Jan. 2, 1968 YASUTSUGU TAKEDA ETAL 3,361,928
TRANSFORMERS HAVING A PLURALITY OF SECONDARY WINDINGS AND CHARGED PARTICLE SOURCES OF DOUBLE PULSING SYSTEM UTILIZING SUCH TRANSFORMERS
Filed Nov. 29, 1963 3 Sheets-Sheet 1

Fig. 1 (a)

PRIOR ART

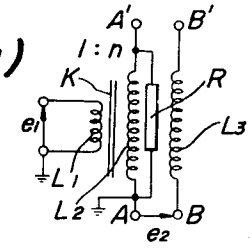
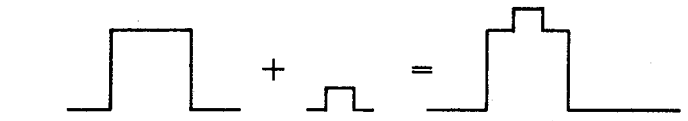



Fig. 1 (b)



Wave form of voltage at point A' + Wave form of second signal voltage = Wave form of voltage at point B'

Fig. 2 (a)

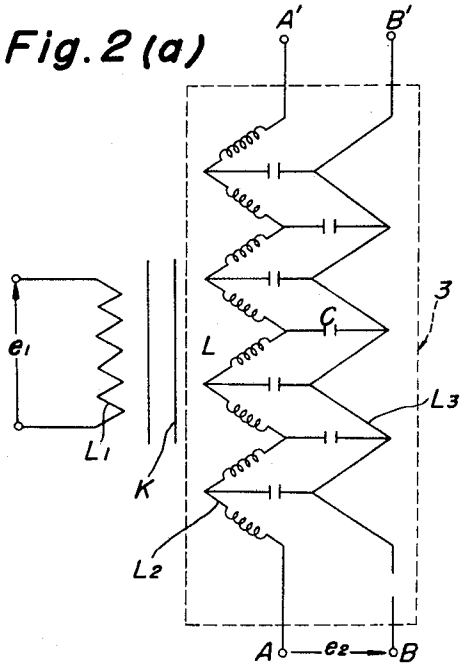
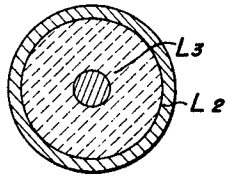



Fig. 2 (b)




INVENTORS
YASUTSUGU TAKEDA
ISAO MATSUI
BY Paul M. Craig, Jr.
ATTORNEY

Jan. 2, 1968 YASUTSUGU TAKEDA ETAL 3,361,928
TRANSFORMERS HAVING A PLURALITY OF SECONDARY WINDINGS AND CHARGED PARTICLE SOURCES OF DOUBLE PULSING SYSTEM UTILIZING SUCH TRANSFORMERS
Filed Nov. 29, 1963 3 Sheets-Sheet 2

