Nov. 30, 1954 J. SCHWARTZ 2,695,967

THERMAL MULTIPLIER

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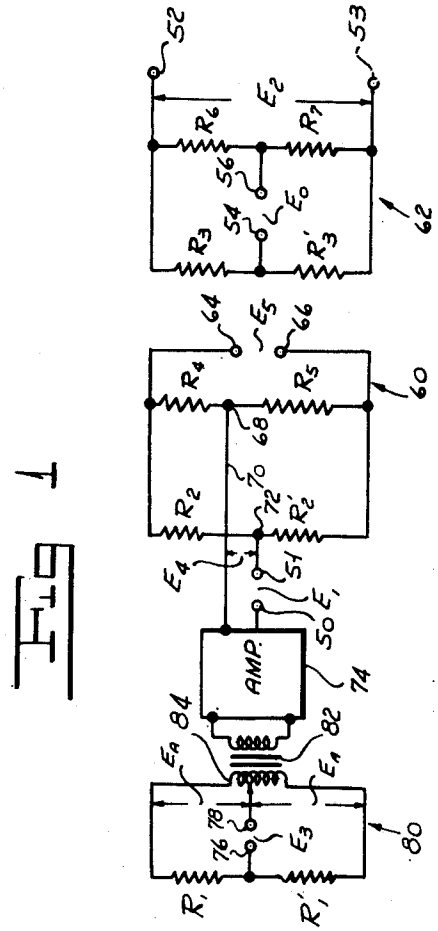


FIG. 1

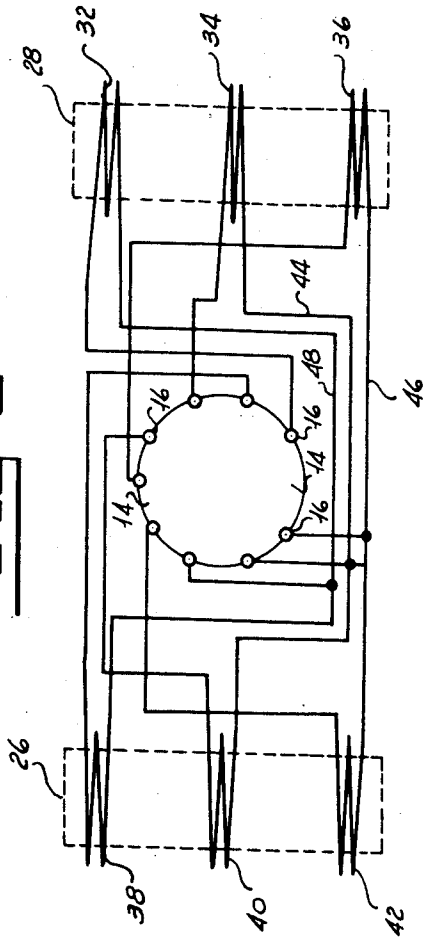


FIG. 2

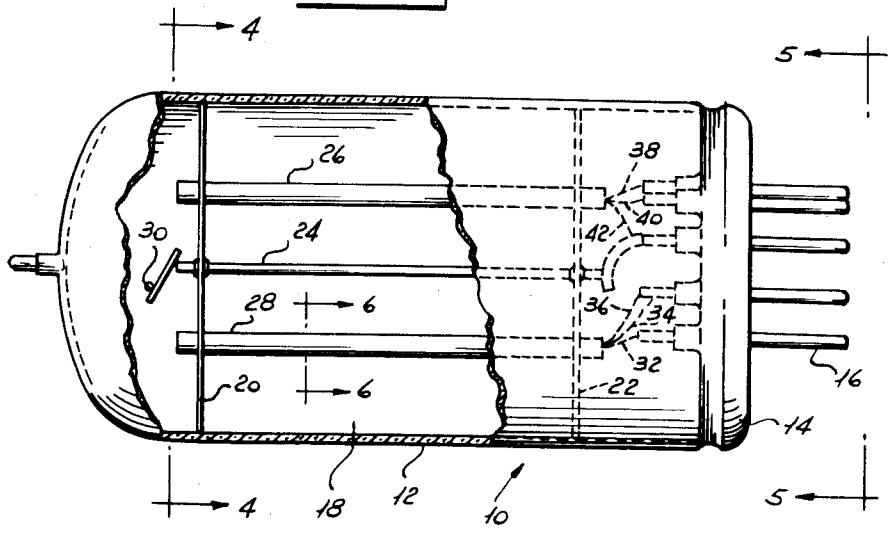
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Fig 3



