

May 7, 1940.

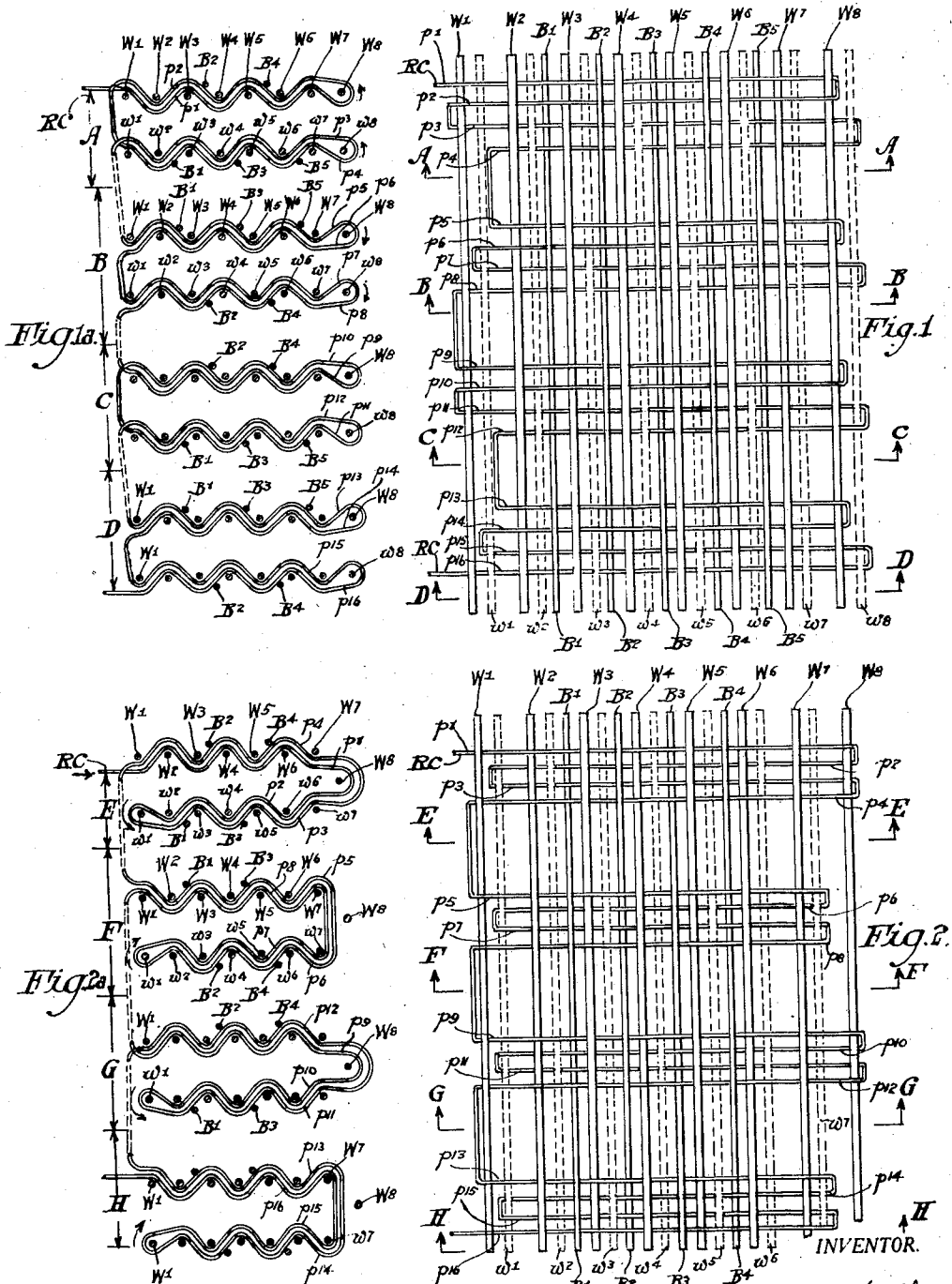
R. E. TARPLEY

2,199,810

WOVEN RESISTOR

Filed Oct. 23, 1936

4 Sheets-Sheet 1



BY

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May 7, 1940.

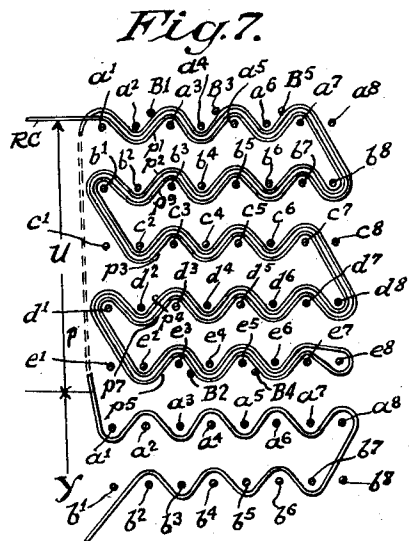
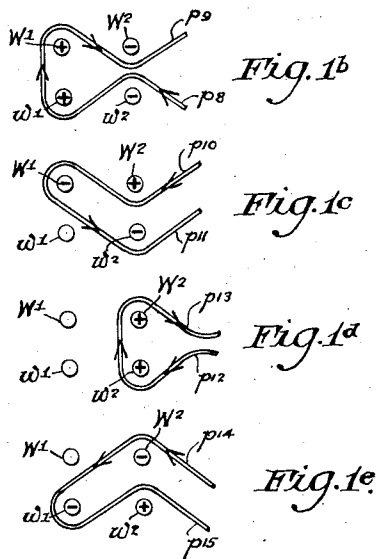
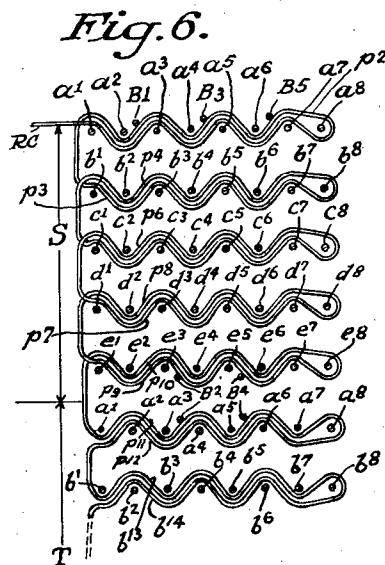
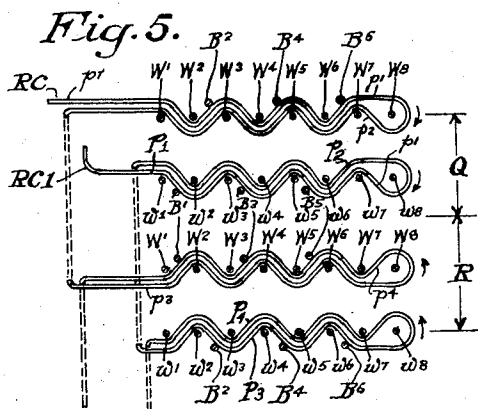
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WOVEN RESISTOR

