A high frequency microwave energy propagation and restricting device uses a structural arrangement which propagates applied electromagnetic energy with counter-directional phase and group velocity, and the phase velocity is made to be lower or higher than the phase velocity which the electromagnetic energy is propagated. The directionizing and restriction of the input electromagnetic energy into the device is controlled by means of an arrangement using a high-pass filter wherein the phase velocity and the group velocity of the electromagnetic waves are opposed to each other; alternatively, the device uses a low-pass filter wherein the group velocity and phase velocity of the electromagnetic waves have the same direction. The high-frequency energy propagation and restricting devices as of the present invention may be advantageously utilized and applied in microwave energy ovens or furnaces which may be of the static or the conveyor type. The device of the invention makes it possible to prevent and/or monitor loss of microwave energy from the zone in which energy is intended to be utilized to treat a workpiece or a product.

2 Claims, 31 Drawing Figures
MICROWAVE OVEN HAVING CONTROLLED WAVE PROPAGATING MEANS

This is a continuation of application Ser. No. 184,169, filed Sept. 27, 1971, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to high-frequency electrical devices comprising electrical high-frequency antenna and/or wave propagation restricting means such as chokes, and high-frequency ovens, furnaces and the like which are provided with such devices.

2. Description of Prior Art

Within the field of high-frequency and microwave technology, there is often a requirement for such devices as a directional antenna for transmitting and receiving electromagnetic waves in one direction only; also required are chokes for restricting the propagation of such waves so that said energy is kept within determined limits in the apparatus. Devices of the first mentioned type have hitherto mainly consisted of high-frequency, quarter-wave or half-wave antenna of the dipole type arranged in front of a reflecting surface at a distance of approximately one-fourth of a wavelength, while devices of the latter type often consist of pockets or recesses having a depth of one-fourth of a wavelength or slots having an extension of one-half of a wavelength, arranged in one or both of the aforementioned surfaces at such positions at which it is desired to arrest wave propagation. With such devices there is normally arranged in the vicinity of the dipole antenna a wave reflecting surface which extends transversely of the wave propagation path between wave propagation boundary surfaces. In certain practical applications of such devices, however, it is impossible to obtain perfect contact between the extremities of the reflecting surface and the wave propagation boundaries, and this results in a restricted application and utility of the device. Furthermore, chokes in the form of pockets, recesses, slots etc. have a deficiency in such applications in that they are only active within very narrow frequency ranges and consequently allow through a significant portion of the energy which it is desired to block.

Such deficiencies constitute a serious problem, particularly in the case of high-frequency heating apparatus and microwave ovens or furnaces in which goods to be heated, or treated in some other way with electrical high-frequency energy, are introduced into a cavity, which is then sealed off and the goods subjected to high-power electrical high-frequency energy, undue leakage of which cannot be tolerated. The same requirement with regard to energy leakage from high-frequency heating apparatus is also manifest in more open high-frequency apparatus. The maximum microwave energy dosage to which the human body can be subjected for long periods of time is 1 mw microwave energy per cm² of body surface. Higher dosages, however, are difficult to prevent, since the energy applied to such apparatus is often of the order of 1 kw or more, and, the development of high-frequency heating apparatus tends towards energies of the range of 10 kw to 100 kw.

SUMMARY OF THE INVENTION

This and other associated problems are solved with the system of the present invention, which is mainly characterized by periodic structures which propagate the applied electromagnetic energy with counter-directional phase and group velocity, and in that said phase velocity is equal to or higher than the phase velocity at which the same energy is propagated.

