Sept. 4, 1934. R. E. TARPLEY 1,972,499

WOVEN RESISTOR

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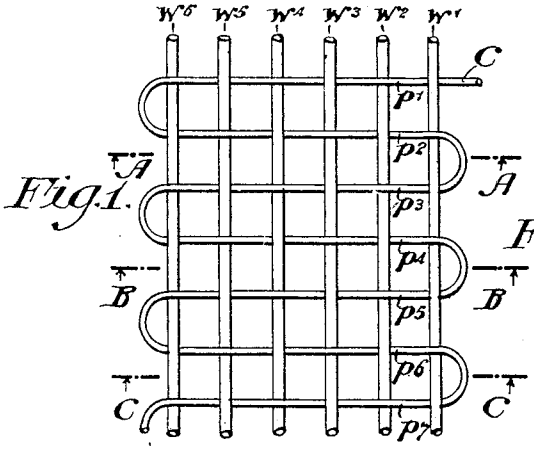


Fig. 1.

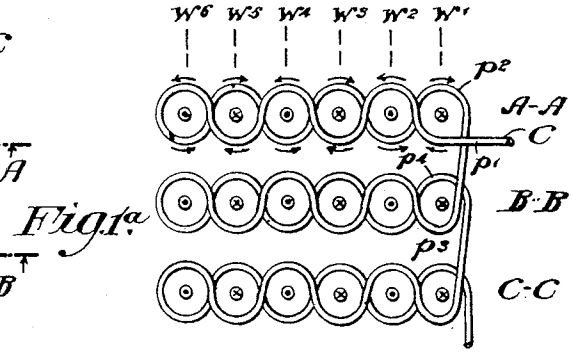


Fig. 1a.

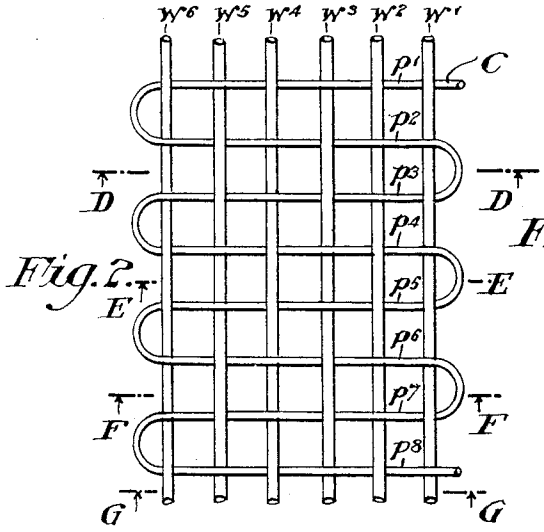


Fig. 2.

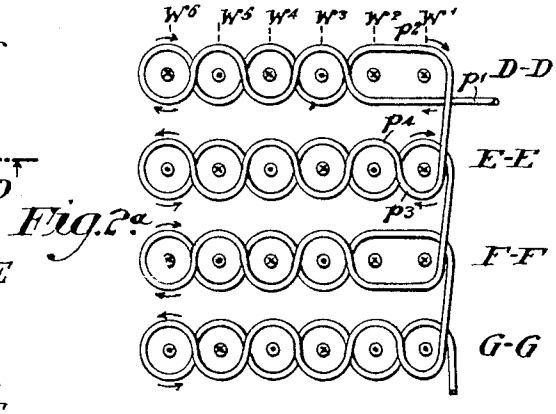


Fig. 2a.

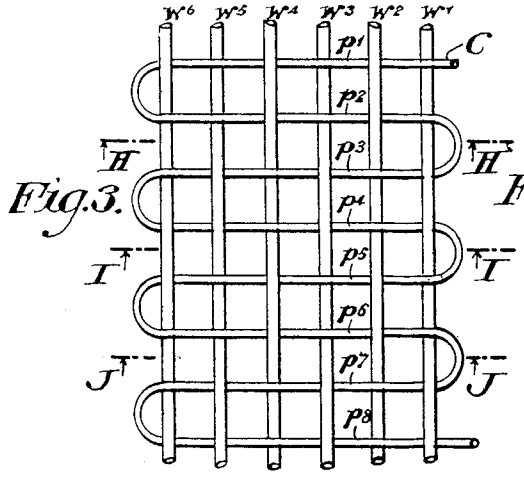


Fig. 3.