Filed Oct. 23, 1936

4 Sheets-Sheet 2



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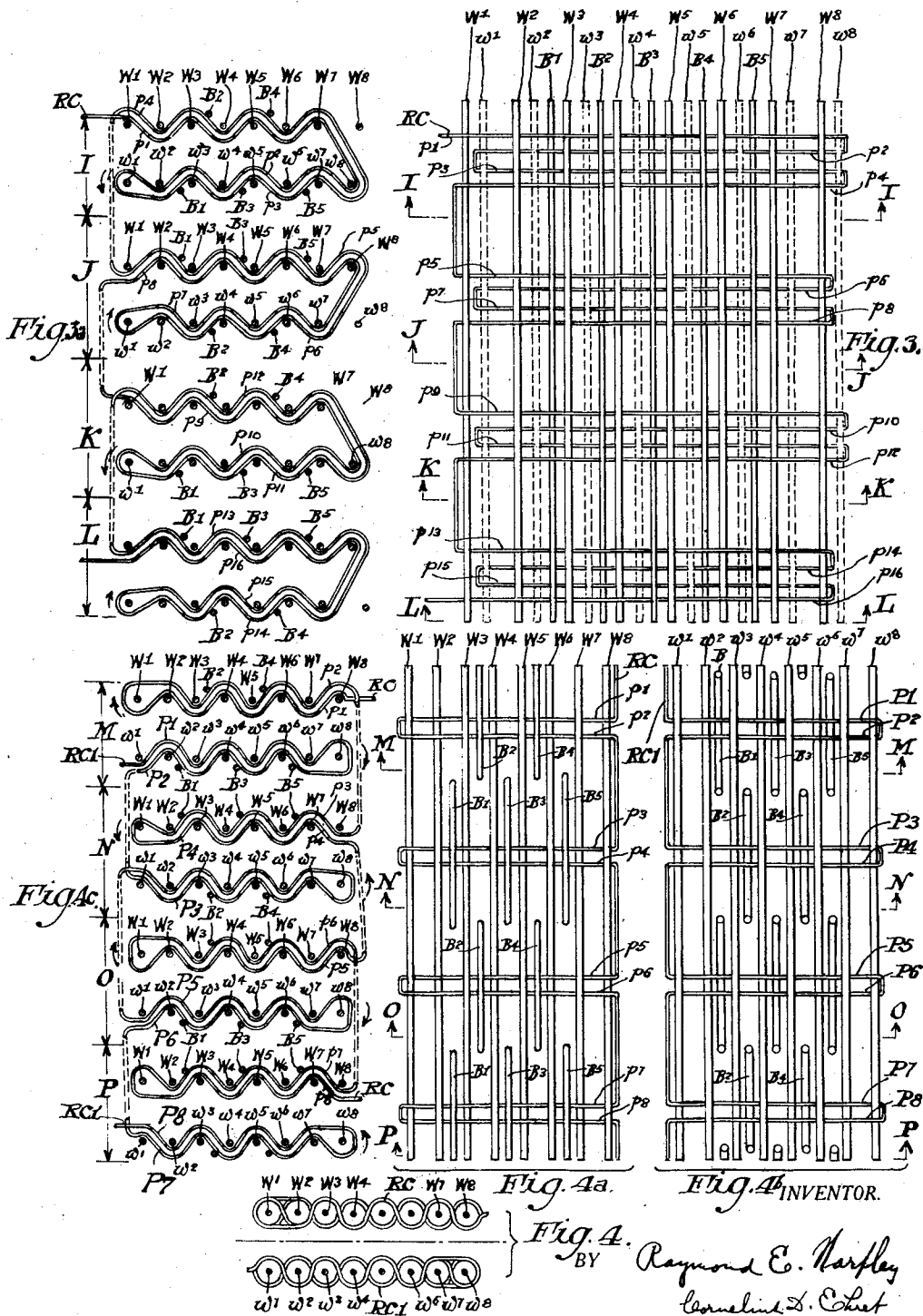
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WOVEN RESISTOR

Filed Oct. 23, 1936

4 Sheets-Sheet 3



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2,199,810

WOVEN RESISTOR

Filed Oct. 23, 1936

4 Sheets-Sheet 4

Fig. 8.

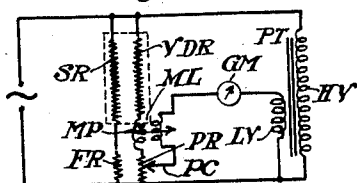


Fig.10.

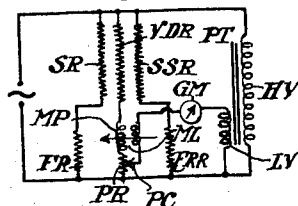


Fig. 9.

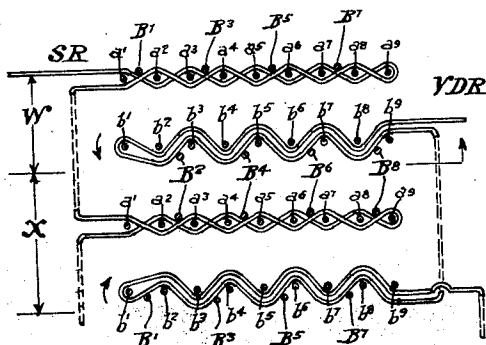


Fig. 11.

