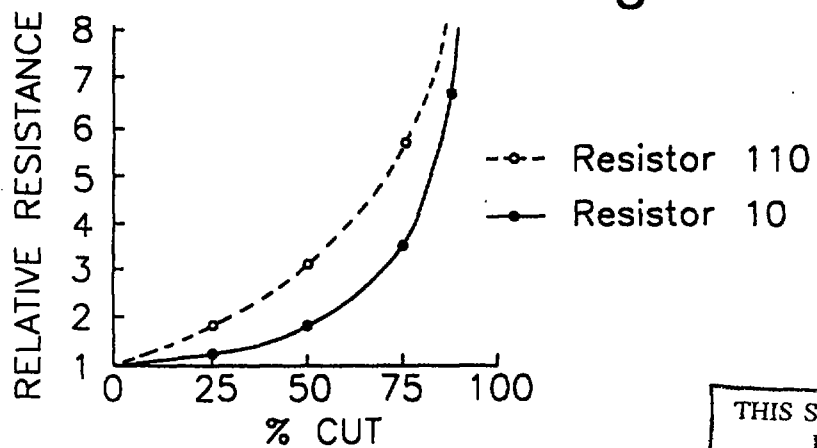


Fig. 2.

Fig. 3.



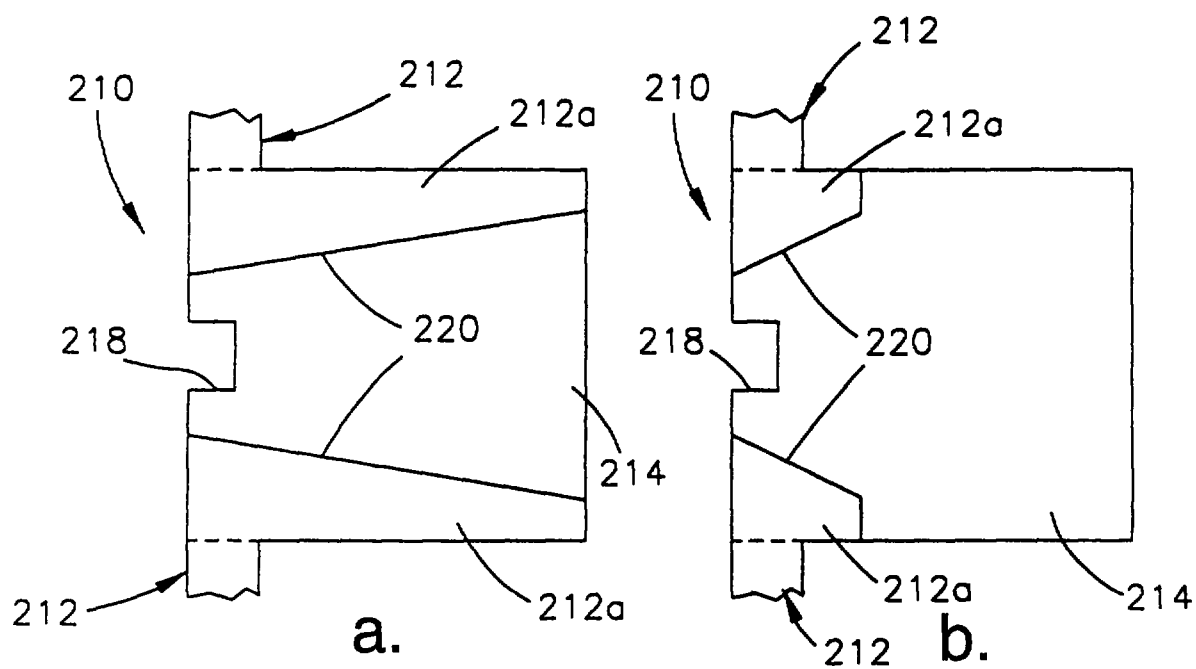
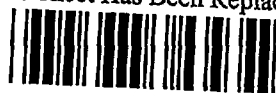


Fig. 4.

