**Aug. 21, 1962** C. E. M. TIBBS **3,050,606**

RADIO FREQUENCY DIELECTRIC HEATING APPARATUS

Filed Feb. 8, 1960 3 Sheets-Sheet 1

Fig. 1.

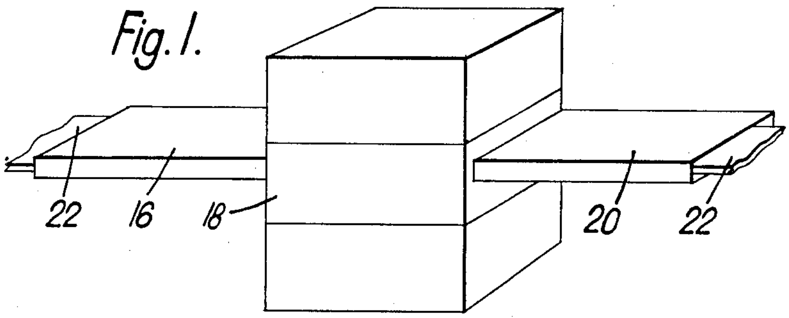



Fig. 2.

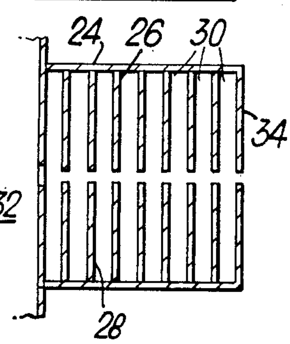



Fig. 3.

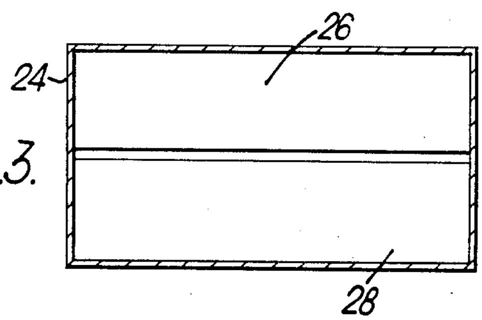
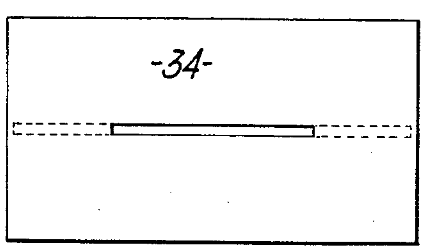



Fig. 4.

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RADIO FREQUENCY DIELECTRIC HEATING APPARATUS

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Fig.5.

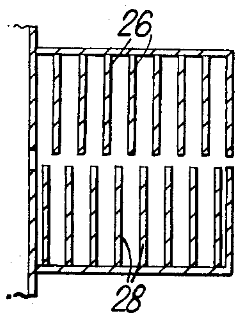


Fig.6.

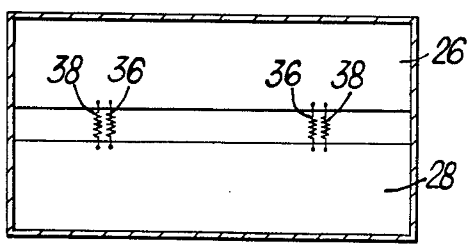


Fig.7.

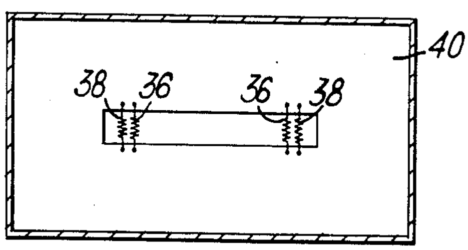


Fig.8.

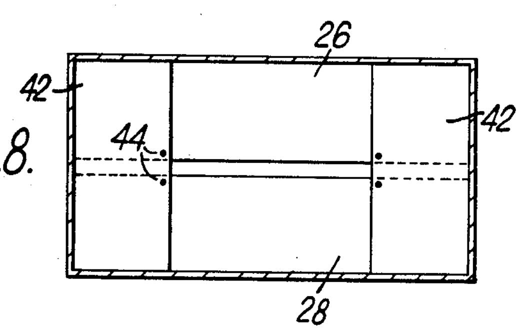


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Fig. 9.