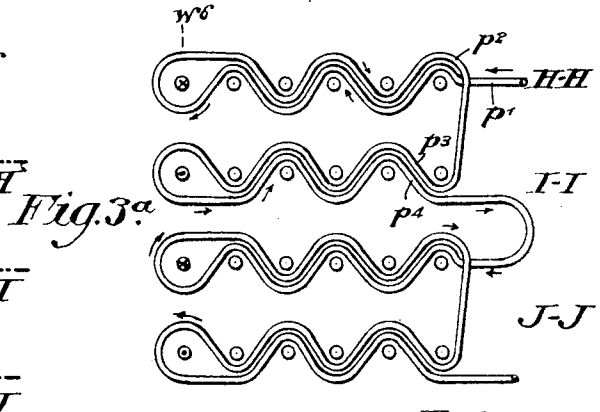


Fig. 3a.

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WOVEN RESISTOR

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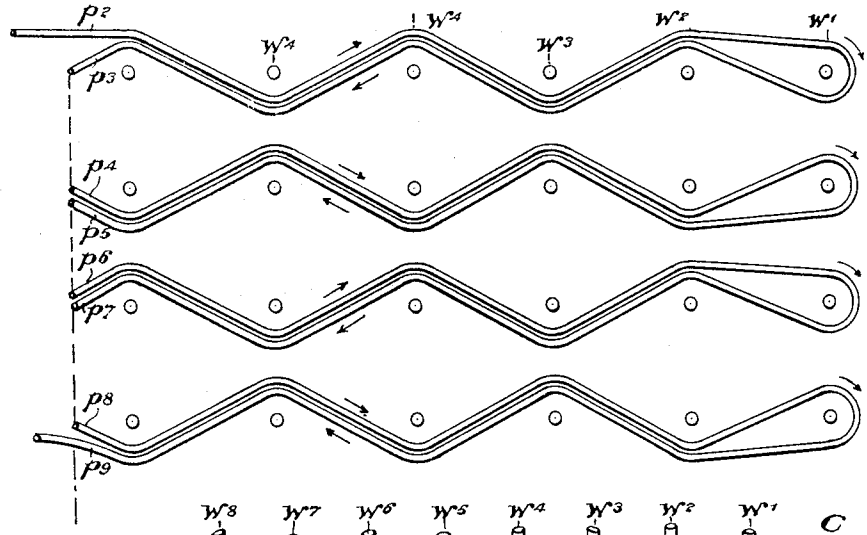