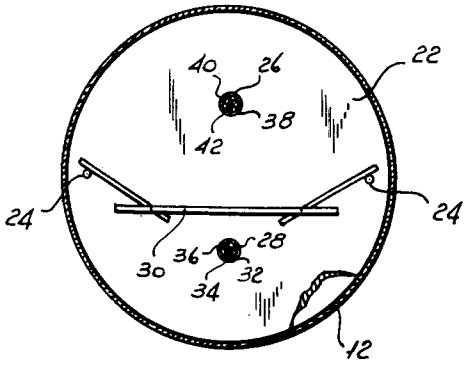


Fig 4

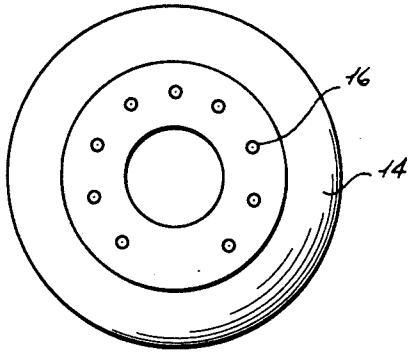


Fig 5

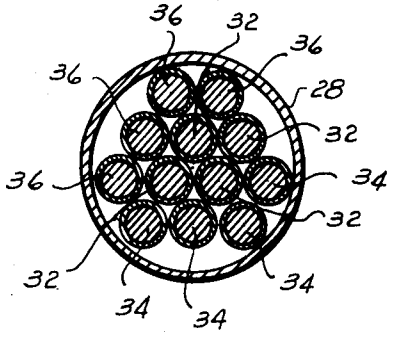


Fig 6

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THERMAL MULTIPLIER

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13 Claims. (Cl. 307—149)

My invention relates to an improved thermal multiplier and more particularly to an electrical means for multiplying and dividing voltages to obtain a voltaget proportional to the product or quotient of the amplitudes of any two given voltages.

In the prior art, voltages have been multiplied through servo-controlled potentiometers. Then too, it has been suggested to use a thermistor, controlled by a heater, connected in loop circuit together with a second thermistor also controlled by the heater and connected in a second circuit. Some devices according to this construction require the use of a load to bias the system in a given direction. None of the arrangements employing thermistors are able to go to zero or reverse polarity. Furthermore, thermistors are unstable devices.

One object of my invention is to provide a multiplier employing a bridge network which will accurately multiply two given voltages to produce a voltage representing their product.

Another object of my invention is to provide a multiplier which will accurately multiply voltages, which has no moving parts.

Another object of my invention is to provide a thermal multiplier for multiplying voltages in which the polarity of one or both of the voltages to be multiplied may be either positive or negative.

Another object of my invention is to provide a thermal multiplier which avoids the use of thermistors and which requires no load.

Other and further objects of my invention will appear from the following description.

In the accompanying drawings which form part of the instant specification and which are to be read in conjunction therewith and in which like reference numerals are used to indicate like parts in the various views:

Figure 1 is a diagrammatic view of a thermal multiplier circuit containing one embodiment of my invention.

Figure 2 is a schematic view showing a thermal multiplier tube forming part of my thermal multiplier.

Figure 3 is a side elevation of the thermal multiplier tube shown schematically in Figure 2.

Figure 4 is a sectional view taken along the line **4—4** of Figure 3.

Figure 5 is an elevation view along the line **5—5** of Figure 3.

Figure 6 is an enlarged sectional view taken along the line **6—6** of Figure 3.