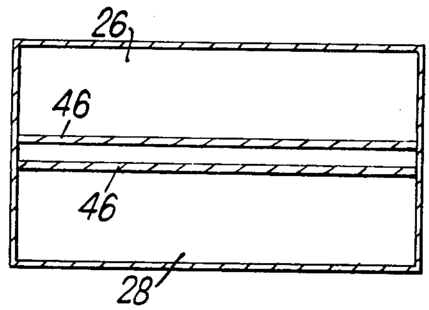



Fig. 10.

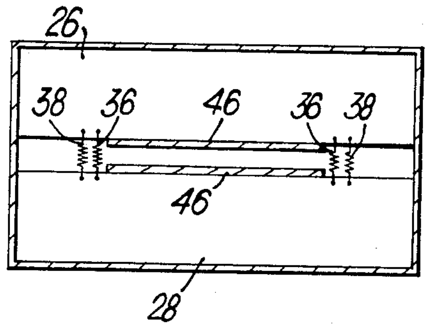



Fig. 11.

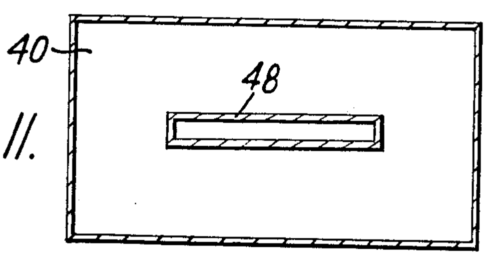



Fig. 13.

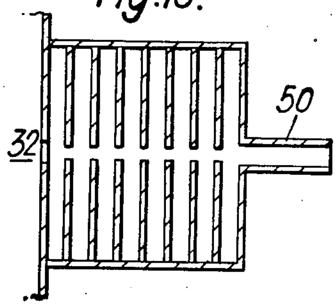
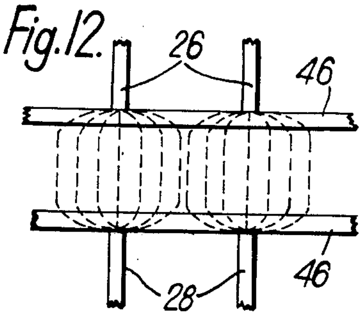



Fig. 12.

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# RADIO FREQUENCY DIELECTRIC HEATING APPARATUS

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Claims priority, application Great Britain Feb. 13, 1959
15 Claims. (Cl. 219—10.55)

This invention relates to radio frequency dielectric heating apparatus of the kind provided with a duct giving access to the heating enclosure.

Such ducts allow the escape of interference radiation, and the attenuation of such radiation is a major problem with apparatus of the kind. In micro-wave waveguide technique, signal-attenuating systems usually require a length equal to one or more wavelengths of the fundamental frequency carried by the waveguide. In dielectric heating apparatus operating at, for example, 36 mc./s., an attenuation of perhaps 30 db must be achieved in a fraction of a wavelength, and the attenuating devices must not obstruct the passage through the duct for the material to be heated. It has already been proposed to use ducts having a length equal to a quarter of the wavelength corresponding to the operational frequency of the apparatus. A conveyor band runs into the oven through the first duct and leaves the oven through the second duct. For an operating frequency of 40 mc./s. the length of each duct is about 7 feet. Ducts of this type are constructed of sheet metal, the width being just sufficient to pass the conveyor band whilst the height is usually just sufficient for the passage of the material to be heated in the dielectric oven.

Whilst ducts of this type achieve a moderate standard of suppression of radiation at the fundamental frequency they do not suppress harmonic radiation satisfactorily. In fact, they may even increase the harmonic radiation above the level which would result had no duct been fitted to the equipment. In one dielectric heating oven operating at approximately 40 mc./s. and using simple radiation ducts of the type describe of length 7 feet, width 3 feet, and internal height 3 inches, it was found that the interference radiation was reduced quite substantially at all frequencies up to 100 mc./s. Above 100 mc./s. the interference radiation began increasing quite rapidly until a frequency of about 150 mc./s. Above this frequency the interference radiation did not increase further. The difference between the level of radiation below about 100 mc./s. and that above 150 mc./s. was between 20 and 30 db. Measurements taken with the ratio frequency dielectric heating oven completely screened and with no ducts at all showed that the levels of harmonics radiated by the oven itself showed no such sudden step. The radiation at the fundamental frequency was normally somewhat higher than that at the harmonic frequency but the harmonics were of substantially equal magnitude up to at least 250 mc./s. The simple interference duct which has been used quite extensively up to the present time therefore produces a small but useful reduction in interference radiation up to a certain frequency above which the radiation level of some of the harmonics may well be increased by the presence of the ducts.