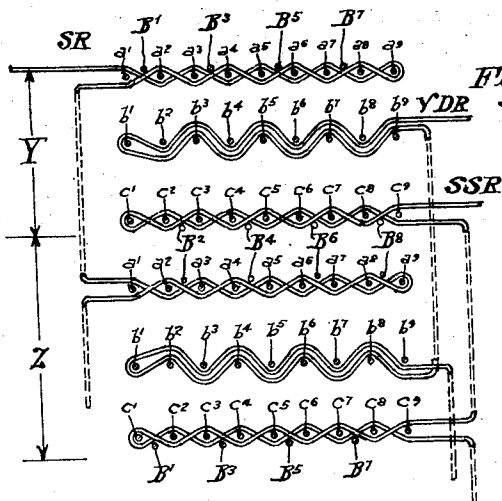


Fig. 12.

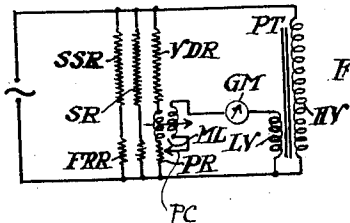
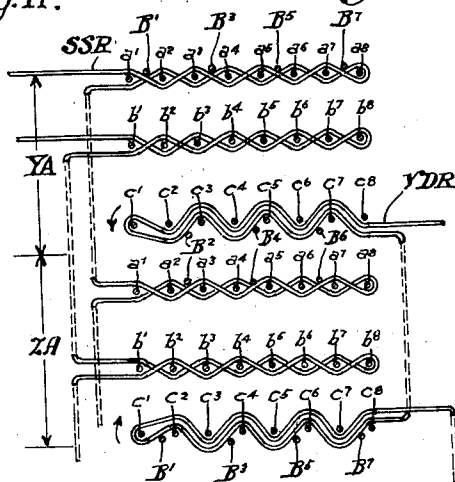


Fig. 13.



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UNITED STATES PATENT OFFICE

2,199,810

WOVEN RESISTOR

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Application October 23, 1936, Serial No. 107,139

20 Claims. (Cl. 201—63)

My invention relates to resistors or resistance units particularly suited for use in attenuators, in high fidelity amplifying systems, in circuits or networks involving high precision measurements especially at high frequencies, including high radio frequencies, and in general for uses in which the phase angles of resistors must be negligible.

In accordance with my invention, the resistance conductor is woven to form a multi-ply or multi-layer web; in the cross-section of some modifications, the woven conductor appears as a plurality of serially-connected bifilar loops, one for each layer of the web; in the cross-section of other modifications, the woven conductor appears as a single, folded bifilar loop, the number of folds depending upon a number of layers of the web; in the cross-section of another modification woven with two conductors, the conductors appear as bifilar loops in different layers or plies; in other modifications woven with two or more conductors, at least one of the conductors is woven into one of the layers of webbing to form bifilar loops, and the other conductor or conductors may be woven in the other layer or layers of the webbing in the simple manner common in textiles.

My invention further resides in features of construction, combination, and arrangement herein-after described and claimed.

For an understanding of my invention, reference is to be had to the accompanying drawings in which:

Fig. 1 illustrates the weaving pattern of one modification;

Fig. 1a is a connected series of cross-sections taken on lines A—A, B—B, C—C, and D—D of Fig. 1;

Figs. 1b-1e are explanatory figures referred to in description of Figs. 1 and 1a;

Fig. 2 illustrates the weaving pattern of a second modification;

Fig. 2a is a connected series of cross-sections taken on lines E—E, F—F, G—G and H—H of Fig. 2;

Fig. 3 illustrates the weaving pattern of a third modification;

Fig. 3a is a connected series of cross-sections taken on lines I—I, J—J, K—K and L—L of Fig. 3;

Fig. 4 is an end view of a fourth modification of the invention;

Fig. 4a is a top plan view of the top layer of Fig. 4 showing the weaving pattern thereof;

Fig. 4b is a top plan view of the lower layer of Fig. 4 showing the weaving pattern thereof;

Fig. 4c is a connected series of cross-sections

taken on lines M—M, N—N, O—O, and P—P of Figs. 4a and 4b;

Fig. 5 is a connected series of cross-sections of a modification of Fig. 4;

Fig. 6 is similar to Fig. 1 except the web has a greater number of plies;

Fig. 7 is similar to Fig. 3a except the web has a greater number of plies;

Fig. 8 illustrates an arrangement for measuring the voltage ratio of a potential transformer;

Fig. 9 is a connected series of cross-sections of resistance webbing used in the system of Fig. 8;

Fig. 10 is a modification of Fig. 8;

Fig. 11 is a connected series of cross-sections of resistance webbing used in the systems of Fig. 10;

Fig. 12 is another modification of Fig. 8;

Fig. 13 is a connected series of cross-sections of resistance webbing used in the system of Fig. 12.

The resistors used in measuring circuits or apparatus such as voltage dividers, bridges, attenuators, or the like, are usually calibrated with direct current or current of a particular frequency; for current measurements at other, and often widely different frequencies, it is essential that the resistors have negligible inductance and capacity, otherwise the variation in phase angle of the resistors introduces error whose magnitude is different for different frequencies and for different settings of the apparatus.

In resistance-coupled amplifiers, it is highly desirable the coupling resistors have negligible inductance and capacity, otherwise the amplifier is subject to frequency discrimination which in audio-frequency amplifiers affects the quality of the reproduced sound.

As will hereinafter appear, resistors constructed in accordance with my invention exhibit substantially pure and constant resistance even at high radio frequencies, for example, of the order of four megacycles per second and higher.

Referring to Figs. 1 and 1a, the resistance conductor RC is woven on two warps of suitable material as silk threads; the upper warp comprises the warp threads or elements W1, W2, W3, etc. and the lower warp comprises the warp threads or elements w1, w2, w3, etc.

The actual number of warp elements is, of course, substantially greater than shown in Figs. 1 and 1a illustrative of the weaving pattern; for clarity, the size of the warp threads and of the conductor is exaggerated; for like reason, the spacing between the elements of the warp and between the picks of conductor is also exaggerated.