Stated in other words, the instant invention will be seen to constitute a device for disposition in a microwave apparatus for restrictively propagating incoming high-frequency electrical energy waves within a given frequency range. The device comprises a base and a plurality of parallelly-spaced electrically conductive elements supported thereon. These elements have a predetermined shape and orientation with respect to one another thereby effecting a predetermined mutual capacitance and inductance. The mutual capacitance and inductance effected is such as to define a high-pass filter which has unusual characteristics with respect to the propagating waves. Specifically, the high-pass filter acts as a controlled wave propagating means for propagating the incoming electrical energy waves within the given frequency range with counter-directional phase velocity and group velocity, the phase velocity in the high-pass filter being equal to or higher than a phase velocity at which the electrical energy waves are propagated in the periodic structure vicinity, the plurality of spaced conducting elements being divided into groups. The invention, therefore, is useful for propagating microwaves not only by absorption or reflection of received waves, but also by transmitting waves in a definite direction much like an antenna.

In its conventionally understood sense, the term “phase velocity” refers to the velocity of propagation of any one phase state, such as a point of zero instantaneous field, in a steady train of sinusoidal waves and it may differ from the velocity of propagation of the disturbance or group velocity. The term “group velocity” refers to the velocity of propagation of a pulse or group of waves.

Electrical high-frequency antenna and wave propagation restricting devices arranged above conducting surfaces in accordance with the invention can be made effective within a far wider frequency range than hitherto known similar devices, and will now be described in detail with reference to the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a diagrammatic illustration of a simplified embodiment of the present invention, adapted to receive and transmit electromagnetic waves and/or to limit wave propagation to within predetermined areas.

FIG. 2 illustrates a high pass filter of the single mode type forming part of the embodiment illustrated in FIG. 1 and with which the phase velocity and group velocity of the electromagnetic waves are opposed to each other.

FIG. 3 illustrates a low pass filter with which the group velocity and phase velocity of the electromagnetic waves have the same direction.

FIG. 4 is an ω-ω̃ diagram for the filters illustrated in FIGS. 2 and 3, in which the letter ω indicates the curve obtained with the filter of FIG. 2 and ω̃ the curve obtained with the filter of FIG. 3.

FIG. 5 illustrates the high pass filter of FIG. 2, modified to form a two-mode filter.

FIG. 6 illustrates the low pass filter of FIG. 3, also modified to form a two-mode filter.
FIG. 7 is an $\omega$-$\delta$ diagram showing the relationship of waves propagated along the filters of FIGS. 5 and 6, curves $a$ and $b$.

FIG. 8 is an $\omega$-$\delta$ diagram obtained with the filters of FIG. 5.

FIG. 9, FIG. 10, FIG. 11 and FIG. 12 and their sections A—A, B—B, C—C, D—D, E—E and F—F respectively illustrate different kinds of biperiodic structures.

FIG. 13 illustrates a conveyor type microwave furnace.

FIG. 14 with section C—C illustrates another type of belt or tunnel furnace.

FIGS. 15 and 16 illustrate microwave furnaces and apparatus comprising a rectangular cavity.