The rapid increase in the number of communication services of all types and in particular the increasing use of television has made it necessary to reduce the interference level radiated by dielectric heating ovens to a substantially lower level than was previously considered necessary. There have been several attempts to improve upon the amount of suppression given by the simple interference duct as described earlier. One known method of reducing radiation from ducts in apparatus of the kind described is to hang rows of trailing chains or other flexible screens from the roof of the duct. This is clearly undesirable as the chains may be pulled over the foodstuffs or other material on the conveyor band as it passes through the duct.

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Before going further, it will be found helpful to examine the reason for the presence of two levels of interference radiation passed by a simple duct. A duct of this type is in fact a short length of waveguide, and all waveguides have a critical pass frequency. For radiation below this critical pass frequency, the waveguide is regarded as operating in the "cut-off" region. In this cut-off region the waveguide shows a substantial attenuation of several db for every foot run of waveguide length. Above the critical frequency the waveguide attenuation is extremely small and it is an extremely efficient means of conveying the radio frequency energy from one point to another.

The critical frequency of the waveguide corresponds with that frequency which has a half wavelength equal to the largest dimension of the waveguide at right-angles to the waveguide axis. For a duct having a width of 36 inches and a height of 2 inches it will, therefore, be seen that the critical pass frequency of the duct when considered as a waveguide is governed by the width of the duct and is a little under 150 mc./s. Measurements show that in fact at and above this frequency there is little or no interference attenuation in a duct having these dimensions, while below this frequency the attenuation increases rapidly with falling frequency and then the rate of increase reduces and the attenuation seems to stabilise at about 100 mc./s., below which frequency the attenuation appears to be more or less constant once again.

According to the present invention the duct includes longitudinally spaced transverse electrically conductive partitions which are so shaped and arranged within the duct that a path is left from one end of the duct to the other for the passage of the material to be heated. The transverse partitions, which are preferably at right-angles to the length of the duct although they may be arranged obliquely across the duct, may take the form of upper partitions extending downwards from the roof to the top of the conveyor path and lower partitions extending upwards from the floor of the duct to the bottom of the conveyor path, or alternatively each partition may be in the form of a panel which closes the duct with the exception of an aperture through which passes the material to be heated. Resistors or resistive material may be connected between the upper and lower partitions or from top to bottom of the aperture in the conductive panel, at the sides of the passage for the material to be heated. Resistive panels may also be arranged parallel to the top and bottom of the duct, along the inner edges of the upper and lower partitions or the inner edges of the aperture in the conductive panel.

If it is desired to reduce the radiation at any particular frequency still further, an extension can be added to the duct defined above, the extension having a length which is equal to one-quarter of the wavelength corresponding to the frequency which is to be attenuated.

In order that the invention may be better understood, a number of embodiments will now be described with reference to the accompanying drawings, in which:

FIGURE 1 shows a typical dielectric heating oven provided with interference attenuation ducts;

FIGURE 2 is a longitudinal cross-sectional view through a duct according to the invention;

FIGURES 3 and 4 are respectively a transverse cross-sectional view and an end view of the duct of FIGURE 2;

FIGURE 5 shows a modified form of the duct of FIGURE 2;

FIGURE 6 shows a duct of the kind illustrated in FIGURE 2 to which resistive damping has been added;

FIGURES 7, 8, 9 and 10 show further forms of duct incorporating resistive damping;

FIGURE 11 shows a duct within which an inner duct of resistive material has been formed;

FIGURE 12 is a diagram explaining the electric field in a duct of the kind shown in FIGURE 11; and

FIGURE 13 is a longitudinal cross-sectional view through a duct provided with a quarter-wave extension.