The upper warp comprises the threads W1, W2, 55

W3, etc. and the lower warp comprises the threads $w1, w2, w3$, etc. For purpose of explanation, it is assumed the weaving begins at the upper left of Figs. 1 and 1a. To avoid lengthy description, the relations between the warp elements and picks of conductor are tabulated below in Table #1. It is assumed for simplicity the number of threads in both warps are even, i. e. " n " of Table #1 is an even number. The letters "o" and "u" are used as abbreviation for "over" and "under" respectively. With this preliminary discussion, Table #1 is self-explanatory of the manner in which the shuttle lays the conductor in the warps.

Table #1

Section	Pick	Movement of shuttle	Warp threads n =even number								Layer
			1	2	3	4	5	6	$n-1$	n	
A	p1	To right	o	u	o	u	o	u	o	u	Upper.
	p2	To left	o	u	o	u	o	u	o	u	Do.
	p3	To right	o	u	o	u	o	u	o	u	Lower.
	p4	To left	---	u	o	u	o	u	o	u	Do.
B	p5	To right	---	o	u	o	u	o	u	o	Upper.
	p6	To left	u	o	u	o	u	o	u	o	Do.
	p7	To right	u	o	u	o	u	o	u	o	Lower.
	p8	To left	u	o	u	o	u	o	u	o	Do.

It is to be understood the positions of the elements of each warp are transposed at the conclusion of the weaving of one section and before weaving of the next section is begun and that the weaving pattern of the subsequent sections corresponds alternately to section A and section B; for example, section C is woven in the same manner as section A and section D is woven exactly the same as section B.

As appears from Figs. 1, 1a and Table #1, the picks of each pair $p1, p2; p3, p4; p5, p6; p7, p8$, lie side by side through the upper and lower warps, except at the edges of webbing, forming bifilar loops in a vertical section of the webbing. Each section is therefore free of any inductive loops about the warp elements except at the edges of the webbing; however, the inductive effects of the end loops of adjacent sections mutually cancel; for example, in section A (Fig. 1) the conductor passes around the end warp element $w8$ of the upper warp in counterclockwise direction, whereas, in section B the conductor passes around the same warp element in clockwise direction; in section A, the conductor passes around the end warp element $w8$ in counterclockwise direction, whereas, in section B the conductor passes around warp element $w8$ in the reverse, or clockwise direction.

The manner in which the inductive effects at the left edge of the webbing are caused mutually to cancel is apparent from Figs. 1b-1e which show four successive loops of conductor at that edge of the web at the transition points between picks $p8$ and $p9, p9$ and $p10, p10$ and $p11$, etc. The inductive effect of the loop of Fig. 1b about the warp elements $w1, w1$, is cancelled by the inductive effect of the loop of Fig. 1c about warp element $w1$ and the inductive effect of the loop of Fig. 1e about warp element $w1$. The inductive effect of the loop of Fig. 1d about warp elements $w2, w2$ is cancelled by the effect of the loop of Fig. 1b upon those same elements. Otherwise stated, the summation of the inductive effects of these loops upon each of the warp elements $w1, w2, w1, w2$ is zero.

The two layers or plies of the woven resistor are held together by the binder warp comprising

the warp elements $B1, B2, B3$, etc. As appears from Figs. 1 and 1a, the positions of the odd-numbered and even-numbered binder threads are transposed after weaving of each section A, B, C, etc. Specifically, as shown in Fig. 1, the odd-numbered binder warp elements $B1, B3, B5$, etc. are, in section A, under the bottom layer of the web, and pass in section B, over the top layer of the web; the even-numbered binder threads $B2, B4, B6$, etc. pass over the top layer of section A and beneath the bottom layer of section B of the web.

The inductance of the web resistor is negligible for reasons discussed above; the capacity effect of the resistor is negligible because there is, in use, only a small difference of potential between any of the immediately adjacent picks of conductor.

The physical size of the completed resistor will, of course, depend upon the desired magnitude of its resistance, the cross-sectional area of the resistance conductor, and the resistivity of the conductor material. To facilitate weaving, the conductor should be flexible but strong; for example, Manganin or Nichrome wire of from .004 to .001" diameter is suitable. The conductor need not be round wire; it may be ribbonlike wire, for example, up to about .004" thick and up to about .020" wide.

For high precision resistors having low temperature co-efficient of resistance, the conductor may be manganin, constantan, or the like; to procure compact resistors of high magnitude of resistance, for example upwards of 100,000 ohms, Nichrome wire may be used. As exemplary of the compactness of the woven resistors of my invention, a 300,000 ohm resistor webbing woven with Nichrome wire of .001 diameter is about 1.1 inches long and 2.35 inches wide; moreover, the web may be folded or rolled lengthwise, further to reduce its space requirements, without appreciably increasing the capacity or inductance.

Preferably, enamel-coated conductor is used because enamel insulation is thinner than silk or cotton and therefore permits the picks of conductor to be packed more closely together in the warp; moreover, a resistor of enamel-coated wire is less subject to variation from its nominal value with time and humidity than resistors using the usual silk or cotton insulation.

When the number of elements in each of the warps is an odd number, rather than an even number as in Fig. 1 and Table #1, a slight variation of the weaving pattern results, as shown by Table #2 infra, in which, as in Table #1, the letters "o" and "u" are used as abbreviations of "over" and "under."

Table #2

Section	Pick	Move- ment of shuttle	Warp threads n =odd number							Layer
			1	2	3	4	5	$n-1$	n	
A	p_1	To right	o	u	o	u	o	u	o	Upper. Do. Lower. Do.
	p_2	To left	o	u	o	u	o	u	u	
	p_3	To right	o	u	o	u	o	u	u	
	p_4	To left	---	u	o	u	o	u	u	
B	p_5	To right	---	o	u	o	u	o	u	Upper. Do. Lower. Do.
	p_6	To left	u	o	u	o	u	o	u	
	p_7	To right	u	o	u	o	u	o	u	
	p_8	To left	u	o	u	o	o	o	o	

It is not essential that both the upper and lower warps have the same number of threads, or that

the number of threads in both warps be even or odd.

The modification shown in Figs. 2 and 2a utilizes a weaving pattern resulting in a two-layer web in which each section of the resistor consists of a single bifilar loop which is folded.

For brevity of explanation, the relations between the warp elements and picks of conductor are tabulated in Table #3 below; the table is based upon the assumption the weaving is begun at the upper left of the Figures 2 and 2a.