Fig. 2b

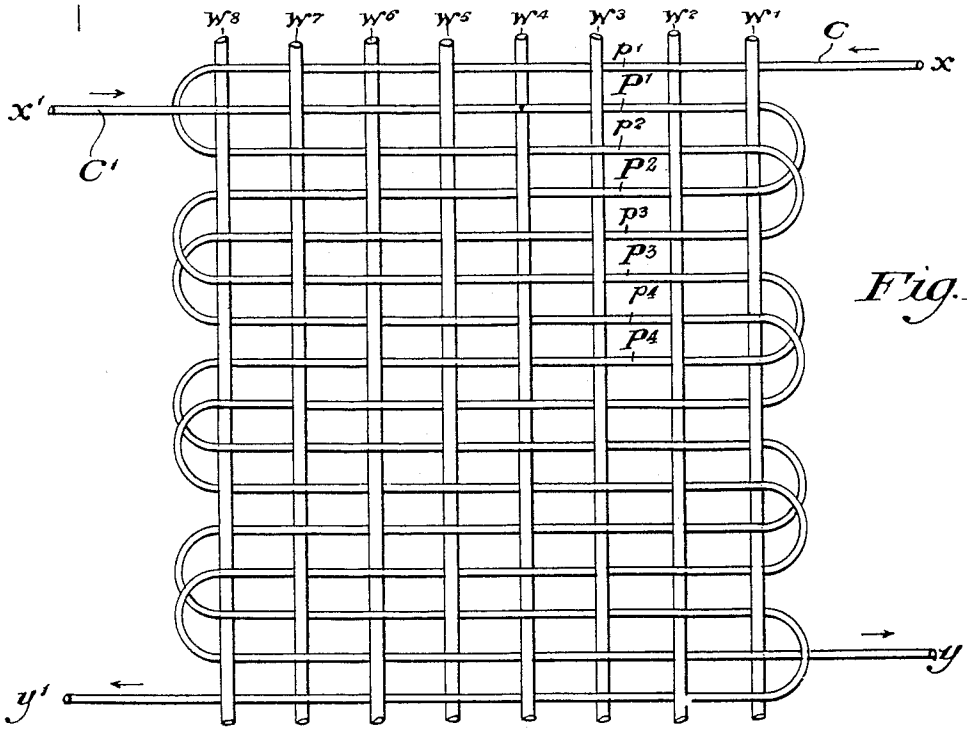


Fig. 10.

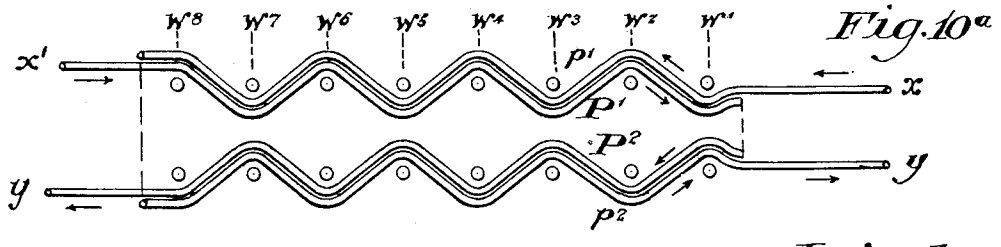


Fig. 10a

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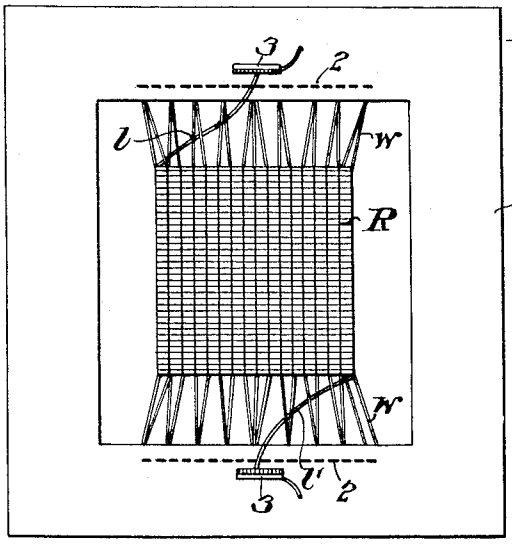
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WOVEN RESISTOR

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Fig.4.



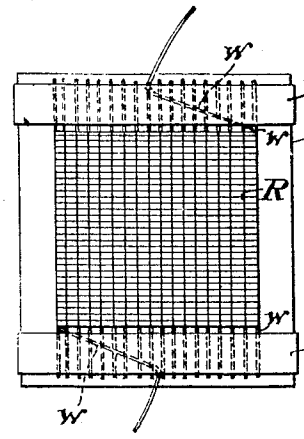


Fig.7.

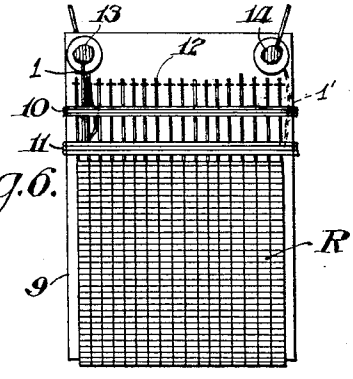


Fig.6.