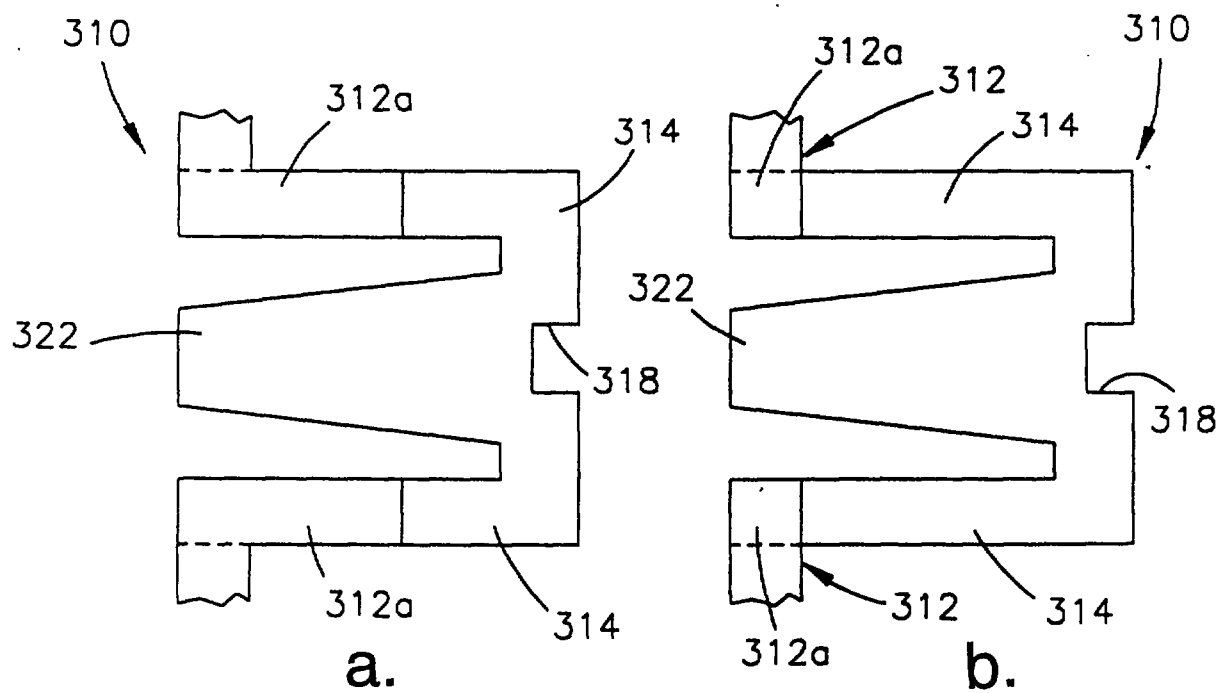
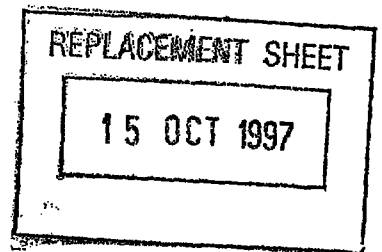


Fig. 5.



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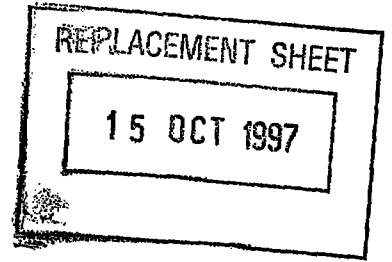
1THICK FILM RESISTORField of the Invention

The present invention generally relates to thick film resistors used in hybrid electronic circuits. More particularly, this invention relates to an improved thick film resistor configuration, by which different resistance values for resistors formed of the same resistor composition can be readily achieved while forming the resistive portions of the resistors to be essentially identical in shape and size, such that packing density of the resistors can be increased.

10 Background of the Invention

Thick film resistors are employed in hybrid electronic circuits to provide a wide range of resistor values, generally between about 0.1 W and about 10 MW. Such resistors are printed on a ceramic substrate using thick film pastes, or inks, which are typically composed of an organic vehicle, a glass frit composition, an electrically conductive material, and various additives used to favorably affect the final electrical properties of the resistor.

Thick film conductors are employed to terminate the resistors of a hybrid circuit, and are typically formed prior to printing the resistor ink such that portions of the resistor ink overlies portions of the conductors. After printing, the resistor ink is dried and then sintered, or fired, to convert the ink into a suitable resistive film that adheres to the ceramic substrate and the underlying terminal portions of its conductors. After firing, part-to-part variations in resistance occur as a result of the difficulty in achieving consistent and uniform film thicknesses during printing of the resistor ink. Therefore, thick film resistors are typically printed to achieve a conservatively low resistance, and then trimmed to increase their resistance values to that required by their circuits. Trimming often entails using abrasive or laser techniques to form a cut into the thick film resistor, thereby increasing the resistor's effective electrical length, resulting in a corresponding increase in electrical resistance.