Referring now to Figure 3, the thermal multiplier tube, indicated generally by the reference numeral **10**, comprises a housing **12** made of glass or other appropriate material, provided with a base **14**, fitted with nine pins **16**. The interior **18** of the housing **12** is evacuated to a vacuum sufficiently low to prevent loss of heat through gas convection, as for example, a vacuum of at least two microns or better. A pair of heat resistant support discs **20** and **22** formed of mica or the like are positioned within the tube and connected by a pair of support rods **24**. The support discs carry a pair of sleeves **26** and **28** made of an appropriate heat resistant or heat conducting metal such as copper, silver, stainless steel or the like. Positioned within each sleeve **26** and **28**, I lodge three separate filaments composed of fine tungsten wire (approximate O. D. .005"). Each filament is four sleeve lengths long and is coated with aluminum oxide or other ceramic or heat resistant insulating material. The support rods **24** may be fitted with a handling member **30** by which the assembly may be positioned within the housing **12**.

The arrangement of the parts is such that the adjacent lengths of each filament are positioned in longitudinal proximity to each other within the sleeve, as can be seen by reference to Figure 6.

Referring now to Figure 2, it will be seen that the three filaments **32**, **34** and **36** are positioned within the sleeve **28**. The four lengths of the filament **32** are arranged as shown in Figure 6. The four lengths of filament **34** are positioned approximately as shown in Figure 6. Similarly, the four lengths of filament **36** are positioned adjacent to each other and in contact with portions of the other two filaments. Thus each filament contacts both of the other filaments through at least a portion of its length and contacts the wall of the sleeve. The three filaments **38**, **40** and **42**, which are lodged within the sleeve **26**, are similarly connected. One end of filament **34** is connected to one end of filament **40** by conductor **44**. Conductor **44** is connected to one of the terminal pins **16** of the base **14**. One end of filament **36** is connected to one end of filament **42** by conductor **46**, and this conductor is connected to one of the base pins. Similarly, one end of filament **32** is connected to one end of filament **38** by means of conductor **48** and this conductor is connected to another one of the base pins. This gives three base pins. The free ends of each of the six filaments are connected to a separate base pin as can be seen by reference to Figure 2, thus giving nine pins in all.

Referring now to Figure 1, resistors R_1, R_2 and R_3 correspond to the filaments **38**, **40** and **42**. Similarly, the resistors R'_1, R'_2 and R'_3 correspond to the filaments **32**, **34** and **36**, housed within the other sleeve.

In the use of the tube, as will be pointed out more fully hereinafter, one of the filaments in each sleeve acts as a controller and the other two filaments within each sleeve act as the controlled resistors. Advantageously, I may make the filaments of tungsten, which will receive a ceramic coating. The arrangement is such that due to the close proximity of the resistor filaments within the sleeve, the temperature assumed by one of the controlled filaments within a sleeve will, by heat transferred from the heater filament directly by radiation and through the sleeve, be assumed by the other controlled filament so that both of the controlled elements of the assembly will arrive at the same temperature over a period of time. This time limit is made as short as possible by the construction just described whereby comparatively large areas for heat radiation and heat exchange are presented.

The thermal multiplier tube just described is connected in a circuit shown in Figure 1. It is desired to multiply voltage E_1, impressed across the terminals **50** and **51**, by a voltage E_2, impressed across terminals **52** and **53**, to obtain a voltage E_0 across the terminals **54** and **56**. A first bridge, indicated generally by the reference numeral **60**, has no electrical connection with a second bridge, indicated generally by the reference numeral **62**. The bridge **60** comprises the resistors R_2 and R'_2 connected in a Wheatstone bridge with resistors R_4 and R_5, the values of the resistors R_4 and R_5 being equal. A constant voltage E_5 is impressed across the bridge input terminals **64** and **66**. One output terminal **68** of the bridge is connected by conductor **70** to the input of the amplifier. The other output terminal **72** of the bridge is connected to the terminal **51**. The terminal **50** is connected to the other side of the input to the amplifier **74**. If we consider the output voltage of the bridge **60** as E_4, the summation voltage of E_1 and E_4 represents the input to the amplifier **74**. A constant voltage is impressed across the terminals **76** and **78** of the control network indicated generally by the reference numeral **80**. The lengths of the filaments are such that $R'_1=R_1$, $R'_2=R_2$ and $R'_3=R_3$. The bridge network **62** is completed by a pair of resistors R_6 and R_7 which are of equal resistance.

