May 14, 1963 W. E. VAN HORNE 3,090,001

IMPEDANCE AND VOLTAGE DIVIDERS

Filed July 17, 1961 2 Sheets-Sheet 1

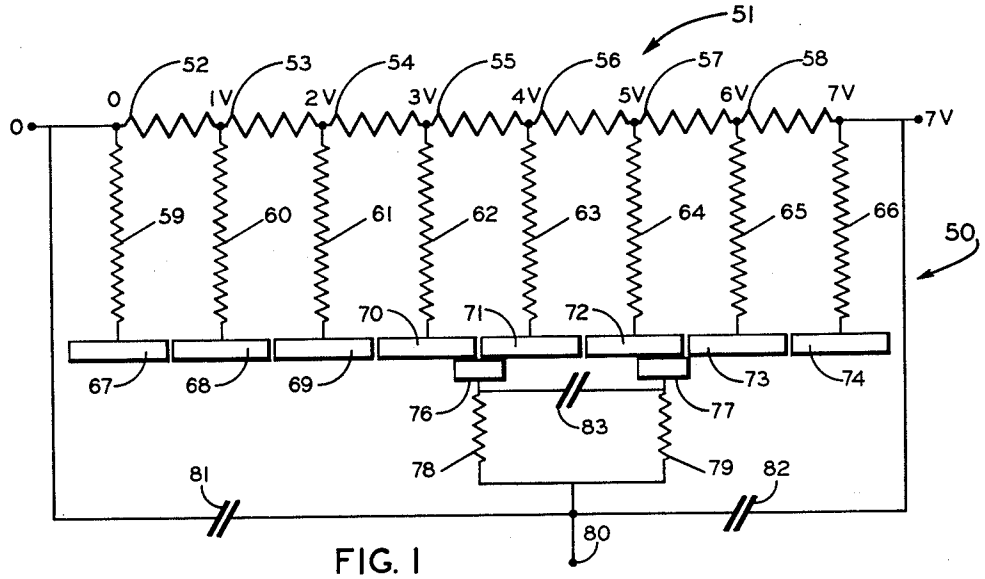

FIG. 1

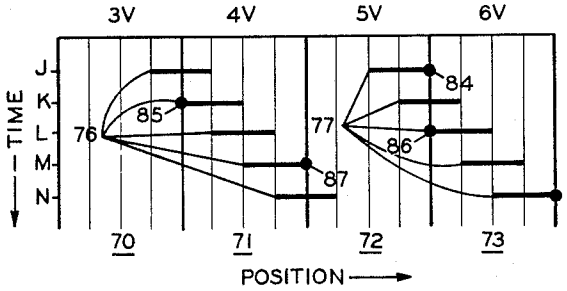

FIG. 3

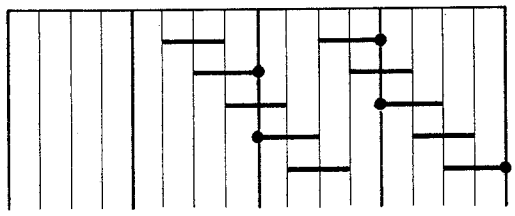

FIG. 4

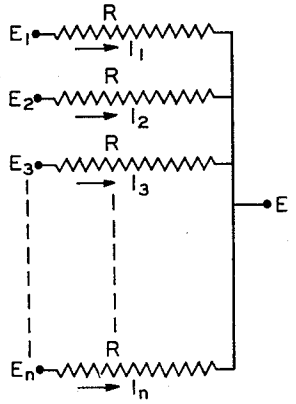

FIG. 2

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IMPEDANCE AND VOLTAGE DIVIDERS