FIGURE 1 shows diagrammatically a typical dielectric heating equipment of the kind to which the invention relates. An entrance duct **16** leads to a heating compartment **18**, the other side of which is connected to an exit duct **20**. A conveyor band **22** carries the material to be heated through the duct **16**, between a pair of electrodes in the heating compartment **18**, and then out through the duct **20**. In the past the ducts **16** and **20** have been made of sheet metal and with a length equal to one quarter of the wavelength corresponding to the fundamental operating frequency of the equipment. Radiation at the fundamental frequency was attenuated in this way, but the importance of suppressing harmonic radiation was not fully appreciated. When attenuation of radiation over a broad frequency band is desired, there is little advantage in calculating the duct length in this manner.

In the embodiment shown in FIGURES 2 to 4, the outer metal wall of the duct is represented at **24**, and the duct is divided by a series of transverse partitions **26** and **28** into a number of compartments **30**. Each transverse partition **26** or **28** is of electrically conductive material and the partitions **26** extend downwards from the top of the duct, the partitions **28** extending upwards from the bottom of the duct. The total height of the duct is 38 inches, the height of each partition is 18 inches, and the space between the upper and lower partitions is 2 inches. The effective electrical height of the duct, as far as the higher harmonic frequencies are concerned, is the space between the two partitions, that is to say 2 inches. The width of the duct is 72 inches and the length (that is to say the distance between the wall of the oven **32** and the outlet of the duct) is 36 inches. As shown in FIGURE 4, the end plates **34** of the duct are in the form of panels which close the duct except for a slot of width 36 inches and height 2 inches. The number of partitions in the duct has been reduced in FIGURE 2 to provide greater clarity. In practice, there were 18 compartments, the partitions being arranged at 2-inch intervals. If particularly strong attenuation of one particular frequency is required, each partition should have a height of about one quarter of a wavelength at this frequency. If the partitions are too small, the radiation will not be greatly attenuated above the critical frequency. The upper and lower partitions may have different heights, if desired.

FIGURE 5 shows a duct similar to that of FIGURE 2 except that the conductive partitions **26** and **28** are staggered in the longitudinal direction of the duct.

In an alternative form, instead of being separated by upper and lower partitions, the compartments **30** of FIGURE 2 may be separated by panels similar to the end plate **34** of FIGURE 4. In yet a further alternative, the compartments are separated by single partitions extending inwards from the top, bottom, or one side of the duct.

Increasing the height of the duct and inserting radiation-reflecting partitions, for example as shown in FIGURES 2 to 5, is found to increase the critical pass frequency of the duct by 50% or more, and in general to provide considerable attentuation of harmonic frequencies below the new critical frequency. However, it may be found that individual harmonics pass through such a duct with little attenuation.

FIGURE 6 shows a duct in which substantially non-inductive resistors **36** and **38** are connected between the upper and lower partitions **26** and **28**. The resistors **38** and **36** are spaced from the side wall by 17 inches and 18 inches respectively, and each resistor has a value of 100 ohms. In general, the effect of adding resistance damping to the radiation-reflecting partitions is to render more uniform the improvement in attenuation of the harmonic frequencies below the critical frequency. It will be found that by changing the values of the resistors **36** and the resistors **38**, the relative attenuation of the harmonic frequencies can be varied.



The duct shown in FIGURE 7 is similar to that of FIGURE 6 except that it employs panels **40** in place of the upper and lower partitions **26** and **28**. Again it is provided with the damping resistors **36** and **38**, the space between the inner resistors serving to provide a passage for the material to be heated. Damping resistors can also be connected between adjacent upper and lower partitions in the duct shown in FIGURE 5, in which the upper and lower partitions are staggered longitudinally.

The number of conductive partitions within the duct may be quite high. As an example the longitudinal spacing of the partitions may be only about one two-hundredths of a wavelength at the fundamental frequency of the radio frequency generator.

In FIGURE 6, the resistors, which are intended to carry radio frequency current which would otherwise have flowed in the side walls of the duct, should not be placed so close to the side wall that the impedance presented to the current by the side wall path is lower than that presented by the resistors.

In the form shown in FIGURE 8 the top and bottom partitions **26** and **28** are joined at each side by an inwardly projecting panel **42** which consists of graphite surfaced resin-bonded paper board. Each panel **42** is bolted to the two partitions at points **44** to provide good electrical contact with each of them.

As an example of the improvement brought about by the combination of conductive partitions and resistive damping, in one apparatus operating at 36 mc./s. the replacement of a duct without partitions or resistive damping by a duct having 18 compartments and provided with resistance damping gave an attenuation improvement of between 20 and 40 db at the second, fourth, fifth and sixth harmonics, and an attenuation improvement of about 10 db at the third harmonic, which with this particular apparatus was already at a comparatively low level with the original duct.