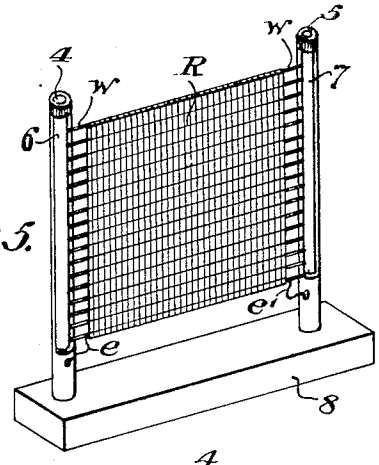


Fig.5.

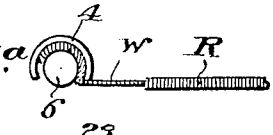


Fig.5a

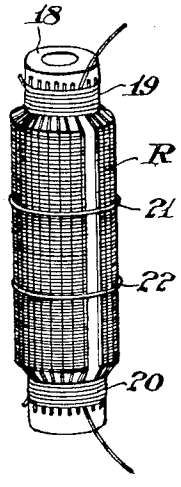


Fig.8.

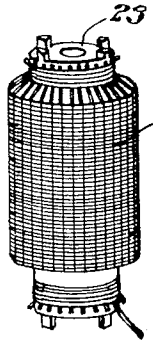


Fig.9.

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UNITED STATES PATENT OFFICE

1,972,499

WOVEN RESISTOR

Raymond E. Tarpley, Philadelphia, Pa., assignor to Leeds & Northrup Company, Philadelphia, Pa., a corporation of Pennsylvania

Application January 14, 1932, Serial No. 586,518

11 Claims. (Cl. 201—63)

My invention relates to resistors, or resistance units having low or negligible inductance and capacity to ensure that their time constant is low throughout a wide range of frequencies, and to permit their use in both direct current and alternating current measuring systems.

In accordance with my invention, resistance conductor is woven on a suitable warp to reduce the capacitative effects to negligible magnitude, the picks of conductor lying in the warp so that their inductive effects annul one another.

More specifically, the conductor is woven in such manner that the warp elements form the cores of non-inductive solenoids, or otherwise expressed, the loops formed by adjacent picks passing on opposite sides of a warp element are individually inductive but cumulatively non-inductive.

More particularly, in some forms of my invention, adjacent picks form a bifilar winding extending across the warp and encircling the warp element at a selvedge edge, and in one modification, these loops are cumulatively non-inductive, so that all of the warp elements form the cores of non-inductive solenoids.

My invention also resides in resistors having the features of construction and arrangement hereinafter described and claimed. For an understanding of my invention and for an illustration of several of the forms it may take, reference is to be had to the accompanying drawings in which:

Fig. 1 illustrates the weaving pattern of a previously known type of woven resistor.

Fig. 1*a* is an explanatory sketch referred to in description of Fig. 1.

Figs. 2 and 3 illustrate the weaving pattern of two forms of improved woven resistors; while Figs. 2*a*, 2*b*, and 3*a* are explanatory figures.

Figs. 4 to 9 inclusive illustrate various mountings for woven resistors.

Fig. 10 illustrates the weaving pattern of still a further modified form of an improved woven resistor, and Fig. 10*a* is an explanatory figure.

Resistors for use with alternating current, or both direct and alternating currents, in addition to the requirements of resistors satisfactory for direct current measurements, should have the characteristic that their effective resistance is independent of frequency, and their reactance negligible at least for a substantial frequency range.

Referring to Fig. 1, the resistance conductor or wire C is woven on a warp comprising the warp elements *w*1, *w*2, etc. of suitable material, as silk threads. For clarity of illustration, the picks *p*1, *p*2 are widely separated, and for like reasons the separation of the warp elements, the diameters of the conductors C and warp elements, is exaggerated. The weave is the ordinary or normal weave in which the conductor C passes alternately over and under the warp elements.