Filed July 17, 1961 2 Sheets-Sheet 2

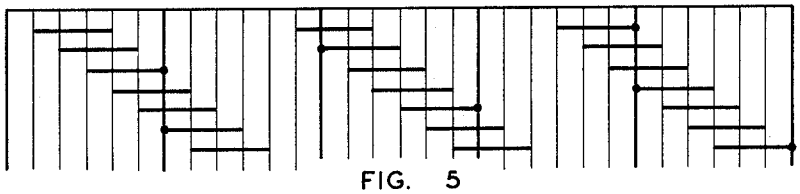

FIG. 5

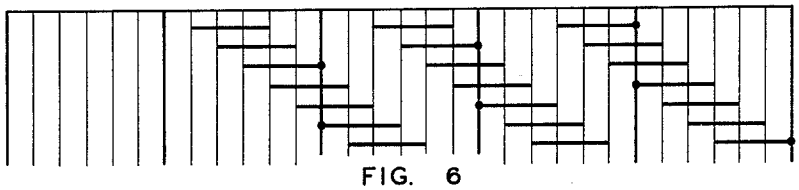

FIG. 6

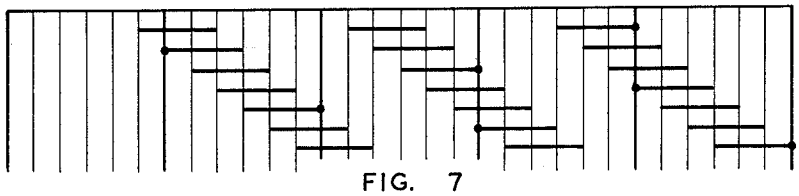

FIG. 7

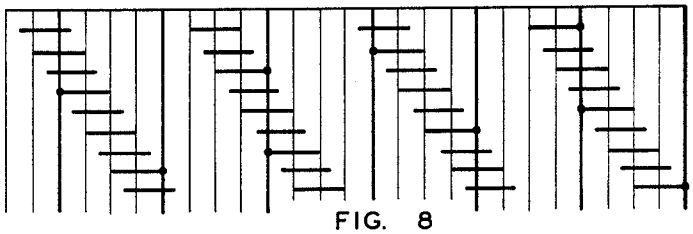

FIG. 8

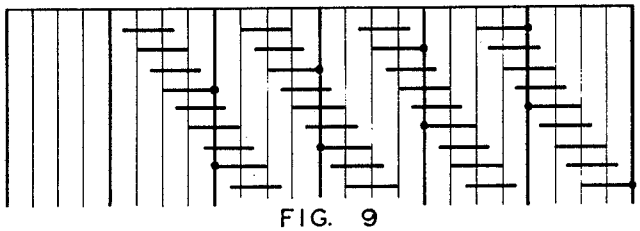

FIG. 9

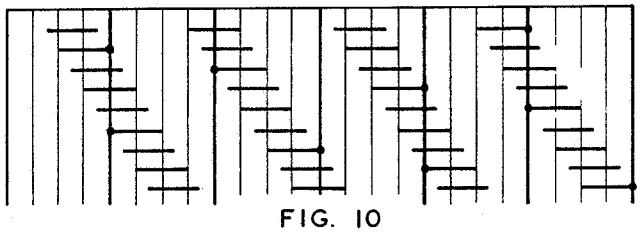

FIG. 10

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United States Patent Office 3,090,001 Patented May 14, 1963

3,090,001

IMPEDANCE AND VOLTAGE DIVIDERS

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Filed July 17, 1961, Ser. No. 124,592
15 Claims. (Cl. 323—79)

This invention relates to impedance and voltage dividers. It has to do especially with essentially stepwise electrical tapping of impedance segments in impedance and voltage dividers wherein at least substantially four times as many steps are obtained as the number of junctions between impedance segments to which connection is made.

In apparatus where it is desired to provide a range of voltages or impedances in a continuously variable manner, as in the volume control of a radio or television set, it is customary to make sliding contact directly on an impedance element. The devices used are commonly known as potentiometers and rheostats. Where it is desired to scan repeatedly over a range of voltages or impedances, however, scanning in a continuous manner generally is not feasible because the friction of the moving contact on the impedance element causes appreciable electrical noise and soon wears out the potentiometer or rheostat. For such purposes, therefore, it is customary to use stepwise scanning through the range of impedances or voltages by means of fixed contacts connected to spaced points on the impedance. The fixed contacts and the slidable contact can all be made of materials having high conductivity and good resistance to wear.