THICK FILM RESISTORAbstract:

A thick film resistor configuration and a method for fabricating thick film resistors, by which such resistors can be processed to achieve targeted electrical resistances. The configuration and method of this invention involve creating thick film resistors for a given hybrid circuit, in which the

5 resistors can be formed from the same resistor composition and have essentially the same peripheral shape and exterior dimensions, yet may differ in resistance by a ratio of 20:1 or more. The resistors are characterized by differences in their resistances being achieved through appropriate modifications to their conductor configurations. As a result, a standardized

10 resistor size can be adopted for a given resistor network, thereby enabling optimal resistor packing for the network since subsequent modifications in resistor lengths and widths for resistor balancing need not be accommodated.

Figure 1

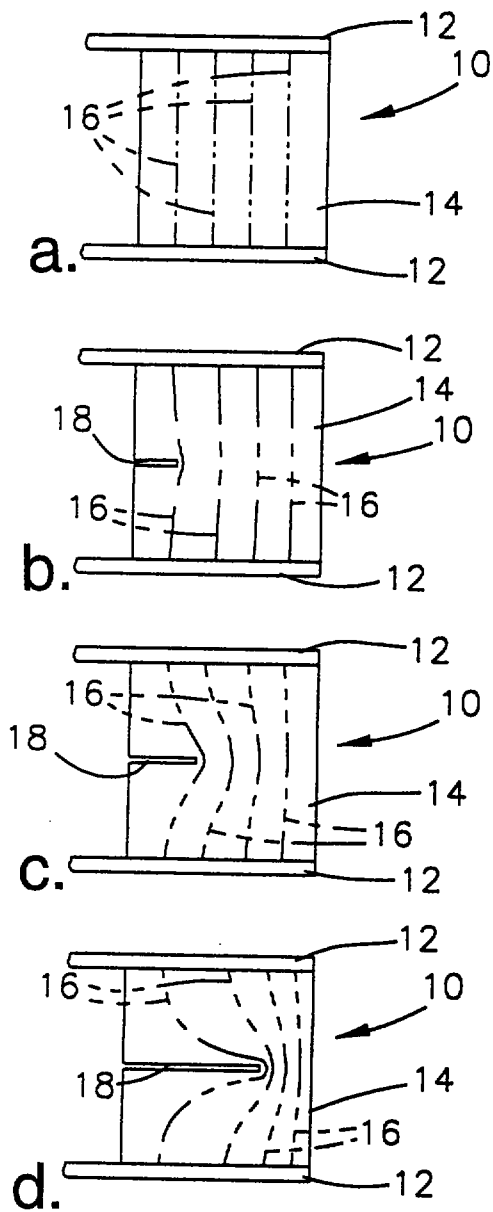


Fig.1.