Fig. 3
PRIOR ART

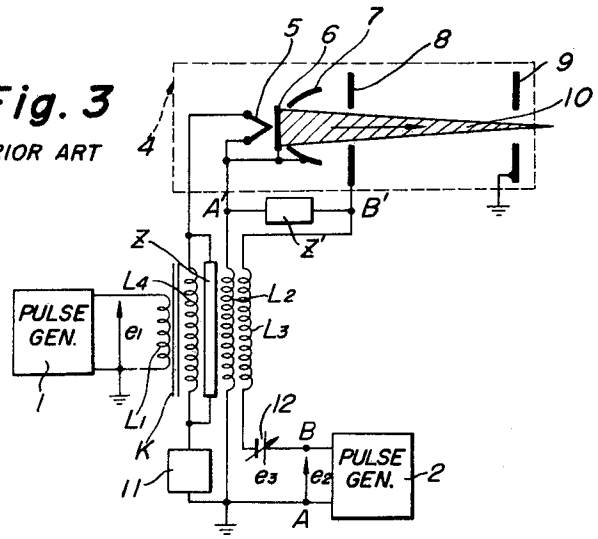
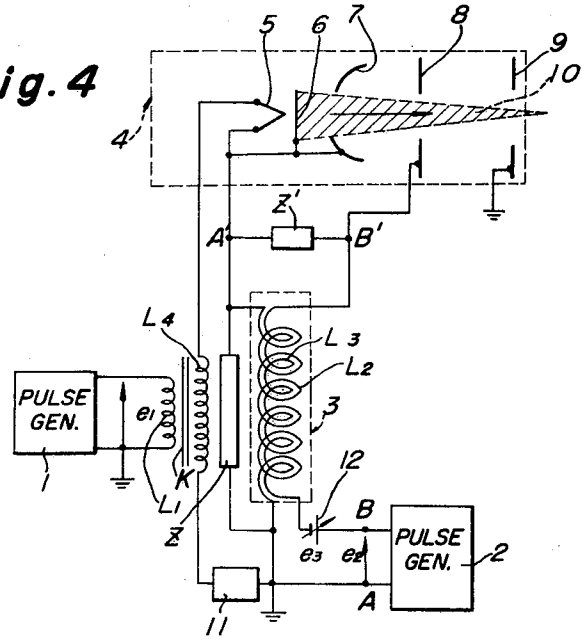



Fig. 4




INVENTORS
YASUTSUGU TAKEDA
ISAO MATSUI
BY Paul M. Craig, Jr.
ATTORNEY

Fig. 5

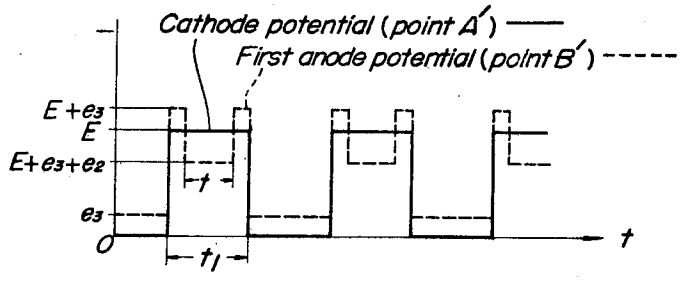
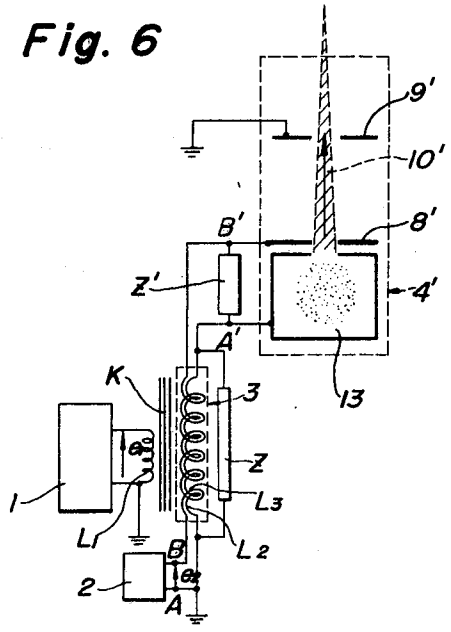



Fig. 6




INVENTORS
YASUTSUGU TAKEDA
ISAO MATSUI
BY Paul M. Craig, Jr.
ATTORNEY

United States Patent Office 3,361,928
Patented Jan. 2, 1968



3,361,928

# TRANSFORMERS HAVING A PLURALITY OF SECONDARY WINDINGS AND CHARGED PARTICLE SOURCES OF DOUBLE PULSING SYSTEM UTILIZING SUCH TRANSFORMERS

Yasutsugu Takeda, Tokyo, and Isao Matsui, Hachioji-shi, Japan, assignors to Hitachi, Ltd., Tokyo, Japan, a corporation of Japan

Filed Nov. 29, 1963, Ser. No. 326,961
Claims priority, application Japan, Nov. 28, 1962, 37/52,185; Aug. 20, 1963, 38/43,610
7 Claims. (Cl. 315—30)

The present invention relates to an improvement in a transformer having a plurality of secondary windings and to a charged particle source double pulsing system utilizing such transformer.