In a common form of such device the fixed contacts may be arranged in a circle as are the commutator segments in a motor or generator, and the sliding contact may be in the form of a brush such as is used in a motor or generator. Although the contacts connected to the impedance are referred to above as the fixed contacts, in rotating devices such as those mentioned above they would ordinarily be the contacts that move, and the brush would remain stationary. As far as the electrical circuit is concerned, however, it is immaterial which contact or contacts move, as long as there is relative sliding movement between them.

Because of various physical limitations and cost considerations, there is a practical limit to the number of taps that can be employed in stepwise electrical tapping devices. Where it is desired to divide a given voltage or impedance range into a large number of discrete steps it would be desirable in many cases to be able to provide more steps than the highest practical number of taps, or the highest practical number of commutator segments, whichever is the limiting factor. It is known that the number of steps can be made substantially twice the number of taps where an impedance is provided between each tap and its respective contact. In a voltage divider circuit of this type, when the movable contact bridges two adjacent fixed contacts the voltage on the movable contact is midway between that of each fixed contact where the impedances connecting the fixed contacts and their respective taps on the main impedance are equal.

It has been found in the present invention that by providing a plurality of movable contacts, properly staggered, the number of steps can be increased to at least substantially four times the number of taps. More specifically where two movable contacts are used, the number of steps is substantially four times the number of taps, where three are used the number of steps is substantially six times the number of taps, and similarly where more movable contacts are employed the number of steps is substantially twice the number of movable contacts times the number of taps.

In the drawings:

FIG. 1 is a schematic diagram illustrating a typical embodiment of the present invention.

FIG. 2 is a schematic diagram illustrating one of the principles involved in the invention.

FIGS. 3–10 are semi-pictorial, schematic views, in the general nature of graphs, illustrating the principles of the staggered contacts in the invention.

Referring to FIG. 1, a typical electrical device **50** of the impedance and voltage divider type comprises a series impedance member **51** comprising the individual impedance segments **52–58**. Where equally spaced essentially stepwise tapping is desired, the impedances **52–58** should all be equal. Connected to the ends of the impedance member **51** and to the junctions between successive segments **52–58** are a plurality of impedances **59–66** having impedances that are substantially equal to each other; and preferably substantially higher than the impedances of the segments **52–58**, to avoid inequalities in the steps that might result if the impedances **59–66** were low enough relatively to provide a substantial reduction in the impedance between junctions of the impedance segments **52–58** during times when certain of the adjacent impedances **59–66** are connected together and thus shunt one or more of the segments **52–58**. The opposite ends of the impedances **59–66** are connected respectively to electrical contacts **67–74**.

The contacts **67–74** are all substantially equal in length and substantially equally spaced, preferably closely, from their adjacent contacts. Thus the distances between the corresponding ends of successive contacts **67–74** are substantially equal. The electrical contacts **67–74** are arranged so that together they form a contact surface such as a plane or a cylindrical surface whereon a slidable contact can be positioned and moved lengthwise relative to the surface, as is indicated by the arrow **75**, to contact at least one of the electrical contacts **67–74** at any position on the surface.

A pair of slidable contacts **76–77** are held, preferably with resilient means such as springs (not shown), at a fixed lengthwise spacing from each other along the contact surface **67–74**; and are slidable relative to the surface in either direction, as is indicated by the arrow **75**. The length of each slidable contact member **76–77** is one-half the distance between the corresponding ends of successive contacts **67, 68**; **68, 69**; **69, 70**; etc. The distance between the nearest edges of the slidable contacts **76, 77** is 1¼ times the distance between the corresponding ends of successive contacts **67, 68** etc.

One end of a coupling impedance **78** is connected to the slidable contact **76**, and the other end is connected to a point **80**. One end of a coupling impedance **79** is connected to the slidable contact **77**, and the other end is connected to the point **80**. One side of a capacitor **81** is connected to one end of the impedance member **51**, and the other side is connected to the point **80**. One side of a capacitor **82** is connected to the opposite end of the impedance member **51**, and the other side is connected to the point **80**. One side of a capacitor **83** is connected to the slidable contact **76**, and the other side is connected to the slidable contact **77**. For convenience in discussion it will be considered that a potential of seven volts is applied across the impedance member **51**, and the voltage across each impedance segment **52–58** thus is one volt, the potentials at the various junctions being as indicated in FIG. 1, ignoring any slight loading effect from the brushes and associated impedances.