As shown most clearly in Fig. 1*a*, with this type of weave, each pair of picks forms an inductive loop about each of the wire elements, and these loops are cumulative, so that each warp element or thread forms the core of an inductive solenoid. Specifically, and referring to Fig. 1*a*, picks *p*1 and *p*2 in effect, and as indicated by the arrows, form loops about the warp threads, so that they are alternately of opposite polarity. Similarly, picks *p*3 and *p*4 form a series of inductive loops about the warp elements which are alternately of opposite polarity. As indicated in the figures the loop formed about warp element 1 by the picks *p*1, *p*2 is of the same polarity as the loop formed around the same warp element by picks *p*3, *p*4. Similarly, every subsequent pair of picks also forms a loop whose inductive effect is cumulative with the inductive effects of the other loops along the same warp element. The loops formed by the picks around each of the remainder of the warp elements are cumulative in their inductive effects.

Resistors so woven exhibit substantial inductance, so that the time constant of such a resistor is of substantial magnitude and for resistors of the same value of resistance and supposedly similar, the time constant varied widely. It was necessary to measure the time constants of the resistors and select those best suited for alternating current uses, and even they introduced large errors in phase angle measurements at higher frequencies, for example 10,000 cycles and upwards.

In accordance with my invention, the time constant of a woven resistor can be made so low that the error introduced for widely different frequencies, is negligible and for resistors of the same resistance and type, the time constant is substantially the same and does not vary widely as with supposedly similar resistors as heretofore made.

Referring to Fig. 2 which illustrates one of the modified forms of weave, it is to be noted that the conductor C in the first pick passes under both the warp elements *w*1 and *w*2. The remainder of the pick is the normal weave, and normal weave is continued until the warp elements *w*1 and *w*2 are again reached, whereupon the conductor now passes over both of these elements. The next pair of picks *p*3 and *p*4 are woven in the normal

manner, but the next pair of picks $p5$, $p6$, are similar to the first pair of picks $p1$, $p2$, that is, in the first pick of the pair, the conductor passes under two adjacent warp elements $w1$, $w2$, and in the next pick the conductor passes over the same two elements. The next pair of picks is of normal weave, the same as picks $p3$ and $p4$. The pattern is repeated with alternate pairs of picks of normal weave and every other pair of picks of the modified weave.

The effect upon the inductance of the woven resistor is apparent from Fig. 2*a* and by comparison with Fig. 1*a*. Taking the warp element $w6$, for example, it is to be noted that the inductive loops formed by the picks are alternately of different polarity so that their inductive effects annul each other, the warp element forming in effect a non-inductive solenoid. Similarly, the warp elements $w5$, $w4$, etc., form the cores of non-inductive solenoids. With this mode of weaving, however, the inductive loops about the warp element $w1$, at one of the selvedge edges, are cumulative so that warp element 1 forms the core of an inductive solenoid. However, this mode of weaving is substantial improvement over that in Fig. 1, as all of the inductive solenoids can be eliminated except one, irrespective of the number of warp elements.

With this type of woven resistor, the inductance is so low as to permit of its use in precision circuits such as used in measuring, through a substantial range of frequencies, without introducing any serious error. It has also been noted in manufacture, in resistors of this type, that the residual inductance of the resistors would be practically identical, whereas the inductance of the previously known type of woven resistor, such as exemplified in Fig. 1, would vary widely, for example, of two resistors having the same resistance and woven in accordance with Fig. 1, one would have three or four times the inductance of the other.

Referring to Fig. 2, it is pointed out that except at the selvedge edge about the warp element $w1$, the picks $p2$, $p3$ lie side by side in the warp, that is, both pass over warp element $w2$, under warp element $w3$, over warp element $w4$, etc. As the current flows through these adjacent picks in opposite directions, the picks in effect form a short, bifilar winding. Similarly, the next pair of picks $p4$, $p5$ lie side by side through the warp, both passing over $w5$, under $w4$, over $w3$, etc., to form another short bifilar section. This is shown most clearly in Fig. 2*b*. As the sections are bifilar, the inductive effect of the picks forming each section annul one another. At the end of each bifilar section, adjacent the right hand selvedge edge, there is formed an inductive loop about the warp element $w1$, and the inductive effects of these loops are cumulative.