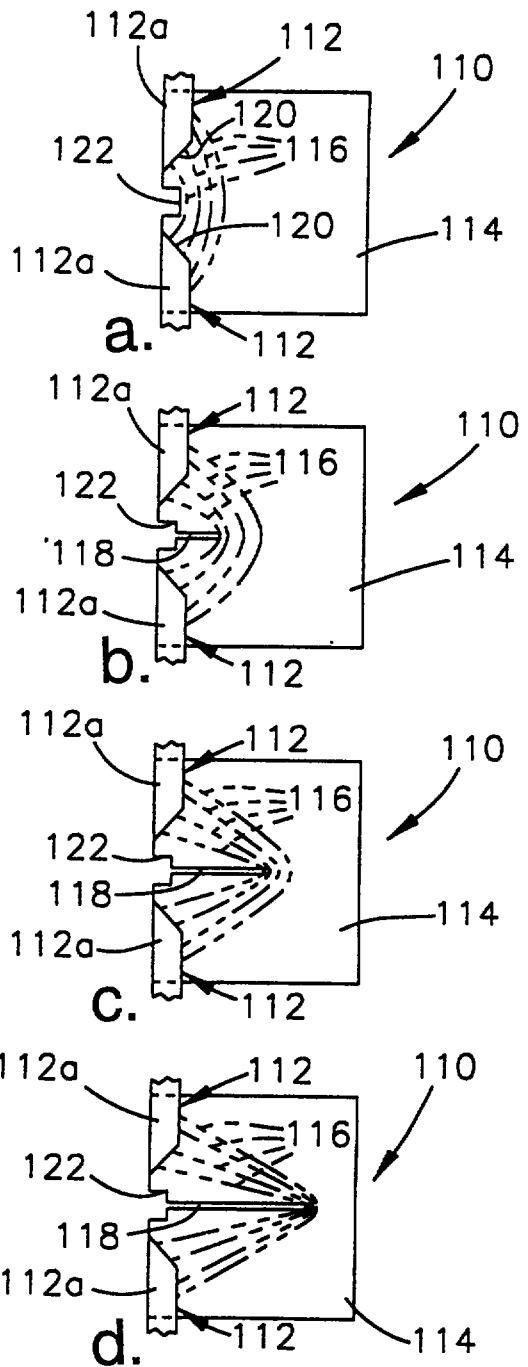
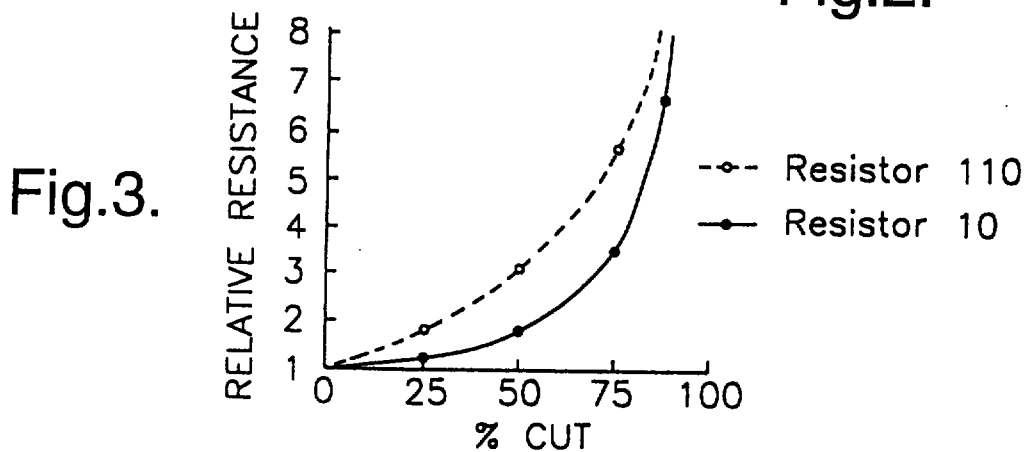


Fig.2.



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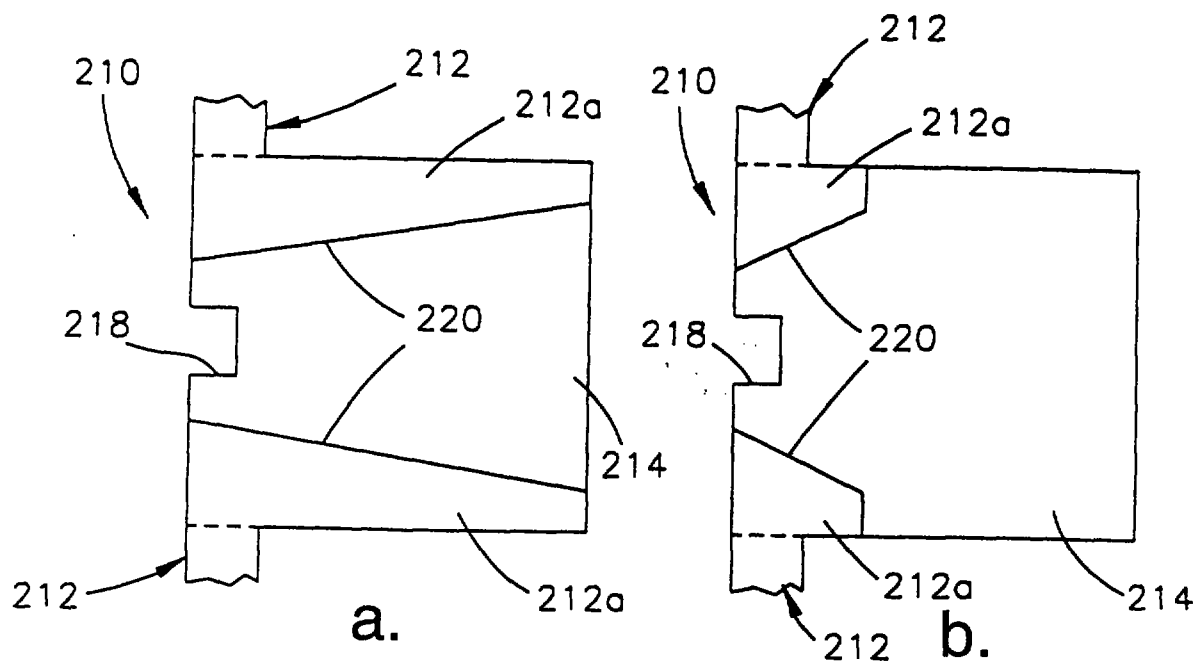


Fig. 4.