An object of the invention is to provide a novel and unique transformer having a plurality of secondary windings whereby a high-fidelity transmission of signals can be made over a wide frequency band. More particularly, the invention intends to provide a transformer having a plurality of secondary windings comprising a distributed constant transmission line constituted by at least two windings of said secondary windings in a manner that said transmission line is provided with good high-frequency band characteristics as well as a good characteristic impedance which is uniform over a wide frequency band, said transmission line being adapted for receiving a second signal voltage at one end thereof, and terminated at the other end by a load impedance element which is approximately matched with the characteristic impedance $Z_0$ of said line.

Another object of the invention is to provide an effective combination of a charged particle source and said transformer having the plurality of secondary windings in order to improve wave form and control characteristic of beam current of a charged particle beam pulsing output. More particularly, the invention intends to provide a charged particle source comprising a high-voltage pulse transformer having a plurality of secondary windings in which a first pulse of high voltage induced between both terminals of said secondary windings is used as an injection voltage for the charged particles, and a distributed constant transmission line constituted by at least two windings of said plurality of secondary windings in which one end of said line is terminated by a load impedance element in matching relation with a characteristic impedance of said line and the other end is arranged to receive the supply of a second pulse voltage therethrough, said second pulse voltage transmitted between both terminals of said load impedance element being utilized as a current control voltage for charged particles.

According to the invention, there is provided a transformer having a plurality of secondary windings comprising a distributed constant transmission line constituted by at least two windings of said secondary windings, said transmission line having a uniform characteristic impedance over a wide frequency band.

According to the invention, there is also provided a charged particle source comprising a high-voltage pulse transformer having a plurality of secondary windings, a distributed constant transmission line constituted by at least two windings of said secondary windings, a first pulse generator for impressing a first pulse voltage on the primary winding of said transformer, a load impedance element disposed at one end of said transmission line, said load impedance element being in matching relation with the characteristic impedance of said line, and a second pulse generator connected to the other end of said line for supplying a second pulse voltage thereto, wherein the high pulse voltage induced between both terminals of said secondary windings is used as a beam injection voltage for charged particles, and the pulse voltage transmitted between both terminals of said load impedance element is used as a current control voltage for the charged particles.



There are other objects and particularities of the invention which will be obvious from the following description with reference to the accompanying drawings, in which:

FIG. 1A is a schematic circuit diagram of a conventional transformer having a plurality of secondary windings;

FIG. 1B is a diagram showing the ideal wave forms of output potentials obtained by the transformer of FIG. 1A;

FIG. 2A is a diagram showing a circuit arrangement of a transformer based on the principle of the invention;

FIG. 2B is a transverse sectional view of a coaxial cable used as the secondary windings of the transformer of FIG. 2B;

FIG. 3 is a schematic circuit diagram of a charged particle source of double pulsing system wherein its modulation circuit comprises a conventional transformer having a plurality of secondary windings;

FIG. 4 is a schematic circuit diagram of an embodiment of a charged particle source of double pulsing system wherein its modulation circuit comprises a transformer according to the invention;

FIG. 5 is a diagram showing the relation of potentials in the charged particle source of FIG. 4; and

FIG. 6 is a schematic circuit diagram of an embodiment of an ion source of double pulsing system wherein its modulation circuit comprises the transformer according to the invention.