The form of winding shown in Fig. 3 is an improvement upon that of Fig. 2 in that all of the warp elements, including the warp elements at both selvedge edges, form the cores of non-inductive solenoids.

Each pair of picks forms a bifilar winding, as in Fig. 2, but in addition the inductive loops formed at one selvedge edge annul one another. Specifically, the pick $p1$ is woven in the normal manner. In pick $p2$, however, the conductor passes over both warp elements $w6$ and $w5$, the remainder of the pick being woven in the normal manner. The normal weave is continued for the remainder of pick $p2$ and all of pick $p3$. In pick $p4$, however, the conductor passes under both warp elements $w6$, $w5$. This sequence is repeated through the weaving. As shown most clearly in Fig. 3*a*, picks $p1$ and $p2$ form a bifilar winding lying side by side through the warp, except at the left-hand end where they loop about the warp element $w6$. Similarly, the picks $p3$ and $p4$ form a bifilar section, lying side by side in the warp except at the left-hand selvedge edge, where they loop about the warp element $w6$. However, the loops formed by these adjacent pairs of picks, are in opposition, the inductive effect of one cancelling or annulling the inductive effect of the other. Similarly, throughout the pattern, each pair of picks forms a bifilar section, and the inductive loops at corresponding ends of adjacent pairs of bifilar sections are in opposition. In view of the foregoing explanation it is apparent that with this type of weave, all of the warp elements are the cores of non-inductive solenoids, and that the residual reactance of a resistor so woven is negligibly small.

In all of the described forms of woven resistors, the distributed capacity is low, because of the fact that there is very small difference of potential about the adjacent picks. As distinguished from a previously known type of resistor in which the distributed capacity is balanced against the distributed inductance, so that the resistance has insubstantial reactance for a given frequency, in accordance with my invention I independently reduce the inductance and capacity with the result that the reactance is low, for a substantial range of frequencies.

In Fig. 4, there is shown one method of mounting a woven resistor. The warp threads W, support the resistance unit R in the window or opening of a frame formed for example by a card 1 of suitable material as fibre, bakelite, or the like. Specifically, the ends of the warp threads are caught by threads 2 looped or stitched through holes in the card or frame 1. The terminal leads 1, 1′ of the unit may be secured in any suitable manner to the terminal card, for example, the ends of the leads may be soldered to a loop of substantially heavier conductor 3. With this method of mounting both sides of the resistance are exposed to the air, offering a substantial surface for radiation of heat, so that the effective resistance is not appreciably affected by the current flowing through it.

Another method of mounting in which both sides of the resistance webbing T is exposed, is shown in Fig. 5. The ends of the warp projecting beyond the resistance unit proper, are clamped against the hollow supporting members 4 and 5, by the bars 6 and 7, as most clearly shown in the detail plan view of Fig. 5*a*. If desired, and as indicated, the terminal leads 1, 1′ may be soldered or otherwise connected to the mounting columns 4 and 5 which are suitably fastened to a block of insulating material 8 to form a mounted resistor unit.

As shown in Fig. 6, the woven resistor may be bent around one end of a card 9 of suitable insulating material, with the warp elements, on opposite sides of the card, projecting towards the other end. The resistor is held against the card in any suitable manner, for example, by binding threads 10, 11, which are wrapped around the projecting warp elements. Alternatively, or in addition, the ends of the warp threads may be caught against the card by the thread 12 which is looped or stitched through the card. The leads 1 and 1′ are soldered or fastened to the eyelets 13, 14, forming a mounted resistor unit.

In Fig. 7, the resistance webbing R is entirely on one side of a card 15. The resistance is held in place by cloth tapes 16 and 17 which, respectively, bind the opposite ends of the warp threads against the card. If desired, and as shown in preceding figures, the warp threads may alternatively, or in addition, be held by threads stitched through the card.