Table #3

Section	Pick	Movement of shuttle	Warp threads n =even number								Layer
			1	2	3	4	5	6	$n-1$	n	
E	p1	To right	u	o	u	o	u	o	u	o	Upper.
	p2	To left	o	u	o	u	o	u	o	u	Lower.
	p3	To right	u	o	u	o	u	o	u	o	Do.
	p4	To left	o	u	o	u	o	u	o	u	Upper.
F	p5	To right	o	u	o	u	o	u	o	u	Do.
	p6	To left	u	o	u	o	u	o	u	o	Lower.
	p7	To right	o	u	o	u	o	u	o	u	Do.
	p8	To left	u	o	u	o	u	o	u	o	Upper.

The subsequent sections are alternately similar to section E and section F, respectively. It is to be understood the positions of the odd and even numbered elements of each warp are transposed at the conclusion of the weaving of one section and before weaving of the next section is begun. Warp element W8, which may be considered as an end element of either warp, is looped by the conductor of alternate sections only.

From Fig. 2a it clearly appears that each section of the woven resistor consists of a folded bifilar loop, one part, or fold, appearing in the upper layer of the web and another part, or fold, appearing in the lower ply of the web. The completed resistor is non-inductive because (a) the current flows in opposite directions in each pair of picks in the upper and in the lower warps; (b) the current in adjacent loops of conductor about lower warp element w1 flows in opposite directions, and (c) the current in adjacent loops of conductor about upper warp element W1 flows in opposite directions.

The plies or layers of the resistance webbing are held together by the binder warp comprising threads B1, B2, B3, etc. As shown in Fig. 2, the odd-numbered binder threads B1, B3, etc. pass under the bottom ply of sections E, G, etc. and over the top layer of the intermediate sections F, H, etc.; the even-numbered binder elements B2, B4, B6, etc. pass over the top layer of the sections E, G, etc. and under the bottom layer of sections F, H, etc.

This weaving pattern also affords a resistor having inappreciable inductance and capacity effects even at high radio frequencies. The resulting woven resistor is compact and may be folded or rolled lengthwise without appreciably increasing its inductance or capacity.

In Figs. 3 and 3a, there is illustrated another pattern for weaving a multi-ply resistance webbing in which the conductor forms a folded bifilar loop in each section.

Again for brevity, the manner in which the picks of conductor are laid by the shuttle is given in tabular form (Table #4); it is assumed the weaving is begun at the upper left of the Figures 3 and 3a and that there is an even number of threads in each of the warps.

Table #4

Section	Pick	Movement of shuttle	Warp threads n =even number								Layer
			1	2	3	4	5	6	$n-1$	n	
I	p1	To right	o	u	o	u	o	u	o	u	Upper.
	p2	To left	u	o	u	o	u	o	u	o	Lower.
	p3	To right	u	o	u	o	u	o	u	o	Do.
	p4	To left	o	u	o	u	o	u	o	u	Upper.
J	p5	To right	u	o	u	o	u	o	u	o	Do.
	p6	To left	u	o	u	o	u	o	u	o	Lower.
	p7	To right	o	u	o	u	o	u	o	u	Do.
	p8	To left	u	o	u	o	u	o	u	o	Upper.

It is to be understood the subsequent sections are alternately similar to sections I and J and that the positions of the odd and even numbered elements of each warp are transposed at the conclusion of the weaving of each section. The plies are held together by the binder warp comprising threads B1, B2, B3, etc.

Each section of the resistor is a bifilar loop and therefore non-inductive; considering the successive sections, conductor RC passes about the end warp element w1 alternately in opposite directions and therefore the net magnetic field about that element is zero. Similarly, the magnetic field along the end warp element W1 is zero because, as appears from Fig. 3, the conductor RC passes about warp element W1 alternately in opposite directions. The capacity effects are inappreciable because there is insubstantial difference of potential between adjacent picks of conductor in the resistor. The resistor webbing may be folded or rolled lengthwise without appreciably increasing the inductance or capacity effects.

When the number of threads in the warps is an odd number, instead of an even number, assumed in Table #4, a slight variation of the weaving pattern results as indicated by Table #5 infra.

Table #5

Section	Pick	Movement of shuttle	Warp threads n =odd number							Layer
			1	2	3	4	5	$n-1$	n	
I	p_1	To right	o	u	o	u	o	u	o	Upper.
	p_2	To left	u	o	u	o	u	o	u	Lower.
	p_3	To right	u	o	u	o	u	o	u	Do.
	p_4	To left	o	u	o	u	o	u	o	Upper.
J	p_5	To right	u	o	u	o	u	o	u	Do.
	p_6	To left	u	o	u	o	u	o	u	Lower.
	p_7	To right	o	u	o	u	o	u	o	Do.
	p_8	To left	u	o	u	o	u	o	u	Upper.

It is not feasible to weave resistors of low and exact magnitude by the foregoing methods, since it would be necessary either to use wire of cross-section unsuitably large for weaving or to adjust the length of the wire more closely than is practicable. The pattern shown in Figs. 4a, 4b, 4c is particularly suited for weaving of lower-valued resistors, though not limited thereto.

This method involves weaving with two shuttles, one of which in weaving of a section forms a bifilar loop of a conductor RC in the upper layer of the webbing, and the other of which forms a bifilar loop of a second conductor RC1 in the lower layer. The picks of conductor RC are identified by the lower case letters and the picks of conductor RC1 are identified by upper case letters. In Figs. 4a, 4b and 4c, and in Table #6 infra, the weaving of conductor RC is assumed

to begin at the upper right of section M and the weaving of conductor RC1 at the lower left of the same section.

Table #6

Section	Pick	Move-ment of shuttle	Warp threads n =even number								Layer
			1	2	3	4	5	6	$n-1$	n	
M	p1	To left	u	o	u	o	u	o	u	o	Upper. Do.
	p2	To right	o	u	o	u	o	u	o	u	Lower. Do.
	P1	To right	u	o	u	o	u	o	u	o	
	P2	To left	o	u	o	u	o	u	o	u	
N	p3	To left	u	o	u	o	u	o	u	o	Upper. Do.
	p4	To right	o	u	o	u	o	u	o	u	Lower. Do.
	P3	To right	u	o	u	o	u	o	u	o	
	P4	To left	o	u	o	u	o	u	o	u	

It is to be understood the subsequent sections are alternately similar to sections M and N and that the positions of the odd and even numbered elements of each of the warps is transposed at the conclusion of the weaving of each section. The plies are held together and the loops of each section maintained in fixed relative position by the binder warp comprising elements B1, B2, B3, etc.