In FIG. 1A, there is shown a transformer having a plurality of windings on its secondary side. In this transformer, an output voltage $E=ne_1$, which is the product of a first signal voltage $e_1$ impressed on its primary winding $L_1$ and a winding ratio $n$, is induced between terminals A and A' and B and B' of its secondary windings $L_2$ and $L_3$. At the same time, in the transformer, a second input signal voltage $e_2$ supplied between the terminals A and B of the secondary windings $L_2$ and $L_3$ will be impressed between the other terminals A' and B'. In this case, the voltages at the points A' and B' are E and $E+e_2$, respectively. That is, the voltage induced at the point B' is the sum of the voltage E induced at the point A' and the second signal voltage $e_2$, as shown in FIG. 1B. In FIG. 1A, R and K denote a matched load resistance and a core of the transformer, respectively.

However, the transformer of the type having a plurality of secondary windings generally known in the art has poor impedance matching between said secondary windings. For example, said transformer is defective in that, when the second signal voltage in the form of a pulse signal is impressed between the terminals A and B, sharpness and flatness of the wave form of the pulse voltage transmitted between the terminals A' and B' is remarkably impaired. Therefore, with such transformer, it is a matter of extreme difficulty to effect the transmission of a signal with a wave form of high fidelity over a wide frequency band. This is a great drawback for the service intended by the transformer of the type having such secondary windings.

The Pierce type three electrode electron gun which is widely used in electron accelerators such as a linear electron accelerator is featured among other characteristics by the following merits: (1) Output beam current and pulse width can optionally be varied independently of beam injection voltage; (2) convergence of the electron beam can be regulated independently of values of its current, beam injection voltage and the like factor; and (3) the generated electron beam has a good wave form.

The good wave form referred to above indicates a wave form which has sharp edges and a flat top.

In FIG. 3, by way of an example of a conventional device of the kind described, the Pierce type electron gun double pulsing system is illustrated which comprises a pulse transformer having a plurality of windings and is adapted to be incorporated in an electron accelerator such as a linear electron accelerator. The device shown in FIG. 3 comprises pulse generators **1** and **2** of any conventional configuration capable of generating rectangular waves, a pulse transformer having a primary winding $L_1$, secondary windings $L_2$, $L_3$ and $L_4$, a core K, and matching load resistances Z and Z'. The Pierce type electron gun is generally indicated at **4**, which as shown comprises a cathode heating filament **5**, cathode **6**, Wehnelt electrode **7**, first anode electrode **8**, and second anode electrode **9**. An electron beam obtained by the electron gun is shown by numeral **10**. Numerals **11** and **12** indicate a filament heating source for said electron gun and a variable D.C. power supply for first anode bias voltage, respectively.

In the arrangement as shown in FIG. 3, the second anode electrode **9** is commonly made to have earth potential, and a first high-voltage pulse, for example, of the order of a pulse width of 5 μsec., recurrence frequency of 360 c./s. and maximum voltage of −40 kv. is impressed on the cathode **6** by means of the pulse generator **1** and the pulse transformer. At the same time, a D.C. bias voltage of the order of −400 v. D.C. is commonly impressed on the first anode electrode **8** against said cathode potential by means of the bias voltage supply **12** so as to keep the electron gun **4** in a cut-off state. In order to obtain the electron beam from the electron gun, a second pulse voltage, for example, of the order of 4 kv. is impressed on the first anode electrode **8** by the pulse generator **2** in series with said bias voltage supply **12** at such time when said second pulse voltage may be superposed on said first high-voltage pulse. Then, the electron gun **4** is freed from the cut-off state only during a time corresponding to the pulse width of said second pulse voltage, and thus electrons are freed from the cathode **6** to be emitted in the form of the electron beam **10** of required pulse shape.

However, as a result of various tests, it has been disclosed that the conventional devices as described above have the following defect. Since such indefinite amounts as mutual inductance of the secondary windings $L_2$ and $L_3$ of the pulse transformer, leakage inductance of each winding and stray capacitance are interposed in the secondary windings, the wave form of the second pulse voltage impressed between the terminals A and B of FIG. 3 will become extremely irregular before it is transmitted between the terminals A' and B' due to such indefinite and complicated impedance division. With such arrangement, required control of the pulsing beam will be a matter of impossibility.