In Fig. 8, the resistance R is mounted by wrapping it upon a frame or spool 18, which is preferably of some material having a low dielectric loss and substantially unaffected by changes in humidity, such as for example, isolantite. The webbing should be mounted so that the warp threads are parallel to the axis of the spool to avoid bringing into proximity, portions of the resistance which are of substantially different potential and to insure low capacity effect of the resistance. The leads as indicated are preferably brought out at opposite ends of the spool. Bringing the leads out at the same end increases the capacity slightly and should be avoided when possible. As indicated, the resistor may be held in place upon the spool by binding threads 19 and 20 which are wrapped around the warp threads projecting from opposite ends of the woven resistor. Particularly if the resistance is of substantial width, one or more additional binding threads 21, 22 may be wrapped around the mounted resistor intermediate its edges.

In Fig. 9, the resistance R is also wrapped upon a frame, as a spool 23, but in this case the resistance is wrapped upon itself in a spiral. As in Fig. 8, the webbing is mounted with the warp threads parallel to the axis of the spool. This method of mounting is particularly advantageous for high resistances since the capacities to ground can be decreased considerably by so rolling the webbing, without appreciably increasing the capacity effect within the resistor. For example, the time constant of a 20,000 ohm woven resistor, mounted upon a 1.5 inch bakelite spool, in a single layer, as in Fig. 8, was 3.4×10^{-8} seconds, while the time constant of a similar resistor rolled on a $\frac{3}{8}$ inch frame, was 1.4×10^{-8} seconds.

With resistors woven in accordance with my invention and ranging from 20 to 20,000 ohms, the variation of resistance with a frequency range of from zero to about 50,000 cycles, is not greater than the precision of measurement. For example, the resistance error in 10,000 ohm woven units is less than .01% for frequencies from zero to at least 50,000 cycles; for resistances under 10,000 ohms the error is less, until at 1000 ohms it does not exceed .001%. For all values of resistances up to 10,000 ohms, the error at 1000 cycles is less than .001%.

The pattern of weave of Fig. 10, also results in a woven resistor of very low time constant, suited for high precision measurement. In this resistor, the style of weave has been termed "cross-shot", because it is formed by the simultaneous weaving of two similar conductors on the warp, that is, one shuttle moves across the warp in one direction and another shuttle moves across the warp in the opposite direction before the harness of the loom transposes the positions of the warp elements.

As shown clearly in Fig. 10, the first pick $p1$ of conductor C, and the first pick P1 of conductor C1, lie side by side, that is, both pass under the same alternate warp elements for example 1, 3, 5, etc., and pass over every other warp element, as 2, 4, 6, etc. Specifically, both picks pass under the warp element $w1$ at one selvedge edge, and side by side pass alternately over and under elements $w2$ to $w7$, both finally passing over warp element $w8$ at the other selvedge edge. Similarly, the next pair of picks, $p2$ of conductor C, and pick P2 of conductor C1, lie side by side in the warp. Both pass over warp element $w1$, and alternately under and over elements $w2$ to $w8$, all as clearly indicated in Fig. 10, in which the size and spacing has been exaggerated to clearly show the relation of the picks to each other and to the warp elements.

In the completed resistor, the ends x, $x1$ of the different conductors are connected together, and the ends y, $y1$ are likewise connected together. The effect of winding the resistor from two conductors as described and connecting them in this manner is readily apparent from Fig. 10a. In each pair of picks $p1$, P1; $p2$, P2; $p3$, P3; etc., the current in one pick is flowing in one direction, while simultaneously current of the same value is flowing in opposite direction through the other pick of the pair, so that in effect each pair of picks form a bifilar winding. The resistor is therefore non-inductive, the individual warp elements forming the cores of non-inductive solenoids.

From another aspect, it can be considered that the picks $p1$, $p2$, etc., of conductor C form inductive loops which are cumulative in their effect in causing the warp elements to be the cores of inductive solenoids, but the picks P1, P2, etc., of the conductor C1 also form inductive loops whose effects are cumulative but in opposition to the inductive effects of those of conductor C, with the result that the inductive effects of the individual windings annul each other.

The resistance webbing of Fig. 10 may be mounted in any desired manner, for example, in any of the various ways shown in Figs. 4 to 9.