Let us now assume that E_3 is the only voltage present. Due to the power developed, the temperature of the filament resistors within the sleeves are raised to a quiescent level. Now let us suppose an amplifier output E_A is developed. This voltage is transformed through transformer **82** to a center tapped secondary winding **84**. The voltage across resistor R_1 will equal E_3+E_A and

the voltage developed across resistor R'_1 will equal E_3-E_A. Thus R_1 will assume a higher temperature due to the increased current flowing through the resistor R_1 and resistor R'_1 will assume a lower temperature due to the reduced current flowing through it. Accordingly, the resistance R_1 will be higher in value, depending upon its temperature coefficient of resistance and the elevation of its temperature. R'_1 will assume a lower resistance, depending upon its temperature coefficient of resistance and the particular lower temperature reached by it. Since resistors R_2 and R_3 will be brought to the same temperature, which temperature is a function of the temperature of resistor R_1, their resistances will respectively increase as the resistance R_1 has increased. In a similar manner, the resistance R'_2 and R'_3 will be decreased as the resistance R'_1 has decreased. Since the external resistances R_4 and R_5 are equal, the variation in resistance R_2 with respect to R'_2 will unbalance bridge **60** so that its output voltage E_4 will equal KE_5 where the value of K is dependent upon the voltage E_A. The external resistor R_6 has a resistance equal to that of external resistor R_7 in the bridge **62**. Accordingly, this bridge will unbalance as the resistance of resistor R_3 changes with respect to the resistance of resistor R'_3. Accordingly, the output voltage of bridge **62**, E_0, will equal KE_2. Eliminating K from these equations, we get

$$E_0=\frac{E_4E_2}{E_5}$$

Let us now assume the application of an input voltage E_1 across terminals **50** and **51**. The amplifier will then develop a voltage E_A of a magnitude such that

$$E_1-E_4=E_e$$

in which K_e represents the error or difference between the input voltage E_1 and the output voltage of the bridge **60**. The gain of the amplifier **74** and the feed-back factor of the loop, however, is sufficiently high such that E_4 will be so small as to be negligible. In this manner, the bridge **60** automatically adjusts its unbalances by varying the resistance R_2 with respect to R'_2 as a function of the input voltage E_1 through the amplifier and the network **80** and my thermal multiplier tube.

Stated differently, the bridge **60** assumes such unbalance that its output voltage is a function of the input voltage applied across terminals **50** and **51**. It will be seen that this result is achieved irrespective of the value of the constant voltage E_5. If, for example, voltage E_5 becomes greater, E_e will tend to become larger. This, however, varies the output of the amplifier in a direction such that the output of bridge **60** will seek the level of the voltage E_1 or in a direction tending to reduce E_e to zero. In other words, the arrangement is such that the output of the amplifier acting through the network **80** and the thermal multiplier tube so adjusts the value of the resistance R_2 with respect to the value of the resistance R'_1 as to reduce the error E_e to zero.

Since, as we have seen, E_1 is equal to E_4, we may substitute E_1 for E_4 in the equation for E_0 above. Thus we obtain

$$E_0=\frac{E_1E_2}{E_5}$$

Since E_5 is a constant, we have accomplished the multiplication desired. The output of bridge **62**, E_0, will be the product of the input voltage E_1 multiplied by the multiplying voltage E_2.