The present invention obviates the drawbacks of prior devices and provides an improved device of the type as will be described in detail hereinunder.

FIG. 2A shows a transformer based on the principle of the invention. In the transformer, two secondary windings $L_2$ and $L_3$ constitute a distributed constant transmission line **3**. The distributed constant transmission line **3** may be formed, for example, of a single coaxial cable having uniform impedance, as shown in FIG. 2B, which comprises the inner conductor $L_3$ coaxially disposed within the outer conductor $L_2$. Said coaxial cable is wound about a central core K. Since the outer and inner conductors $L_2$ and $L_3$ of the coaxial cable **3** equivalently constitute the distributed constant transmission line, the characteristic impedance $Z_o$ of the coaxial transmission line **3** takes a definite value which is determined from the formula $Z_o=\sqrt{L/C}$, wherein L is a distributed conductance between the two conductors $L_2$ and $L_3$, and C is a distributed capacitance. Therefore, it will be extremely easy to obtain matching between output impedance $Z_g$ of the signal voltage supply to be connected between the terminals A and B of the transmission line **3** and load impedance $Z_e$ to be connected between the terminals A' and B', and characteristic impedance $Z_o$ of the transmission line **3**. Further, since this matching is maintained over a wide frequency band, the wave form of the second signal voltage impressed between the terminals A and B can be transmitted with fidelity between the terminals A' and B'. Thus, it will be understood that the transformer of the invention comprises the distributed constant transmission line having uniform characteristic impedance formed by at least two windings of the plurality of secondary windings and has a notable merit in that a signal wave form can be transmitted with fidelity through said transmission line over a wide frequency band.



FIG. 4 illustrates the Pierce type electron gun double pulsing system wherein its modulation circuit comprises the pulse transformer of the invention having a plurality of secondary windings. In FIG. 4, like parts illustrated in FIG. 3 are shown by like numerals to indicate their identity. In the drawing, numeral **3** designates a coaxial cable wound about a core K in a manner that its inner and outer conductors constitute the secondary windings $L_3$ and $L_2$ of the pulse transformer. Supposing that the secondary windings $L_2$, $L_3$ and $L_4$ have the same number of turns, with the turns ratio of the secondary windings to the primary winding $L_1$ being $n$, and a pulse voltage $e_1$ is impressed on the primary winding $L_1$ by the use of the first pulse generator **1**. Then, a voltage $E=-ne_1$ will be induced between the both terminals of each secondary winding $L_2$, $L_3$ and $L_4$. Therefore, the pulse voltage $E=-ne_1$ will be impressed on the cathode **6** as shown in FIG. 5. Meanwhile, a voltage comprising output pulse voltage $e_2$ of the second pulse generator **2** superposed on output voltage $e_3$ of the D.C. bias voltage supply **12** is transmitted between the terminals A' and B' by way of the distribution constant transmission line formed by the inner and outer conductors of the coaxial cable **3**. Therefore, the voltage at the first anode **8** relative to the cathode **6** varies from $e_3$ to $e_3+e_2$ in a pulsing manner as shown in FIG. 5. Therefore, by selecting the voltage $e_3$ of the D.C. bias voltage supply **12** in a manner that it has a sufficient value for maintaining the electron gun **4** in its cut-off state when there is no second pulse voltage $e_2$, by selecting the second pulse voltage $e_2$ in a manner that the electron gun **4** is freed from the cut-off state when said second pulse voltage $e_2$ is supplied, and by operating the first and second pulse generators in synchronism with each other so that the second pulse width $\tau_2$ is included within the first pulse width $\tau_1$, it is possible to take out the electron beam **10** from the cathode **6** during a period of the second pulse width $\tau_2$ only and thus to accelerate the electron beam. Further, in case the electron current taken out of the cathode **6** is in a space charge limited zone, the value of the current of the emitted electron beam can easily be controlled by varying the value of the pulse voltage $e_2$. Moreover, the pulse width of the electron beam taken out of the cathode **6** may easily be varied by varying the pulse width of the pulse voltage $e_2$. It will be apparent that such an electron gun double pulsing system can be effectively used as the modulation circuit of an electron accelerator such as a linear electron accelerator.