With the form of duct shown in FIGURE 9 there is a 2 inch longitudinal spacing between partitions, and two resistive panels **46** lie parallel with the top of the duct and extend for the whole of the length of the duct. The height of the space between the resistive panels is 4 inches. One panel **46** is connected to the lower edge of each of the upper partitions **26**, and the other panel **46** is similarly connected to the upper edges of each of the lower partitions **28**, the two panels forming an inner duct. We have found however that the panels **46** need not make contact with the conductive partitions, and that a small air gap between the edges of the conductive partitions and the panels **46** presents little impedance to the flow of radio frequency currents between the partitions and the panels.

In FIGURE 10 the panels **46** extend only for the width of the passage for the material to be heated and resistors **36** and **38** are connected between upper and lower partitions at the sides of this passage. In one embodiment employing the arrangement shown in FIGURE 10, the vertical distance between the horizontal resistive panels **46** was 4 inches, the longitudinal spacing between the transverse conductive partitions was 2 inches, and the two resistors of each pair were arranged at 17 inches and 18 inches from the nearest side of the duct. The resistive panels were of asbestos cement coated with resistance material to give a resistance of approximately 3,000 ohms per unit square of area. The end panels of the duct were of the form shown in FIGURE 4, but the height of the slot was 4 inches. A staggered arrangement of the partitions **26** and **28** can be used in the apparatus of FIGURES 9 and 10.

Resistive panels appear to be more effective than resistors in attenuating interference above the critical frequency, but the combination illustrated in FIGURE 10 is yet more effective, enabling an average attenuation improvement of 10–15 db above critical frequency in the tested equipment.

In FIGURE 11, an inner duct 48 of high surface resistance is spaced from the outer metal shell by a transverse conductive panel 40 having a slot to accommodate the inner duct, which consists of insulating board on the inner surface of which is deposited a high resistance film of carbon. Each metal panel 40 is bent at a right-angle at its inner and outer edges to form flanges (not shown) by means of which the panel is riveted or bolted to the inner duct 48 and also to the outer shell to provide good electrical contacts.

It appears that without the inner duct space current at frequencies above the critical frequency would flow between the top and bottom partitions, and that when an inner duct of high surface resistance is added, additional space current at these frequencies flows between the upper and lower walls of the inner duct. The inclusion of the high-resistance board seems to be equivalent to connecting resistors between successive transverse upper partitions and between successive transverse lower partitions, and capacitance exists between the upper and lower resistors. The additional space current between the upper and lower high-resistance boards has first to flow through the high resistance board, in which a substantial proportion of the space current is converted into heat, thereby attenuating the radiation from the duct. As shown in FIGURE 12, the connection of flat resistance panels across the edges of the conductive partitions by increasing the capacitance between the top and bottom of the duct also cause lines of electrostatic flux to flow outwards from the edges of the partitions, along the resistive panels, before crossing the gap between upper and lower panels.

The insulating panels 46 and 48 may be an asbestos cement board (for example, that sold under the trade name "Sindanyo" and made by Turners Asbestos Co. Ltd.) and it may be painted with a colloidal graphite solution to which a synthetic resin is added as binder, the painted board being baked for 15 to 30 minutes to produce the required stable conducting film. A suitable graphite solution is sold under the trade name "Dag" and is supplied by the makers (Acheson Colloids Ltd. of Plymouth, England), in mixes suitable for producing layers of medium resistance values. However, other materials such as wood, cardboard, concrete, foam rubber, foam polystyrene and textile materials may be employed in place of the asbestos cement board. As alternatives to painting a base board with a colloidal graphite solution, a thin sheet of high-resistance material can be used. Such a sheet can be produced, for example, by mixing powdered graphite with cement, and may have a thickness of three-eighths of an inch. Asbestos may be added to the board to improve its mechanical properties.

For maximum attenuation, the resistance of the board forming the inner duct should vary from point to point. In general, it should be lower at the sides of the duct and higher along the top and bottom surfaces of the duct, but the optimum values of resistance at different points will vary with the dimensions of the duct.