Owing to the arrangement of my invention just described, if no voltage is applied to the terminals **50** and **51**, the bridge **60** will remain in balance with a zero voltage output. In other words, both resistors R_1 and R'_1 will be heated to the same temperature and hence resistors R_2 and R'_2 will remain equal in value. Similarly, resistors R_3 and R'_3 will remain equal in value. Accordingly, the output E_0 of my multiplier will be zero irrespective of what voltage is applied across terminals **52** and **53**. In a similar manner the polarity of the voltage E_1 will determine the polarity of the product together with the polarity of the voltage E_2. If, for example, voltage E_1 were of negative polarity, while voltage E_2 were of positive polarity, the change of value of the resistance of resistor R'_1 with respect to the value of the resistance of the resistor R_1 would be in the opposite direction from that which would occur if E_1 were of positive polarity. Stated differently, if the positive terminal of a voltage were applied to terminal **50**, the bridge would be unbalanced in one direction. If a negative potential were applied to terminal **50**, the bridge **60** would unbalance in the opposite direction. It will be seen, therefore, with my multiplier, the polarity of output voltage E_0 can reverse and can go through zero. This is not possible with the voltage multiplying arrangements employing thermistors requiring a load.

By making resistors R_1 and R'_1 equal to each other, resistors R_2 and R'_2 equal to each other, and resistors R_3 and R'_3 equal to each other, and making the controlled resistance elements subject to the same temperature conditions, a very accurate result can be obtained. Since the resistors are made out of the same material, they will behave similarly. The particular temperature coefficients of resistance need not be known. Sufficient time, of course, must be allowed to permit a stable temperature condition to be reached. The construction of my thermal multiplier is such that this is reached in a comparatively short period of time. Extended heat-exchange surfaces are provided by employing resistors of small cross-sectional area and comparatively great lengths pressed closely adjacent each other and by making the sleeve tubes of heat resistant and heat conducting material. The two sleeves **26** and **28** are supported by heat insulating material so substantially no conduction between the sleeves takes place. The evacuated envelope in which the sleeves are placed, prevents all passage of radiant heat energy from one sleeve to the other. Accordingly, each sleeve **26** and **28** will assume its own temperature, independent of the temperature of the other sleeve.

It will be seen that I have accomplished the objects of my invention. I have provided a multiplier employing a bridge network which will accurately multiply two given voltages to produce a voltage representing their product. I have provided a thermal multiplier for multiplying voltages which has no moving parts and in which the polarity of one or both of the voltages to be multiplied may be either positive or negative. I have provided a novel multiplier tube which is of especial use in my thermal multiplier. It will be further observed that by the simple expedient of keeping voltage E_2 constant and varying the voltage E_5, inverse multiplication and division can be readily performed, as will be apparent to those skilled in the art.

It will be understood that certain features and subcombinations are of utility and may be employed without reference to other features and subcombinations. This is contemplated by and is within the scope of my claims. It is further obvious that various changes may be made in details within the scope of my claims without departing from the spirit of my invention. It is therefore to be understood that my invention is not to be limited to the specific details shown and described.

Having thus described my invention, what I claim is:

1. A thermal multiplier including in combination a first pair of resistors and a second pair of resistors connected in a Wheatstone bridge having a pair of input terminals and a pair of output terminals, thermal means for varying the resistance of one of the first pair of resistors with respect to the resistance of the other of the first pair of resistors in accordance with a first voltage, means for impressing a second voltage across the input terminals of the bridge and means for removing a voltage representing the product of the first and second voltages from the output terminals of the bridge.

2. A thermal multiplier including in combination a first pair of resistors and a second pair of resistors connected in a Wheatstone bridge having a pair of input terminals and a pair of output terminals, thermal means for increasing the resistance of one of the first pair of resistors and for decreasing the resistance of the other of said first pair of resistors in accordance with a first voltage, means for impressing a second voltage across the input terminals of the bridge and means for removing a voltage representing the product of the first and second voltages from the output terminals of the bridge.

3. A thermal multiplier including in combination a first pair of resistors and a second pair of resistors connected in a Wheatstone bridge having a pair of input terminals and a pair of output terminals, thermal means for increasing the resistance of one of the first pair of resistors and for decreasing the resistance of the other of said first pair of resistors in accordance with a first voltage, means for impressing a second voltage across

the input terminals of the bridge and means for removing a voltage representing the product of the first and second voltages from the output terminals of the bridge, the temperature coefficients of resistance of the resistors of the first pair and their resistances being equal and the resistances of the resistors of said second pair being equal.