Hereinunder, description will be made on a more materialized basis with regard to actual performance of the device shown in FIG. 4. With the output pulse voltage $e_1$ of the first pulse generator **1** of 5 kv., pulse width of 5 μsec., recurrence frequency of 360 c./s., and turns ratio of the transformer windings $n=8$, the first pulse voltage of −40 kv. is impressed on the cathode **6**. On the other hand, bias voltage $e_3=-400$ v. for the first anode **8** with respect to the cathode **6** is provided by the D.C. bias voltage supply **12**, and the electron gun **4** is in its

cut-off state when there is no second pulse. Assume that the second pulse for taking out the beam has a voltage $e_2$ of 4 kv., pulse width of 2 μsec., and recurrence frequency of 360 c./s. When the second pulse voltage $e_2$ is added to said D.C. bias voltage $e_3$, the potential of the first anode **8** with respect to the cathode **6** is made to vary in a pulsing manner from −400 v. to +3.6 kv. Then, it is possible to obtain an intensive pulsing electron beam having a beam current of the order of 200 ma. with the pulse width of 2 μsec. and recurrence frequency of 360 c./s. Both of the pulse rise time and the pulse fall time of the second pulse voltage transmitted between the terminals A′ and B′ are below 0.05 μsec. when the coaxial cable **3** with the characteristic impedance $Z_0=50\Omega$ is used and a matching resistance Z′ of 50Ω is provided. On the contrary, in the conventional transformer as shown in FIG. 3 wherein no consideration is given to the impedance matching, measurement indicates 0.35 μsec. for both of the pulse rise time and pulse fall time. Therefore, it will be apparent that the invention provides a better characteristic than with the conventional arrangement. Thus, it will be known that, according to the device of the invention, the wave form of the pulse impressed between the terminals A and B of FIG. 2A can be transmitted under fidelity between the predetermined electrodes of the electron gun, and the device of the invention is advantageous in its ease and precision of control of the electron beam.

It should be understood that the invention is in no way limited to the electron gun as described hereinabove, and the invention is equally effectively applicable to the entirety of so-called charged particle sources including ion sources for emitting ions such as of hydrogen, helium or argon.

FIG. 6 shows a case wherein the invention is adapted to such ion source. In FIG. 6, like parts illustrated in FIGS. 3 and 4 are designated by like numerals to show the identity of those parts. Ions are generated in an ionization chamber **13** of an ion source **4** using discharge in magnetic fields. First pulse voltage of the order of 300~500 kv. with pulse width of 1 msec. and recurrence frequency of 10 c./s. is impressed on said ionization chamber **13** as an injection voltage. On the other hand, second pulse voltage of 0~10 kv. is impressed in synchronism with said first pulse voltage so as to draw out the ions from the ionization chamber **13** only during a desired period within the pulse width of said first pulse voltage while controlling an amount of an ion current **10′**. Then, it is possible to take out the desired definite amount of ion current during the period corresponding to the second pulse width. In FIG. 6, said first pulse voltage is obtained by boosting the pulse voltage $e_1$ generated by the pulse generator **1** in the pulse transformer $T_2$. The second pulse voltage is generated by the pulse generator **2** and transmitted to the high-voltage side through the coaxial secondary windings $L_2$ and $L_3$, for example, in the form of the coaxial cable **3**. Thus, the second pulse voltage can be impressed between a current control electrode **8′** and the ionization chamber **13** without being rendered irregular in its pulse wave form, and the pulsing ion current **10′** having satisfactory wave form can be obtained.