To understand the operation of the present invention it is helpful to consider the diagram of FIG. 2, wherein E, E_1, E_2, E_3, . . . E_n represent voltages (potentials), I_1, I_2, I_3, . . . I_n represent currents, and R represents impedance, which for simplicity will be considered to be

a pure resistance, the impedances of all of the elements shown in FIG. 2 being equal. From elementary theory it is apparent that

$$\begin{aligned} E &= E_1 - RI_1 \\ &= E_2 - RI_2 \\ &= E_3 - RI_3 \\ &\cdot \\ &\cdot \\ &\cdot \\ &= E_n - RI_n \end{aligned}$$

from which

$$nE = E_1 + E_2 + E_3 + \ldots + E_n - R(I_1 + I_2 + I_3 + \ldots + I_n)$$

Where no current passes the point at E

$$I_1 + I_2 + I_3 + \ldots + I_n = 0$$

and

$$nE = E_1 + E_2 + E_3 + \ldots E_n$$

Thus the voltage E is the arithmetic mean, or more loosely the "average," of the voltages E_1, E_2, E_3, . . . E_n.

If current is drawn through the point at E, as is the case in some rheostat applications, the above equations do not apply exactly, and the voltage E is not precisely the arithmetic mean of the individual voltages; but it is very close thereto. As long as the impedances **59–66**, **78**, **79** are substantially larger than the impedances of the segments **52–58**, the loading effect is small and any variation from the above equations is negligible.

Where essentially stepwise electrical tapping is desired, the capacitors **81–83** are omitted from the circuit of FIG. 1. Referring to FIGS. 1 and 3, the circuit of FIG. 1 without the capacitors **81–83** operates in accordance with the following explanation.

In FIG. 3 the heavy vertical lines represent the insulation or space between contacts in the contact surface, and the blank spaces between the heavy vertical lines represent the contacts **70**, **71**, **72**, **73**, which have the potentials 3 volts, 4 volts, 5 volts, and 6 volts, respectively, as indicated, when not shorted to an adjacent contact. The heavy horizontal lines represent the slidable contacts **76**, **77**, as indicated, at successive positions on the contacts **70–73**. Considering the contacts **76**, **77** to be moving uniformly to the right, with time indicated in the vertical direction and increasing as one reads down on the diagram, it is seen that just before time J the contact **76** was at a potential of 3.5 volts, the contact **77** was at a potential of 5 volts, and the point **80** thus was at a potential of 4.25 volts, the arithmetic mean between the voltages at the contacts **76**, **77**.

At time J the contact **77** makes connection with the contact **73** as well as the contact **72**, as is indicated by the heavy dot **84**. This raises the potential at the contact **77** to 5.5 volts, and the potential at the point **80** thus is raised to 4.5 volts, since the contact **76** is still at the same potential as it had just before the time J. At time K the contact **77** remains at the same potential, 5.5 volts, but the contact **76** breaks its connection with the contact **70**, as is indicated by the heavy dot **85**, and thus its potential is increased to 4 volts, and the potential of the point **80** is increased to 4.75 volts. Similarly at time L, with the potential of the contact **76** remaining the same, the potential at the contact **77** increases one-half volt as it breaks connection with the contact **72**, as is indicated by the heavy dot **86**, and the voltage at the point **80** is increased one-fourth volt to the new potential of 5 volts. In like manner, with the potential of the contact **77** remaining the same, the contact **76** at time M makes connection with the contact **72**, as is indicated by the heavy dot **87**, raising its potential by one-half volt and the potential of the point **80** by one-fourth volt. Finally, at time N the potential at the point **80** is raised another one-fourth volt in similar manner, so that it is now at a potential one volt greater than its potential at time J, the contacts **76**, **77** being in the same corresponding positions as they were at time J, but each at a one volt higher potential.

From FIGS. 1 and 3 and the above discussion, it is apparent that as the contacts **76**, **77** move together one-fourth the distance between the corresponding ends of successive contacts **67–74**, one of the contacts **76**, **77** either makes or breaks a connection, and thus changes its potential by one-half volt and the potential of the point **80** by one-fourth volt. The action is the same in either direction.