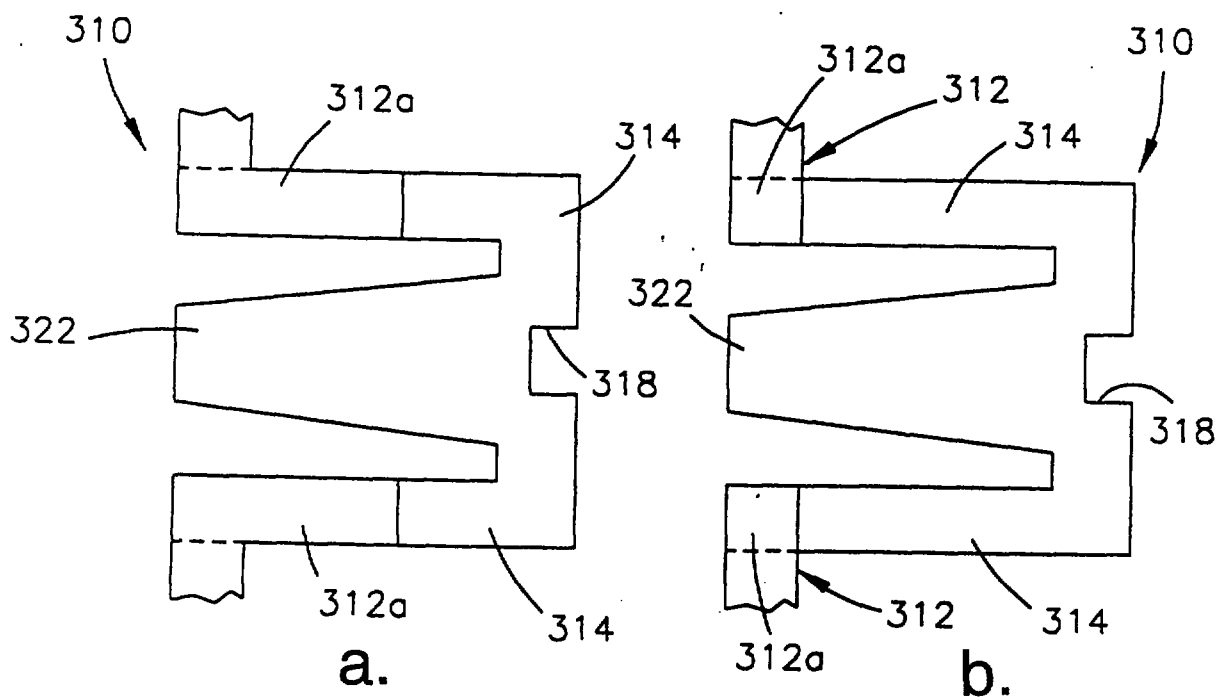
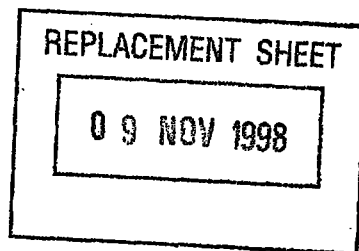


Fig. 5.



CLAIMS

1. A method for forming thick film resistors, the method comprising the steps of: forming each of a pair of thick film resistors to have a resistive portion and a pair of conductors, each of the conductors having a terminal portion, the resistive portions of each of the thick film resistors
5 having approximately equal footprints and formed from substantially identical resistive materials; and for each of the thick film resistors, forming the terminal portions and opposite edge portions of the resistive portion to overlap such that the terminal portions establish a current path therebetween through the resistive portion, the terminal portions being sized and shaped to
10 determine a length for the current path and thereby affect a resistance value for the thick film resistor, the resistance value for a first of the thick film resistors differing from the resistance value of a second of the thick film resistors as a result of the terminal portions of the one thick film resistor differing in size and shape from the terminal portions of the second thick film
15 resistor; further comprising the step of forming the terminal portions of at least one of the thick film resistors to have opposing tapered edges that diverge relative to each other so as to affect the length of the current path and the resistance value of the at least one thick film resistor, the tapered edges promoting a linear relationship between the length of the current path and the
20 resistance value of the at least one thick film resistor.