4. A thermal multiplier including in combination a first pair of resistors and a second pair of resistors connected in a Wheatstone bridge having a pair of input terminals and a pair of output terminals, a heating resistor, means for positioning one of the resistors of the first pair in heat-exchange relation with the heating resistor, means for heating the heating resistor in accordance with a first voltage whereby to unbalance the bridge agreeable thereto, means for impressing a second voltage across the input terminals of the bridge and means for removing a voltage representing the product of the first and second voltages from the output terminals of the bridge.

5. A thermal multiplier including in combination a first pair of resistors and a second pair of resistors connected in a Wheatstone bridge having a pair of input terminals and a pair of output terminals, the resistances and the thermal coefficients of resistance of the resistors of the first pair being equal, the resistances of the resistors of the second pair being equal, a pair of heating resistors, means for positioning one of the resistors of the first pair in heat-exchange relation with one of the heating resistors, means for positioning the other resistor of the first pair in heat-exchange relation with the other of said heating resistors, means for heating said heating resistors, means agreeable to a first voltage for increasing the heating of the first heating resistor and for decreasing the heating of the second heating resistor whereby to unbalance the bridge in proportion to said first voltage, means for impressing a second voltage across the input terminals of the bridge and means for removing a voltage representing the product of the first and second voltages from the output terminals of the bridge.

6. A thermal multiplier including in combination a first pair of resistors and a second pair of resistors connected in a Wheatstone bridge having a pair of input and a pair of output terminals, a third pair of resistors and a fourth pair of resistors connected in a second Wheatstone bridge having a pair of input terminals and a pair of output terminals, a heating resistor, means for impressing a constant voltage across the input terminals of the second bridge, means for impressing the output voltage of the second bridge and a first voltage in series across the heating resistor, means for positioning one of the resistors of the first pair and one of the resistors of the third pair in heat-exchange relation with said heating resistor, whereby to unbalance the second bridge to bring its output voltage equal to the first voltage and opposite in sign and to unbalance the first bridge agreeable to the first voltage, means for impressing a second voltage across the input terminals of the first bridge and means for removing a voltage representing the product of the first and second voltages from the output terminals of the first bridge.

7. A thermal multiplier including in combination a first pair of resistors equal in resistance and having the same temperature coefficient of resistance, a second pair of resistors equal in resistance connected in a Wheatstone bridge having a pair of input terminals and a pair of output terminals, a third pair of resistors equal in resistance and having the same temperature coefficient of resistance and a fourth pair of resistors equal in resistance connected in a second Wheatstone bridge having a pair of input terminals and a pair of output terminals, means for impressing a constant voltage across the input terminals of the second bridge, a pair of heating resistors, means for impressing a second constant voltage across the pair of heating resistors whereby to raise their temperatures, means for impressing the output voltage of the second bridge and a first voltage across said heating resistors in push-pull relationship whereby to increase the temperature of one of said heating resistors and decrease the temperature of the other of said heating resistors, means for positioning one of the resistors of the first pair and one of the resistors of the third pair in heat-exchange relation with one of the heating resistors, means for positioning the other of the resistors of the first pair and the other of the resistors of the third pair in heat-exchange relation with the other of said heating resistors whereby to unbalance the second bridge to bring its output voltage to a value equal to the first voltage and opposite in sign and to unbalance the first bridge in proportion to the first voltage, means for impressing a second voltage across the input terminals of the first bridge and means for removing a voltage representing the product of the first and second voltages from the output terminals of the first bridge.