In FIG. 4, which is the same type of diagram as FIG. 3, with legends and reference numerals omitted for convenience, it is apparent that the same action takes place. In every movement of one-fourth the distance between corresponding ends of successive contacts **67–74** the contacts **76**, **77** take turns making or breaking a connection, thus raising one of the individual voltages one-half volt, and the average voltage, at the point **80**, one-fourth volt. In FIG. 4 the spacing between the contacts **76**, **77** is three-fourths the distance between the corresponding ends of successive contacts **67–74**. The action is similar for any spacing of an odd number of quarters of the distance between the corresponding ends of successive contacts **67–74**. The spacing must be at least three-fourths of that distance, however. Otherwise three successive contacts **67–74** would be shorted at the wrong time in some positions, and this would provide a conflicting action. In other words, the distance between the contacts **76**, **77** may be ¾, 5/4, 7/4, 9/4, or any higher odd number of fourths of the distance between the corresponding ends of successive contacts **67–74**. The lengths of the contacts **76**, **77** may be increased to ⅜, 5/2 7/2, or any odd number of halves of the distance between the corresponding ends of successive contacts **67–74**; since the action is the same as that described and illustrated in FIGS. 3 and 4, except that the longer contacts short out one or more of the contacts **67–74** in addition to those as indicated in FIGS. 3 and 4. The alternate making and breaking of connections with every movement of one-fourth the distance between the corresponding ends of successive contacts **67–74** still takes place, however, in the same manner as illustrated in FIGS. 3 and 4.

For three or more slidable contacts the spacing principle is the same, and may be generalized by stating that successive slidable contacts are spaced any number of halves times the distance between the corresponding ends of successive contacts **67–74** plus an equally spaced or even staggering over such a half distance. In the case of three contacts, the closest spacing is two-thirds of the distance between the corresponding ends of successive contacts **67–74**. Stated differently, this is one-half the aforementioned distance plus one-sixth of that distance; or still differently, one-half the distance plus ⅓ of ½. This spacing is illustrated in FIG. 6.

From FIG. 6 it is apparent that every ⅙ distance of movement across a contact **67–74** causes one of the slidable contacts to make or break a connection, and that the contacts take turns so that in every half distance of movement each has made or broken a connection. In the next half distance of movement each slidable contact successively makes or breaks (the opposite of what it did in the first half distance of movement); bringing the slidable contacts back to the same corresponding position as before the movement, but with each moved over the length of one contact **67–74**.

FIGS. 5 and 7 illustrate other convenient spacings for three slidable contacts. In FIG. 5 the spacing is 1⅙ of the distance between the corresponding ends of successive contacts **67–74**; and in FIG. 7 the spacing is ⅝ of the aforementioned distance, which is ½ plus ⅔ of ½. The staggering is equal in this case also because with the middle contact spaced from the right-hand contact by ½ plus ⅔ of ½, and the left-hand contact spaced from the middle contact by the same distance, the spacing be-

tween the left-hand contact and the right-hand contact thus is ½ plus ⅓ of ½.

FIGS. 8–10 illustrate similar action where four slidable contacts are employed. Here the spacing between successive slidable contacts is any number of halves of the distance between the corresponding ends of successive contacts **67–74** and fourths of that half distance such that the slidable contacts are staggered from the others by ¼ and ½ of the half distance. In FIG. 8 the spacing is 1⅛ of the distance between the corresponding ends of successive contacts **67–74**; in FIG. 9 the spacing is ⅝ of the aforementioned distance; and in FIG. 10 the spacing is ⅞ of the aforementioned distance. From FIGS. 8–10 it is apparent that these spacings provide uniform or even staggering such that for every movement of ⅛ (¼ of ½) the distance between the corresponding ends of successive contacts **67–74** the slidable contacts take turns making and breaking connections, changing one of the four potentials by ½ volt, and the average potential by ⅛ volt.