It is also characteristic of this type weave that the variation in time constant is even materially less than the previously described modifications. An advantage of the weave shown in Fig. 10 is that it facilitates production of woven resistors of much lower value than can be conveniently made with the styles of weaving shown in Figs. 2 to 3, which are more suited to the higher values of resistances. As it is difficult to weave resistors from wire larger than #35, the weaves of Figs. 2 and 3, are not as well suited for the lower resistance values as the weave of Fig. 10 since the high resistance per unit length of fine wire makes it difficult accurately to adjust low values of resistance, and further the amount of wire used is so small that it is difficult to obtain sufficient radiating area for dissipation of heat. These difficulties are overcome in the "cross-shot" weave since fine wire, facilitating weaving, can be used and the lower values obtained by connecting the two conductors electrically in parallel.

Aside from the fact that the "cross-shot" weave is better suited for the lower values of resistance, it has the further advantage that the inductance of a "cross-shot" woven resistor, having a certain resistance and certain total cross-sectional area for the two parallel wires, is appreciably less than that of a unit of the same resistance and cross-section produced by the methods of weaving of Figs. 2 or 3. The "cross-shot" woven resistor is specifically claimed in copending application of Tarpley and Behr, Serial No. 590,334, filed February 2, 1934.

While I have illustrated several preferred and specific forms of my invention, it is to be understood that my invention is not limited thereto

but is comprehensive in scope with the appended claims.

What I claim is:

1. A woven resistor comprising a warp of insulating material and in which adjacent picks of resistance conductor woven back and forth across the warp for carrying current in opposite directions lie side by side through the warp.

2. A woven resistor comprising a warp of insulating material and in which the picks of resistance conductor woven back and forth across the warp are disposed in pairs, with the picks of each pair disposed side by side across the warp, and with the picks of adjacent pairs crossing on opposite sides of elements of the warp.

3. A woven resistor comprising a warp of insulating material and in which each pair of picks of resistance conductor woven back and forth across the warp forms a bifilar section extending across the warp.

4. A woven resistor comprising a warp of insulating material and in which each pair of picks of resistance conductor woven back and forth across the warp forms a bifilar section extending across the warp and encircling a warp element at the selvedge edge.

5. A woven resistor comprising a warp of insulating material and in which each pair of picks of resistance conductor forms a bifilar section extending across the warp and having a loop about a warp element at a selvedge edge, the alternate loops encircling said warp element in one direction and every other loop encircling said warp element in the reverse direction.

6. A resistor comprising a woven unit of resistance conductor and in which warp elements of insulating material constitute the cores of non-inductive solenoids formed by the weaving of the conductor, and a form on which said unit is wrapped, without folding, with the warp elements substantially parallel to the axis of the form to ensure that the capacitative reactance shall be low.

7. A resistor comprising a woven unit of resistance conductor and in which warp elements of insulating material constitute the cores of non-inductive solenoids, and a form on which said unit is wrapped, without folding, in several layers with the warp elements substantially parallel to the axis of the form to reduce the time-constant of the resistor.

8. A woven resistor comprising a warp on which are woven picks of continuous resistance conductor, the relation of adjacent picks to each other and to the warp being such that the inductive effects produced by looping of picks of conductor over and under warp elements are opposed by inductive effects produced by looping of other picks over and under warp elements so that they constitute the cores of non-inductive solenoids.

9. A woven resistor comprising a warp on which are woven picks of continuous resistance conductor, the relation of adjacent picks to each other and to the warp being such that the inductive effects produced by looping of picks of conductor over and under warp elements are opposed by inductive effects produced by looping of other picks over and under warp elements so that all warp elements constitute the cores of non-inductive solenoids.

10. A woven resistor comprising a warp of insulating material on which is woven a single continuous resistance conductor, all picks of said conductor having such relation to each other and the warp that elements of the warp constitute the cores of non-inductive solenoids.

11. A woven resistor comprising a warp of insulating material on which is woven a single continuous resistance conductor, all picks of said conductor having such relation to each other and the warp that all elements of the warp constitute the cores of non-inductive solenoids.

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