8. A thermal multiplier including in combination a multiplying bridge, a control bridge and a heating network, said multiplying bridge comprising a first pair of resistors having equal resistances and equal temperature coefficients of resistance and a second pair of resistors equal in resistance connected in a Wheatstone bridge having a pair of input terminals and a pair of output terminals, said control bridge comprising a third pair of resistors equal in resistance and having the same temperature coefficient of resistance and a fourth pair of resistors equal in resistance connected in a second Wheatstone bridge having a pair of input terminals and a pair of output terminals, said heating network comprising a pair of heating resistors having equal resistances connected in a network with a center tapped secondary winding of a transformer having a primary winding, means for impressing a first constant voltage across the input terminals of the control bridge, means for impressing a second constant voltage across said heating resistors in parallel whereby to raise the temperature of said heating resistors, an amplifier having a pair of input terminals and a pair of output terminals, means for connecting the output of the amplifier across the primary winding of the transformer, means for impressing the output voltage of the control bridge and a first voltage in series across the input terminals of the amplifier whereby to increase the voltage across one of said heating resistors and decrease the voltage across the other of said heating resistors in proportion to said first voltage, means for positioning one of the resistances of the first pair and one of the resistances of the third pair in heat-exchange relation with one of the heating resistors, means for placing the other of the resistors of the first pair and the other of the resistors of the third pair in heat-exchange relation with the other of said heating resistors, the sign of the first constant voltage being such that the thermal unbalancing of the control bridge will be such that its output voltage will be equal to the first voltage and opposite in sign, means for impressing a second voltage across the input terminals of the multiplying bridge, the constuction being such that the multiplying bridge will be thermally unbalanced proportional to said first voltage, and means for removing a voltage representing the product of the first and second voltages from the output terminals of the multiplying bridge.

9. A thermal multiplier tube including in combination a first resistor, a second resistor, means for positioning said resistors in heat-exchange relation with each other, means for electrically insulating the resistors from each other, means for applying a heating voltage across the first resistor and means for connecting the second resistor in a thermal multiplier circuit.

10. A thermal multiplier tube including in combination a heat-conducting sleeve, a heating resistor positioned in said sleeve, a heated resistor positioned in said sleeve in heat-exchange relation with the heating resistor, means for electrically insulating the resistors from each other, means for applying a heating voltage across the heating resistor and means for connecting the heated resistor in a thermal multipiler circuit.

11. A thermal multiplier including in combination a heat-conducting sleeve, a heating resistor positioned in said sleeve, a pair of heated resistors positioned in said sleeve in heat-exchange relation with the heating resistor, means for electrically insulating the resistors from each other, means for applying a heating voltage across the heating resistor and means for connecting each of the pair of heated resistors in a thermal multiplier circuit.

12. A thermal multiplier including in combination an evacuated envelope, a first heat-conducting sleeve supported in said envelope, a second heat-conducting sleeve supported in said envelope and thermally insulated therefrom, a first heating resistor positioned in the first sleeve, a first heated resistor positioned in the first sleeve in heat-exchange relation with the first heating resistor, means for electrically insulating the first heating and

heated resistors from each other, a second heating resistor positioned in the second sleeve, a second heated resistor positioned in the second sleeve in heat-exchange relation with the second heating resistor, means for electrically insulating the second heating resistor from the second heated resistor, means for applying a heating voltage across the first heating resistor, means for applying a heating voltage across the second heating resistors and means for connecting the first and second heated resistors in a thermal multiplier circuit.

13. A thermal multiplier tube including in combination an evacuated envelope, a first heat conducting sleeve positioned in said envelope, a second heat-conducting sleeve positioned in said envelope and thermally insulated therefrom, a first heating resistor positioned in the first sleeve, a first pair of heated resistors positioned in the sleeve in heat-exchange relation with the first resistor, means for electrically insulating the first heating resistor

and each of the first pair of heated resistors from each other, a second heating resistor positioned in the second sleeve, a second pair of heated resistors positioned in the second sleeve in heat-exchange relation with the second heating resistor, means for electrically insulating the second heating resistor and each of said second pair of heated resistors from each other, means for applying a heating voltage across said first heating resistor, means for applying a heaping voltage across the second heating resistor and means for connecting said first and second pairs of heated resistors in a thermal multiplier circuit.

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