To generalize, for any number of slidable contacts, the length of the contacting surface of each slidable contact member in the lengthwise slidable direction is equal to an odd integral multiple of one-half the distance along the lengthwise slidable direction between the corresponding ends of successive contacts **67–74**, and the distance in the lengthwise slidable direction between the nearest edges of successive slidable contacts is equal to an integral multiple of one-half the distance along the lengthwise slidable direction between the corresponding ends of successive contacts **67–74** plus a fraction of said half distance, wherein the denominator of the fraction is the number of said slidable contacts and the numerator is an integer such that the sum of any said numerator plus any at least one other said numerator equals an integer different from the denominator and any multiple thereof. The above generalization is intended to indicate in more precise terms what is meant by the equally spaced or even staggering within a half distance, as discussed above.

Referring back to FIG. 1, where it is desired to approach a continuous voltage change rather than a stepwise change, the capacitors **81** and **82**, connected between the point **80** and the ends of, or any other desired points on, the impedance member **51**, may be included in the circuit. The voltage across a capacitor cannot change instantaneously. It can change only gradually according to an exponential function, at a rate dependent upon the capacitance and other circuit values affecting the "time constant." The values of the capacitances **81**, **82** can be chosen such that the time constants for the various positions of the slidable contacts **76**, **77** provide a fairly smooth, rather than a stepwise, change of voltage at the normal operating speed of the slidable contacts **76**, **77**.

Still further smoothing of the voltage at the point **80** as a function of position of the contacts **76**, **77** moving at their normal speed can be provided by including also the capacitor **83** connected between the slidable contacts **76**, **77** (and with additional capacitors between other pairs of contacts where more than two slidable contacts are employed), since the capacitor **83** similarly causes the potential between the contacts **76**, **77** to change gradually rather than instantaneously when one of the contacts **76**, **77** makes or breaks a connection. The capacitor **83** should not be used between any contacts that are spaced less than the distance between the corresponding ends of successive contacts **67–74**, because shorting of the capacitors at certain positions would result in arcing.

Where it is desired that the stepwise tapping, or the smoothed tapping with the capacitors added, is to be directly proportional to the position of the slidable contacts (or as a function of time where the slidable contacts are moved at a uniform speed) the impedances of the segments **52–58** should be equal and the staggering of the slidable contacts should be even, as discussed above. Where it is desired to obtain a different function of voltage or impedance, either in a stepwise or a substantially continuous manner, the impedances of the segments **52–58** may be made unequal in a predetermnied manner or the staggering of the slidable contacts may differ from that specified above, or both. Such variations are considered to be within the scope of this invention, but are too numerous to be discussed individually. The impedances **59–66** could even be made unequal in a predetermined manner to provide certain functions, as could the impedances **78**, **79**, and other coupling impedances where more than two slidable contacts are employed. Ordinarily the impedance segments **52–58**, the impedances **59–66** and the coupling impedances **78**, **79** would be substantially pure resistances, especially in direct current circuits, but other types of impedance could be employed where desired. For convenience, only seven impedance segments **52–58** are shown in FIG. 1. In practice, a hundred or more such impedance segments are more typical. Any desired number, of course, may be used.

While the forms of the invention herein disclosed constitute preferred embodiments, it is not intended to describe all of the possible equivalent forms or ramifications of the invention. It will be understood that the words used are words of description rather than of limitation, and that various changes may be made without departing from the spirit or scope of the invention.

What is claimed is:

1. In an electrical device of the impedance divider and voltage divider type comprising a plurality of impedance segments connected in series, a plurality of impedances each connected at one end to an end of a different one of said segments and at the opposite end to a different electrical contact, said electrical contacts being positioned in the same sequence as said segment ends to which the ends of said impedances are respectively connected, each said electrical contact being positioned closely adjacent to the next said contact but insulated therefrom, said electrical contacts together forming a contact surface whereon a slidable contact can be positioned and moved lengthwise relative to said surface to contact at least one said electrical contact at any position thereon; means for making electrical connection to said electrical contacts to provide essentially stepwise electrical tapping of said impedance segments in at least substantially four times as many steps as the number of said electrical contacts, comprising a plurality of lengthwise fixedly-spaced and relatively lengthwise-sidable contact members, and means for providing relative lengthwise movement between said contact members and said contact surface.