2. A method as recited in claim 1 further comprising the step of forming the terminal portions of each of the thick film resistors to have opposing tapered edges that diverge relative to each other so as to affect the length of the current path and the resistance value of their corresponding thick
5 film resistor, the resistance value for a first of the thick film resistors differing from the resistance value of a second of the thick film resistors as a result of the terminal portions of the one thick film resistor having a different length



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along the tapered edges from the terminal portions of the second thick film resistor.

3. The thick film resistors formed by the method recited in claim 1.

4. The thick film resistors as recited in claim 3, wherein the thick film resistors are buried resistors of a multilayer thick film hybrid circuit.

5. A method for forming a thick film resistor, the method comprising the steps of: forming a resistive portion and a pair of conductors, each of the conductors having a terminal portion, the terminal portions and opposite edge portions of the resistive portion overlapping such that the terminal portions establish a current path therebetween through the resistive portion; and forming the terminal portions to have opposing tapered edges that diverge relative to each other, the current path being established between the tapered edges such that the tapered edges determine a length for the current path and thereby affect a resistance value for the thick film resistor.

6. A method as recited in claim 5, wherein the terminal portions are formed to extend substantially parallel to each other along the opposite edge portions of the resistive portion.

7. A method as recited in claim 5, wherein the terminal portions are formed to extend substantially collinear to each other in a direction substantially transverse to the opposite edge portions of the resistive portion.

8. A method as recited in claim 5, further comprising the step



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of forming a breach in the resistive portion at an edge thereof and between the terminal portions.

9. The thick film resistor formed by the method recited in claim 5.

10. The thick film resistor as recited in claim 9, wherein the thick film resistor is a buried resistor of a multilayer thick film hybrid circuit.

11. A method as recited in claim 5, further comprising the step of trimming the thick film resistor by forming a trim cut in the resistive portion at an edge thereof between the terminal portions, the trim cut being formed to have a length sufficient to increase the length of the current path and therefore the resistance value of the thick film resistor, the tapered edges of the terminal portions promoting a linear relationship between the length of the breach and the resistance value of the thick film resistor.

12. A method as recited in claim 11 wherein the forming steps entail forming a plurality of resistive portions and a corresponding plurality of pairs of conductors to form a corresponding plurality of thick film resistors, the resistive portions being formed from substantially identical resistive materials to have approximately equal footprints, and wherein the trimming step yields at least one of the thick film resistors having a different resistance value than another of the thick film resistors as a result of the trim cut of the at least one thick film resistor having a different length than the other thick film resistor.

13. The thick film resistor formed by the method recited in claim 11.



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14. The thick film resistor as recited in claim 13, wherein the thick film resistor is a buried resistor of a multilayer thick film hybrid circuit.

15. A method as recited in claim 5 wherein the forming step entails forming the terminal portions to have lengths in a direction along the tapered edges so as to substantially achieve the resistance value for the thick film resistor.

16. A method as recited in claim 15 wherein the thick film resistor is a first thick film resistor and the forming steps entail forming a second resistive portion and a second pair of conductors to form a second thick film resistor, the second resistive portion being formed from a
5 substantially identical resistive material and to have an approximately equal footprint as that of the first thick film resistor, the terminal portions of the second thick film resistor being formed to have opposing tapered edges that diverge relative to each other, the second thick film resistors having a different resistance value than the first thick film resistors as a result of the
10 terminal portions of the second thick film resistor being longer than the terminal portions of the first thick film resistor.

17. The thick film resistor formed by the method recited in claim 15.

18. The thick film resistor as recited in claim 17, wherein the thick film resistor is a buried resistor of a multilayer thick film hybrid circuit.



THICK FILM RESISTOR

Field of the Invention

The present invention generally relates to thick film resistors used in hybrid electronic circuits. More particularly, this invention relates to an improved thick film resistor configuration, by which different resistance values for resistors formed of the same resistor composition can be readily achieved while forming the resistive portions of the resistors to be essentially identical in shape and size, such that packing density of the resistors can be increased.

Background of the Invention

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