At the left edge of the web, the ends of the bifilar loops in the upper warp each substantially encircle the end warp element W1, but since they encircle the element alternately in opposite directions the net inductive effect is substantially zero. Similarly, the adjacent loops of conductor RC about the warp element W8 (Fig. 4a) are in bucking inductive relation. Except at the edges of the web, the pairs of picks p1, p2; p3, p4, etc. lie side by side through the warp and form no inductive loops about the warp elements.

In the lower warp, the inductive loops of conductor RC1 about the warp element w1 are alternately in opposite directions so that their net inductive effect is inappreciable; similarly, the inductive loops about the warp element w8, at the right edge of the web, are alternately in opposite directions to effect mutual cancellation of their inductive effects. Except at the edges of the web, the picks of conductor RC1 in each section of the resistor lie side by side through the lower warp, forming no inductive loops about the warp elements.

To complete the resistor, the two upper terminals of conductors RC and RC1 are connected together and the two lower terminals of the different conductors are connected together, the current passing through the conductors in parallel and in the same direction lengthwise of the web. There is, therefore, no appreciable difference of potential between adjacent bifilar loops of the same conductor in either layer or between adjacent bifilar loops of the different conductors in different layers.

As in the other modifications, the plies or layers are held together by a binder warp including elements B1, B2, B3, etc., whose positions may be transposed between weaving of the successive sections of the resistance webbing.

Within reason, the cross-sections of the two conductors may differ materially, facilitating obtainment of a desired magnitude of resistance for a desired length and width of the web.

Using manganin wire within the range of from #38 AWG to #44 AWG, woven resistors of this type, having values from about 25 to about 800 ohms, are about 0.55 inch long and from 0.3 to 0.8 inch wide; for the same range of wire size,

woven resistors of this type, from about 120 to about 1500 ohms, are about 1.1 inches long and 0.8 inch wide.

The inductive and capacitive reactances of these resistors are inappreciable even at high radio-frequencies, for example, of the order of 4 megacycles per second.

When the number of elements in each of the warps is an odd number rather than an even number as in Table #6, a slight variation of the pattern results as apparent from Table #7 infra.

Table #7

Section	Pick	Move-ment of shuttle	Warp threads n =odd number							Layer
			1	2	3	4	5	$n-1$	n	
M	p1	To left	o	u	o	u	o	u	o	Upper. Do.
	p2	To right	u	o	u	o	u	o	u	Lower. Do.
	P1	To right	o	u	o	u	o	u	o	
	P2	To left	u	o	u	o	u	o	u	
N	p3	To left	u	o	u	o	u	o	u	Upper. Do.
	p4	To right	o	u	o	u	o	u	o	Lower. Do.
	P3	To right	u	o	u	o	u	o	u	
	P4	To left	o	u	o	u	o	u	o	

It is not essential the number of elements in each warp be the same; neither is it essential the shuttles start from opposite sides of the web, for as shown in Fig. 5, the weaving of both layers of each section may begin at the same side of the web; in section Q, for example, the picks p1, p2 of conductor RC form a bifilar loop extending from the left edge of the upper layer of the web and pick P1, P2 of conductor RC1 form a bifilar loop extending from the same edge of the lower layer of the web; similarly, in section R, the bifilar loops in the upper and lower layers extend from the left edge of the webbing.

The invention is not limited to two-ply webs; if desired, the resistance conductor may be woven on a materially greater number of warps. By way of example, Fig. 6 shows one section and part of a second of a five-ply resistance web having a weaving pattern generally similar to Figs. 1 and 1a. For purpose of Table #8 below, it is assumed all warps have the same number of elements and that the number of elements in each warp is an even number.

Table #8

Section	Pick	Move-ment of shuttle	Warp threads n =even number								Layer
			1	2	3	4	5	6	$n-1$	n	
S	p1	To right	o	u	o	u	o	u	o	u	a
	p2	To left	u	o	u	o	u	o	u	o	a
	p3	To right	o	u	o	u	o	u	o	u	b
	p4	To left	u	o	u	o	u	o	u	o	b
	p5	To right	o	u	o	u	o	u	o	u	c
	p6	To left	u	o	u	o	u	o	u	o	c
	p7	To right	o	u	o	u	o	u	o	u	d
	p8	To left	u	o	u	o	u	o	u	o	d
	p9	To right	o	u	o	u	o	u	o	u	e
	p10	To left	u	o	u	o	u	o	u	o	e
T	p11	To right	u	o	u	o	u	o	u	o	a
	p12	To left	u	o	u	o	u	o	u	o	a
	p13	To right	u	o	u	o	u	o	u	o	b
	p14	To left	u	o	u	o	u	o	u	o	b
	p15	To right	u	o	u	o	u	o	u	o	c

To convert Table #8 to one suited for an odd number of warp threads in each layer, it is only necessary to omit the column under "1" and re-number columns 2 to 6 as 1 to 5. In Fig. 6 the shuttle begins weaving at the top layer of each section; it is feasible, however, to weave alternate sections from top to bottom and the intervening

sections from bottom to top. As in the other modifications, the plies are held together by a binder warp comprising threads B1, B2, B3, etc.