2. In an electrical device of the impedance divider and voltage divider type comprising a plurality of impedance segments, having individual impedances in accordance with a predetermined desired function, connected in series, a plurality of impedances, each connected at one end to an end of a different one of said segments and at the opposite end to a different electrical contact; each junction between said segments being connected to one end of one of said plurality of impedances and said electrical contacts being positioned in the same sequence as said junctions to which the ends of said impedances are respectively connected, each said electrical contact being positioned closely adjacent to the next said contact but insulated therefrom, said electrical contacts together forming a contact surface whereon a slidable contact can be positioned and moved lengthwise relative to said surface to contact at least one said electrical contact at any position thereon; means for making electrical connection to said electrical contacts to provide essentially stepwise electrical tapping of said impedance segments in at least substantially four times as many steps as the number of said electrical contacts, comprising a plurality of lengthwise fixedly-spaced and relatively lengthwise-slidable contact members; and means

for providing relative lengthwise movement between said contact members and said contact surface.

3. In an electrical device of the impedance divider and voltage divider type comprising a plurality of impedance segments, each substantially equal in impedance, connected in series, a plurality of substantially equal impedances, each connected at one end to an end of a different one of said segments and at the opposite end to a different electrical contact, each junction between said segments being connected to one end of one of said plurality of impedances and said electrical contacts being positioned in the same sequence as said junctions to which the ends of said impedances are respectively connected, each said electrical contact being positioned closely adjacent to the next said contact but insulated therefrom, the distances between the corresponding ends of successive contacts being substantially equal, said electrical contacts together forming a contact surface whereon a slidable contact can be positioned and moved lengthwise relative to said surface to contact at least one said electrical contact at any position thereon; means for making electrical connection to said electrical contacts to provide equally spaced essentially stepwise electrical tapping of said impedance segments in at least substantially four times as many steps as the number of said electrical contacts, comprising: a plurality of lengthwise fixedly-spaced and relatively lengthwise-slidable contact members; and means for providing relative lengthwise movement between said contact members and said contact surface; the length of the contacting surface of each said relatively slidable contact member in the lengthwise slidable direction being equal to an odd integral multiple of one-half the distance along said lengthwise slidable direction between the corresponding ends of successive said electrical contacts; said relatively slidable contact members being evenly staggered between integral multiples of one-half said distance along said lengthwise slidable direction between the corresponding ends of successive said electrical contacts.

4. In an electrical device of the impedance divider and voltage divider type comprising a plurality of impedance segments, each substantially equal in impedance, connected in series, a plurality of substantially equal impedances, each connected at one end to an end of a different one of said segments and at the opposite end to a different electrical contact, each junction between said segments being connected to one end of one of said plurality of impedances and said electrical contacts being positioned in the same sequence as said junctions to which the ends of said impedances are respectively connected, each said electrical contact being positioned closely adjacent to the next said contact but insulated therefrom, the distances between the corresponding ends of successive contacts being substantially equal, said electrical contacts together forming a contact surface whereon a slidable contact can be positioned and moved lengthwise relative to said surface to contact at least one said electrical contact at any position thereon; means for making electrical connection to said electrical contacts to provide equally spaced essentially stepwise electrical tapping of said impedance segments in at least substantially four times as many steps as the number of said electrical contacts, comprising: a plurality of lengthwise fixedly-spaced and relatively lengthwise-slidable contact members; means for providing relative lengthwise movement between said contact members and said contact surface; the length of the contacting surface of each said relatively slidable contact member in the lengthwise slidable direction being equal to an odd integral multiple of one-half the distance along said lengthwise slidable direction between the corresponding ends of successive said electrical contacts; the distance in said lengthwise slidable direction between the nearest edges of successive said slidable contacts being equal to an integral multiple of one-half said distance along said lengthwise slidable direction between the corresponding ends of successive said electrical contacts, plus a fraction of said half distance, wherein the denominator of said fraction is the number of said slidable contacts and the numerator is an integer such that the sum of any said numerator plus any at least one other said numerator equals an integer different from said denominator and any multiple thereof; a plurality of coupling impedances, one for each said slidable contact, having impedances substantially equal to each other; each said coupling impedance being connected at one end to its respective said sliding contact and at the opposite end to the opposite end of each of the other said coupling impedances; the junction of said opposite ends of said coupling impedances being the point at which is provided said equally spaced essentially stepwise electrical tapping.