As stated above, the inclusion of resistive material in combination with the conductive partitions is found to have the effect of rendering more uniform the level of attenuation over the frequency band. Thus, if with a particular generator a duct employing conductive partitions only is found to allow one harmonic to pass through with little attenuation, the addition of resistors or resistive panels will in general improve the attenuation of this harmonic.

Further attenuation at the particular frequency may also be obtained by adding to a duct of the form shown in FIGURE 2 an extension having the cross-sectional dimensions of the aperture in the end panel of the duct of FIGURE 2 and having a length equal to approximately



one-quarter of a wavelength at the frequency for which additional attenuation is required. An arrangement of this kind is shown in FIGURE 13 in which the extension 50 has a length of 16¾ inches, which corresponds to a quarter wavelength at the frequency of 180 mc./s.

It was found that the addition of such an extension, with the generator previously referred to and with a duct provided with both partitions and resistors, provided further attenuation of about 15 db over a frequency band of ±10% of the calculated frequency, and could be used, for example to reduce interference over a television frequency band.

More than one quarter-wavelength extension 50 may be included. If desired, the quarter-wave extension 50 may be supplemented by a similar extension which projects from the inner end of the duct into the oven 32. This inner extension may be given a length equal to a quarter wavelength of a different harmonic frequency if desired.

Improved attenuation may also be obtained by placing end to end two or more ducts of the form shown in FIGURE 12 (that is to say including an extension 50), and again the extensions 50 may be of lengths equal to quarter-wavelengths of different harmonic frequency.

If desired, the individual resistors 36 in FIGURE 6 may be replaced by two continuous resistive panels connected to the upper and lower partitions at the points previously connected to the resistors 36. The two rows of resistors 38 may be similarly replaced by resistive panels.

The best results were obtained using a conveyor belt of insulating material. If a metal conveyor belt is used, it should make good electrical contact with the edges of the high-resistance duct, and where this is impossible there should be good capacitive coupling between the belt and the duct.

The height of the duct and therefore of the partitions within the duct can be varied from point to point along the duct in order to alter the shape of the attenuation characteristic over the required frequency range. Similarly, where resistors or resistive panels are used, the resistance values may be varied from point to point along the duct to give the desired attenuation characteristic.

I claim:

1. A radiation attenuation duct for radio frequency dielectric heating equipment having a fundamental frequency less than 500 mc./s., including a plurality of transverse electrically conductive partitions of sheet material, the planes of which make an angle with the direction of the duct and which are spaced from one another in the direction of the duct at distances which are small in comparison with a quarter wave length at the fundamental operating frequency of the equipment, the partitions being mounted within said duct to define a longitudinal path from one end of said duct to the other for the passage of the material to be heated.

2. A radiation attenuation duct according to claim 1, including an upper series of partitions which extend downwards from the top of the duct and a lower series of partitions which extend upwards from the bottom of the duct, said upper and lower partitions defining an intermediate longitudinal space for the passage of the material to be heated.

3. A radiation attenuation duct for radio frequency dielectric heating equipment having a fundamental frequencly less than 500 mc./s. including a plurality of transverse electrically conductive partitions of sheet material, the planes of which make an angle with the direction of the duct and which are spaced from one another in the direction of the duct at distances which are small in comparison with a quarter wave length at the fundamental operating frequency of the equipment, the plurality of partitions including an upper series extending downwards from the top of said duct and a lower series extending upwards from the bottom of said duct, the par-

titions of said lower series being staggered in the direction of the duct with respect to the partitions of said upper series and said upper and lower partitions defining an intermediate longitudinal space for the passage of the material to be heated.

4. A radiation attenuation duct according to claim 3, in which successive upper and lower partitions within said duct are connected by further electrically conductive partitions extending inwards from the sides of said duct.

5. A radiation attenuation duct according to claim 1, including means for dissipating radio-frequency electrical energy, mounted at the side of the passage for the material to be heated.

6. A radiation attenuation duct according to claim 1, in which the outer end of said duct is connected to an extension which is aligned with the passage for the material to be heated, whereby radiation at a frequency for which the length of the extension is approximately one-quarter of a wavelength is further attenuated.

7. Dielectric heating equipment comprising a heating compartment connected to at least one duct constructed in accordance with claim 1.