Another example of a multi-ply resistance web having more than two plies is shown in Fig. 7. The weaving pattern is generally similar to that shown in Figs. 3 and 3a in that each section is a folded bifilar loop, the number of folds corresponding to the number of layers of plies of the webbing. Assuming the webbing has five layers and that there is an even number of warp threads in each layer, the method of weaving is clear from Table #9 below:

Table #9

Section	Pick	Movement of shuttle	Warp threads n=even number								Layer
			1	2	3	4	5	6	n-1	n	
U	p1	To right	o	u	o	u	o	u	o	u	a
	p2	To left	o	u	o	u	o	u	o	u	b
	p3	To right	o	u	o	u	o	u	o	u	c
	p4	To left	o	u	o	u	o	u	o	u	d
	p5	To right	o	u	o	u	o	u	o	u	e
	p6	To left	o	u	o	u	o	u	o	u	e
	p7	To right	o	u	o	u	o	u	o	u	d
	p8	To left	o	u	o	u	o	u	o	u	c
	p9	To right	o	u	o	u	o	u	o	u	b
	p10	To left	o	u	o	u	o	u	o	u	a
V	p11	To right	u	o	u	o	u	o	u	o	a
	p12	To left	u	o	u	o	u	o	u	o	b
	p13	To right	u	o	u	o	u	o	u	o	c
	p14	To left	u	o	u	o	u	o	u	o	d
	p15	To right	u	o	u	o	u	o	u	o	e
	p16	To left	u	o	u	o	u	o	u	o	e
	p17	To right	u	o	u	o	u	o	u	o	d
	p18	To left	u	o	u	o	u	o	u	o	c
	p19	To right	u	o	u	o	u	o	u	o	b
	p20	To left	u	o	u	o	u	o	u	o	a

Again, it is to be noted, the net inductive effect along each of the warp elements is zero. The subsequent sections are alternately similar to sections U and V. It is not necessary that the number of warp elements be even in each warp, or the same for different warps.

From the modifications specifically illustrated and described, it should be apparent to those skilled in the art how to utilize the invention to provide a resistance webbing having smaller or greater number of plies and which has inappreciable inductance and capacitance.

The woven resistors of any of the modifications herein described may be mounted in any suitable manner, for example, as shown in Figs. 4 to 9 of my Patent No. 1,972,499.

As exemplary of the advantage obtained by use of the hereinbefore described resistors, tests made at 4 megacycles on a three-dial attenuator with steps of 0.1, 1.0 and 10 decibels for settings between 0 and 50 decibels disclosed a maximum phase shift of less than 2°. This attenuator had at 1000 kilocycles (1 megacycle per second) substantially the same phase angle (less than 0.5 degree) as an earlier model had at 50 kilocycles; the earlier model used woven resistors of the type disclosed in my aforesaid Patent No. 1,972,499 and the impedances of the series and shunt resistors of its pads were selected to give minimum phase shift.

To utilize the woven resistors herein described to their fullest advantage in an attenuator, the several expedients (described in my divisional application Serial No. 270,128, filed April 26, 1939) of grounding the inactive attenuator pads adjacent to the selected pads, shielding, proper arrangement or layout of the resistors of the pads and of the various mounting drums for the pad resistors, etc. are of material benefit, particularly

at high frequencies. With inferior resistors, these considerations are not important because of large errors due to the resistors themselves.

When the woven resistors herein described are used in other types of measuring apparatus, as bridges, voltage dividers, or the like, or in amplifying systems, as coupling resistors for example, due consideration should be given to the layout, wiring, and selection of the associated elements of the apparatus or system if the full benefit of this type resistor is to be realized.

Woven resistors of the multi-ply type woven with two or more conductors may be used to advantage in systems for measuring the voltage-ratio of potential transformers. Referring to Fig. 8, the high-voltage winding HV of potential transformer PT is connected to a source of high-voltage alternating current. One terminal of the low-voltage winding LV is connected to one terminal of the high-voltage winding and the other terminal of winding LV is connected through a suitable indicating instrument GM, for example a vibration galvanometer, to the contact PC adjustable along calibrated resistance PR in series with resistance VDR across the high-voltage winding. The resistances VDR and PR provide a voltage-dividing resistance so that the voltage-ratio of the transformer can be determined by adjusting contact PC until there is minimum response of galvanometer GM or equivalent. Resistance PR may be provided with a suitable scale cooperating with contact PC to afford direct indication of the voltage-ratio.

To measure the phase-angle of the potential-transformer PT, the calibrated mutual inductance ML and contact PC are varied to obtain zero deflection or response of galvanometer GM. From the readings of the calibrated resistance PR and of the mutual inductance, the phase shift of the transformer may be computed.

In measuring circuits of this type, the inductive reactance of the primary MP of the mutual inductance is low compared to the total resistance in series with it across the line so that insofar as its effect is concerned, the current through resistance PR is in phase with the applied voltage.

With the simple arrangement thus far described, there is substantial error because of capacity effects between resistance VDR and conductors or apparatus which are of substantially different potential. Because of these capacity effects, the current through measuring resistance PR and coil MP of the mutual inductance ML is not in phase with the voltage applied to winding HV of the transformer. These effects can be rendered negligible by use of a shielded resistor formed by weaving resistance VDR on one warp of a multi-ply web and concurrently weaving a second resistance SR on another warp of the web, Fig. 4 for example. The conductor used for weaving the shielding resistance SR while preferably of the same length as resistance VDR need not be of the same nominal resistance nor of material having low temperature coefficient of resistance. At one end of the webbing, the resistance conductors are connected together; the terminal of resistance VDR at the other end of the web is connected through primary MP of the mutual inductance to the resistance PR and the terminal of resistance SR is connected to resistance FR equal in magnitude to the resistance of PR and MP. Preferably, the webbing is rolled lengthwise about a suitable core or form of insulating material, such as "Isolanite," having low dielectric losses to

form, in effect, two concentric tubes, the inner one comprising the voltage-dividing resistance VDR and the outer one comprising the shielding resistance SR. Since each increment of length of resistance VDR is at the same potential as an immediately adjacent increment of length of resistance SR there is no flow of displacement or charging current from resistor VDR.

It is not necessary that resistance VDR, SR be so woven in the web that each of them has negligible phase angle; for example, referring to Fig. 9, the conductor woven to form resistor VDR is disposed in the warp in the same manner as one of the conductors of Fig. 4 but the conductor woven in the upper warp to form the shielding resistance SR follows the simple weaving pattern common in weaving of textiles. From Fig. 9, which illustrates two successive cross-sections W, X, of a multi-ply web of this type, the weaving pattern for the two conductors is self-evident.