5. Apparatus according to claim 4, wherein each of said plurality of substantially equal impedances has substantially higher impedance than each said impedance segment.

6. In an electrical device of the impedance divider and voltage divider type comprising a plurality of impedance segments, each substantially equal in impedance, connected in series, a plurality of substantially equal impedances, each connected at one end to an end of a different one of said segments and at the opposite end to a different electrical contact, each junction between said segments being connected to one end of one of said plurality of impedances and said electrical contacts being positioned in the same sequence as said junctions to which the ends of said impedances are respectively connected, each said electrical contact being positioned closely adjacent to the next said contact but insulated therefrom, the distances between the corresponding ends of successive contacts being substantially equal, said electrical contacts together forming a contact surface whereon a slidable contact can be positioned and moved lengthwise relative to said surface to contact at least one said electrical contact at any position thereon; means for making electrical connection to said electrical contacts to provide equally spaced essentially stepwise electrical tapping of said impedance segments in substantially four times as many steps as the number of said electrical contacts, comprising: a pair of lengthwise fixedly-spaced and relatively lengthwise-slidable contact members; means for providing relative lengthwise movement between said contact members and said contact surface; the length of the contacting surface of each said relatively slidable contact member in the lengthwise slidable direction being equal to an odd integral multiple of one-half the distance along said lengthwise slidable direction between the corresponding ends of successive said electrical contacts; the distance in said lengthwise slidable direction between the nearest edges of said slidable contacts being equal to an integral multiple of one-half said distance along said lengthwise slidable direction between the corresponding ends of successive said electrical contacts, plus one-fourth of said distance; a pair of coupling impedances, one for each said slidable contact, having impedances substantially equal to each other; each said coupling impedance being connected at one end to its respective said sliding contact and at the opposite end to the opposite end of the other said coupling impedance; the junction of said opposite ends of said coupling impedances being the point at which is provided said equally spaced essentially stepwise electrical tapping.

7. Apparatus according to claim 4, wherein said electrical connection making means provides substantially six times as many steps as the number of said electrical contacts, wherein the number of said relatively slidable contact members is three, and wherein the denominator of said fraction is three.

8. Apparatus according to claim 4, wherein said electrical connection making means provides substantially six times as many steps as the number of said electrical

contacts, wherein the number of said relatively slidable contact members is three, and wherein said fraction of said half distance is one-third.

9. Apparatus according to claim 4, wherein said electrical connection making means provides substantially six times as many steps as the number of said electrical contacts, wherein the number of said relatively slidable contact members is three, and wherein said fraction of said half distance is two-thirds.

10. Apparatus according to claim 4, wherein said electrical connection making means provides substantially eight times as many steps as the number of said electrical contacts, wherein the number of said relatively slidable contact members is four, and wherein the denominator of said fraction is four.

11. Apparatus according to claim 4, wherein said electrical connection making means provides substantially eight times as many steps as the number of said electrical contacts, wherein the number of said relatively slidable contact members is four, and wherein said fraction of said half distance is one-fourth.

12. Apparatus according to claim 4, wherein said electrical connection making means provides substantially eight times as many steps as the number of said electrical contacts, wherein the number of said relatively

slidable contact members is four, and wherein said fraction of said half distance is three-fourths.

13. Apparatus according to claim 4, wherein at least one capacitor is connected at one side to said junction of said coupling impedances and at the other side to an end of a different one of said series impedance segments, to modify said essentially stepwise electrical tapping to provide a substantially continuous variation where substantially uniform relative lengthwise movement between said slidable contact members and said contact surface is provided.

14. Apparatus according to claim 4, wherein a pair of capacitors are connected at one side to said junction of said coupling impedances and at the opposite side to the ends of said series impedance segments, to modify said essentially stepwise electrical tapping to provide a substantially continuous variation where substantially uniform relative lengthwise movement between said slidable contact members and said contact surface is provided.

15. Apparatus according to claim 4, including at least one capacitor, each said capacitor being connected across a different pair of said relatively slidable contact members.

No references cited.