8. A radiation attenuation duct for radio frequency dielectric heating equipment having a fundamental frequency less than 500 mc./s., including a plurality of transverse electrically conductive panels of sheet material, the planes of which make an angle with the direction of the duct and which are spaced from one another in the direction of the duct at distances which are small in comparison with a quarter wavelength at the fundamental operating frequency of the equipment, the panels being mounted within said duct, each panel having external dimensions equal to the internal cross-sectional dimensions of the duct and being formed to define an aperture, the apertures in said panels being aligned within said duct to provide a path for the material to be heated.

9. A radiation attenuation duct according to claim 8, including at least one electrical resistor connected across said aperture in each panel, from the top of said aperture to the bottom, at the side of the passage for the material to be heated, said electrical resistor serving to dissipate radio frequency energy within said duct.

10. A radiation attenuation duct for radio-frequency dielectric heating equipment having a fundamental frequency less than 500 mc./s. including an upper series of longitudinally spaced transverse electrical conductive partitions mounted within and extending downwards from the top of said duct and a lower series of longitudinally spaced transverse electrically conductive partitions mounted within and extending upwards from the bottom of said duct, said partitions being of sheet material and longitudinally spaced from one another at distances which are small in comparison with a quarter-wavelength at the fundamental operating frequency of the equipment, said upper and lower partitions defining an intermediate longitudinal space for the passage of the material to be heated, and at least one electrical resistor connected between each pair of adjacent upper and lower partitions at the side of said passage to dissipate radio-frequency energy within said duct.

11. A radiation attenuation duct for radio-frequency dielectric heating equipment having a fundamental frequency less than 500 mc./s. including an upper series of longitudinally spaced transverse electrical conductive partitions mounted within and extending downwards from the top of said duct and a lower series of longitudinally spaced transverse electrically conductive partitions mounted within and extending upwards from the bottom of said duct, said partitions being of sheet material and having planes which make an angle with the direction of the duct and being spaced from one another in the direction of the duct at distances which are small in comparison with a quarter wavelength at the fundamental operating frequency of the equipment, said upper and lower partitions defining an intermediate longitudinal space for the passage of the material to be heated, and at least one resistive transverse panel extending inwards from the side of said duct to connect each pair of adjacent upper and lower partitions, said resistive transverse panel serving to dissipate radio-frequency energy within said duct.



12. A radiation attenuation duct for radio frequency dielectric heating equipment having a fundamental frequency less than 500 mc./s., including a plurality of transverse electrically conductive partitions of sheet material, the planes of which make an angle with the direction of the duct and which are spaced from one another in the direction of the duct at distances which are small in comparison with a quarter wavelength at the fundamental operating frequency of the equipment, the partitions being mounted within said duct to define a longitudinal path from one end of said duct to the other for the passage of the material to be heated, and a longitudinally arranged panel of resistive material forming a wall of said passage and electrically coupling the longitudinally aligned inner edges of said conductive partitions.

13. A radiation attenuation duct according to claim 12, including an inner duct the sides of which are formed by resistive material and which encloses the passage for the material to be heated, the inner duct being spaced from the outer duct by means of said transverse conductive partitions.

14. A radiation attenuation duct for radio frequency dielectric heating equipment having a fundamental frequency less than 500 mc./s. including a plurality of transverse electrically conductive partitions of sheet material, the planes of which make an angle with the direction of the duct and which are spaced from one another in the direction of the duct at distances which are small in comparison with a quarter wavelength at the fundamental operating frequency of the equipment, said plurality of partitions, including an upper series extending downwards from the top of said duct and a lower series extending upwards from the bottom of said duct, said duct further including at least one panel resistor which is parallel with and spaced from a side of said duct and which makes substantially continuous electrical contact with said upper and lower conductive partitions, said upper and lower partitions and said panel resistor defining a longitudinal space for the passage of the material to be heated.

15. A radiation attenuation duct for radio frequency dielectric heating equipment having a fundamental frequency less than 500 mc./s. including a plurality of transverse electrically conductive partitions of sheet material extending from one side of said duct to the other substantially at right angles to the direction of said duct, said partitions being spaced from one another in the direction of the duct at distances which are small in comparison with a quarter wave length at the fundamental operating frequency of the equipment, said plurality of partitions including an upper series extending downwards from the top of the duct and a lower series extending upwards from the bottom of the duct, the partitions of said lower series being vertically aligned with corresponding partitions of said upper series, said upper and lower partitions defining an intermediate longitudinal space for the passage of the material to be heated.

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