A double shield for the voltage-dividing resistance VDR may be provided, Fig. 10, by weaving a three-ply web with three conductors. The resistance conductor woven on the inside or intermediate warp is used as the voltage-dividing resistance VDR and the resistance conductors woven on the warps on the opposite sides of the intermediate warp are used as the shielding resistances SR, SRR. All three resistances are preferably woven of conductors of equal length; it is only necessary accurately to calibrate resistance VDR, the other two need not be of the same nominal resistance nor of material having low temperature coefficient of resistance. At one end of the webbing all three conductors are connected to one side of the supply line and the other terminals of the conductor are connected to the other side of the line through the resistances FR, PR and FRR. This type of webbing may be used flat or rolled lengthwise if desired.

All three of the conductors may be woven so that each, as shown in Fig. 4, forms a bifilar loop in each section of the webbing but this is not necessary. As shown in Fig. 11, the conductor VDR in the middle layer is woven similarly to conductor RC, for example, of Fig. 4; the conductors SR and SSR are woven on the top and bottom warps in the simple manner usual in textiles. From Fig. 11, showing two successive sections Y, Z of a web of this type, the mode of weaving is evident.

As appears from Figs. 12 and 13, the voltage dividing resistance VDR may be woven in an outer layer of a three-ply warp and the shielding resistances SR, SRR woven in the other two layers. As shown in Fig. 13, only the conductor forming resistance VDR need be woven to form a bifilar loop in each of the sections of the webbing. From Fig. 13, showing two successive sections YA, ZA of the webbing, the pattern of weaving is readily understood. Preferably, the webbing is so folded the resistance VDR is substantially enclosed within the two overlying shields afforded by the resistors SR and SSR woven in other plies of the same webbing. Shielded resistors of the type shown in any of Figs. 8 to 13 may also be used to advantage as series resistors for the potential coil of high-voltage wattmeters and in general for applications in which it is desired to derive a current which is in phase with an applied voltage.

While I have specifically illustrated and described preferred methods and arrangements,

it is to be understood my invention is not limited thereto but is co-extensive in scope with the appended claims.

What I claim is:

1. A woven resistor having inappreciable reactance and comprising a plurality of warps, resistance wire woven thereon to form a multi-layer web, and a binder warp holding the adjacent picks of resistance wire in the different layers in relatively fixed positions.
2. A woven resistor comprising a plurality of warps and resistance wire woven thereon to form a multi-layer web, the woven wire appearing in a cross-section of the web as bifilar loops in different layers of the web.
3. A woven resistor comprising a plurality of warps and resistance wire woven thereon to form a multi-layer web, the woven wire appearing in a cross-section of the web as a plurality of serially-connected bifilar loops in different layers of the web.
4. A woven resistor comprising a plurality of warps and resistance wire woven thereon to form a multi-layer web, the woven wire appearing in a cross-section of the web as a plurality of serially-connected bifilar loops, one for each layer of the web.
5. A woven resistor comprising a plurality of warps and resistance wire woven thereon to form a multi-layer web, the woven wire appearing in a cross-section of the web as a folded, bifilar loop, the number of folds corresponding to the number of layers of the web.
6. A woven resistor comprising a plurality of warps and resistance wire woven thereon to form a multi-layer web, the woven wire appearing in a cross-section of the web as bifilar loops and in different layers of the web.
7. A woven resistor comprising a plurality of warps and resistance wire woven thereon to form a multi-layer web, the woven wire appearing in a cross-section of the web as bifilar loops similarly extending from the same edge of the web and in different layers thereof.
8. A woven resistor comprising a plurality of warps and resistance wire woven thereon to form a multi-layer web, the two picks of wire in a cross-section of each layer lying side by side through the warp except at an edge of the web.
9. A woven resistor comprising a plurality of warps and resistance wire woven in sections on said warps to form a multi-layer web, each section appearing as bifilar loops in different layers of the web, the alternate sections being similarly woven on said warps, and each section differing from the adjacent sections in that the positions of the warp elements with respect to the picks of the conductor are transposed.
10. A woven resistor comprising a plurality of warps and resistance wire woven in sections on said warps to form a multi-layer web, the woven wire appearing in each section as a folded bifilar loop, the number of folds corresponding to the number of layers of the web, the alternate sections being similarly woven on said warps, and each section differing from the adjacent sections in that the positions of the warp elements with respect to the picks of conductor are transposed.
11. The method of making a resistor having inappreciable time constant which comprises weaving resistance wire on superposed warps to form a multi-ply web.
12. The method of making a resistor having inappreciable time constant which comprises weaving resistance wire on superposed warps

that adjacent picks lie side by side through each of the warps.

13. The method of making a resistor having inappreciable time constant which comprises weaving resistance wire on superposed warps by passing the wire through one warp, then around an end warp element, then through the first warp in reverse direction, then through the second warp, around the end element of the second warp, and then through the second warp in reverse direction.

14. The method of making a resistor having inappreciable time constant which comprises weaving resistance conductor on superposed warps by passing the conductor in one direction through one warp, then through the other warp in reverse direction, looping the conductor about an end element of the second warp, and then passing the conductor in the first direction through the second warp and through the first warp in the reverse direction.

15. The method of making a resistor having inappreciable time constant which comprises weaving resistance wire on superposed warps by passing the wire back and forth through each of the warps in succession to form a resistor section, transposing the positions of the elements in the warps, and then passing the conductor back and forth through each of the warps in succession to form the next resistor section.

16. The method of making a resistor having inappreciable time constant which comprises

weaving resistance wire on superposed warps by passing the wire through the warps in succession, and then passing the wire through the warps in reverse sequence.

17. The method of making a resistor having inappreciable time constant which comprises weaving resistance wire on superposed warps to form a multi-layer web by passing picks of wire from sides of the web and in different layers thereof.

18. The method of providing an incrementally equi-potential shield for a measuring circuit resistance which comprises weaving resistance wires on warps to form a multi-ply web, utilizing one of said wires as the measuring circuit resistance, and so connecting the other of said wires that throughout the web each increment of its length is at substantially the same potential as the adjacent increment of length of the measuring circuit resistance.

19. A multi-layer web comprising two or more resistance conductors woven on different warps, and a binder warp for maintaining fixed the relative position of picks of conductor in different layers.

20. A multi-layer web comprising two or more resistance conductors woven on different warps, at least one of said conductors being so woven as to form a bifilar loop in each section of the web.

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