Charged particles of high energy obtained from the charged particle source of the invention comprising the electron gun or ion source having the constitution as described above are adapted, for example, for the purpose of irradiation on high polymer materials in the field of radio-chemistry or machining by charged particle beams or nuclear physics experiments. Further, when it is desired to obtain a charge particle beam of high energy, the pulsing charged particle beam with good wave form obtained by the device of the invention can be further accelerated by means of a linear electron accelerator or Van de Graaff accelerator which per se is well known.

What is claimed is:

**1.** In a charged particle beam generator including

(1) a charged particle source from which charged particles are emitted,

(2) accelerating means for accelerating the charged particles emitted from said charged particles source, and

(3) control means positioned between said charged particle source and said accelerating means for controlling the emission of the charged particles, the improvement comprising,

(4) a pulse transformer including a primary winding and a plurality of secondary windings, at least two of said secondary windings being formed into a distributed constant transmission line having a uniform characteristic impedance over a wide frequency band,

(5) means for supplying a first pulse voltage to said primary winding of said pulse transformer,

(6) a matching impedance element having an impedance matching the characteristic impedance of said distributed constant transmission line constituted of said two secondary windings of the pulse transformer,

(7) means for connecting said matching impedance element between one pair of corresponding end terminals of said two secondary windings at one end of the distributed constant transmission line,

(8) means for connecting said pair of end terminals to said charged particle source and control means, respectively,

(9) means for supplying a second pulse voltage between the other pair of end terminals of said two secondary windings positioned at the opposite end of the distributed constant transmission line to that of said first mentioned pair of end terminals, and

(10) means for connecting said accelerating means to one of said last mentioned pair of end terminals.

**2.** A charged particle beam generator as defined in claim **1**, wherein said means for supplying said first and second pulse voltages are synchronized to produce outputs substantially coincident in time.

**3.** A charged particle beam generator as defined in claim **2**, in which said first pulse voltage has a longer pulse duration of time than that of said second pulse voltage.

**4.** The combination comprising a pulse transformer including a primary winding and a plurality of secondary windings, at least two of said secondary windings being formed into a distributed constant transmission line having a uniform characteristic impedance over a wide frequency band, means for supplying a first pulse voltage to said primary winding of said pulse transformer, a matching impedance element having an impedance matching the impedance of said transmission line connected between the corresponding ends of said two secondary windings at one end of said transmission line, and means for supplying a second pulse voltage between the other ends of said two secondary windings positioned at the opposite ends of said transmission line to said one end thereof.

**5.** A charged particle beam generator as defined in claim **4**, wherein said means for supplying said first and second pulse voltages are synchronized to produce outputs substantially coincident in time.

**6.** A charged particle beam generator as defined in claim **4**, in which said first pulse voltage has a longer pulse duration of time than that of said second pulse voltage.

**7.** A pulse transformer comprising a primary winding and a plurality of secondary windings, at least two of said secondary windings being formed into a distributed constant transmission line having a uniform characteristic impedance over a wide frequency band, said two secondary windings being formed by a coaxial cable, said coaxial cable being formed of an inner conductor coaxially disposed within an outer conductor, said inner

and outer conductors being wound about a central conductor serving as the core of said transformer and being insulated from each other and from said core.


**References Cited**

UNITED STATES PATENTS

| | | | |
|---|---|---|---|
| 3,197,723 | 9/1965 | Dortort | 336—195 |
| 3,193,722 | 7/1965 | Opitz | 315—30 |
| 2,717,328 | 9/1955 | Kazan | 315—30 |





| | | | |
|---|---|---|---|
| 2,149,387 | 3/1939 | Brown | 336—195 |
| 2,814,759 | 11/1957 | Vonderschmitt | 328—228 |
| 2,912,616 | 11/1959 | Marchese | 315—14 |
| 3,051,918 | 8/1962 | Germeshausen | 333—26 X |
| 3,054,926 | 9/1962 | Graham | 328—231 X |
| 3,195,076 | 7/1965 | Morrison | 333—26 |



ORIS L. RADER, *Primary Examiner.*

T. J. MADDEN, *Assistant Examiner.*