**DETAILED DESCRIPTION OF THE EMBODIMENTS**

Referring to FIG. 1, the system according to the invention comprises a periodic structure 1 and preferably a conducting surface 2. In the illustrated embodiment the surface 2 has an extension and the periodic structure is provided with a surface 4 and an extension 5 of said surface. The end of the periodic structure 1 located nearest the surface extensions 3, 4 is connected to an electric conductor which may be, for example, a coaxial conductor having an inner conductor 6 and an outer conductor 7. For electromagnetic waves propagated there along, the periodic structure 1 should present opposed phase and group velocity of the waves. Structures which fulfill these requirements may be designed in many different ways. They are often constructed of distributed circuit elements, although in principle they can also be constructed mainly of bunched circuit elements. The following description however will be made mainly with reference to distributed circuit elements. A periodic structure, such as the periodic structure 1 illustrated in the drawing, which fulfills the aforementioned requirements, consists of circuit elements including a high pass filter with series-connected capacitors 8 and parallel connected inductances 9, as illustrated in FIG. 2. The structure which propagates electromagnetic waves with co-directional phase and group velocities corresponds in the case of concentrated circuit elements to a low pass filter having series connected inductances 10 and parallel connected capacitors 11, as illustrated in FIG. 3. Wave propagation along periodic structures having the period $L$ is normally described by the $\omega$-$\delta$ diagram, in which $\omega$ is the angular frequency of the electromagnetic wave ($\omega = 2\pi f$ = the frequency) and 100 its electrical phase angle over the period length $L$. The phase angle $\phi$ can, in the case of wave propagation, also be expressed by the phase constant $\beta = (\omega/v)$ in which $v$ is the phase velocity of the propagating wave whereby a relation connecting $\phi$, $\beta$ and $L$ may be written as $\phi = \beta L$. FIG. 4 illustrates the $\omega$-$\phi$ diagram for electromagnetic waves along periodic structures where $a$ the phase velocity is opposed to the group velocity, thus the $\omega$-$\delta$ diagram for waves along high pass filters as shown in FIG. 2, and $b$ the $\omega$-$\phi$ diagram for periodic structures in which the phase velocity has the same direction as the group velocity, thus the structure illustrated in FIG. 3. The feature characteristic of case $a$ is that the phase angle $\phi$ is highest ($\phi = \pi$) at the lowest frequency and zero at the highest, and in case $b$ that the highest phase angle ($\phi = \pi$) appears at the highest frequency and the lowest phase angle ($\phi = 0$) appears at the lowest frequency. The phase velocity $v$ of the electromagnetic wave at a point in the $\omega$-$\delta$ diagram (FIG. 7) is equal to Ltg$\alpha$ for the angle $\alpha$, when a line through the origin intersects said point in the diagram, then $v = \omega/\beta$. Hence, since the phase angle can vary between zero and $\pi$, the phase velocity $v$ can thus vary between infinity and the finite value $v = 2L\omega/\beta$, where $L\omega$ is the wavelength of the propagating wave and $c$ is the speed of light. Consequently, in the $\omega$-$\phi$ ($\omega = \beta L$) diagram there is normally a point at which the phase velocity is equal to the speed of light. If the periodic structure illustrated in FIG. 1 is removed, the electromagnetic waves II can only be propagated at approximately the speed of light along the remaining surfaces 2, 3, 4 and 5. By the inclusion of the periodic structure 1, propagation of the waves is disturbed, whereewith electromagnetic waves II are propagated at a phase velocity which is normally slightly lower than the speed of light $c$. Those waves I which are propagated along the periodic structure 1 and the phase velocity of which is in the region of or higher than that of the waves II become coupled to the waves II in a manner whereby the energy from one wave I is transferred to wave II and vice versa. When surfaces 2 and 5 are included in the structure, the periodic structure 1, in the case of bunched circuit elements of the embodiments illustrated in FIGS. 2 and 3, corresponds in principle to the conducting filters having 2-mode characteristics illustrated in FIGS. 5 and 6. These figures show series inductances 13, the inductance of surface 2 and 5 per unit of length $L$ and the parallel capacitances 12, the capacitance per the same period length between the surface 2 and the surface of the periodic structure nearest said surface 2. In such two mode conductors, two separate waves I and II are always liable to propagate, which waves when their phase velocities coincide or when in respect of one conductor exceed the speed of light $c$ or approach the speed of light are coupled to each other. A graph for such conductors may have the appearance illustrated in FIG. 7, where $a$ corresponds to the $\omega$-$\phi$ diagram for a high-pass filter (FIG. 2) when a conducting surface 2, 5 is included in the device, as shown in FIG. 5, and $b$ is the corresponding graph of a low pass filter (FIG. 3) when the surfaces 2, 5 are incorporated in the device as shown in FIG. 6.

With frequencies lower than $\omega$, only waves II are propagated, as illustrated in the diagram, these waves having a phase velocity $L\omega$ which is slightly lower than the speed of light $c$. At frequencies above $\omega$, coupling takes place between waves II and the waves I propagating along the periodic structure 1. When a low pass filter according to FIG. 6 is employed, a gradual transition from waves II to wave I already begins at the frequency $\omega$. When a high-pass filter conductor $a$ is employed, transition coupling between waves I and II takes place at frequencies between and adjacent the frequencies $\omega_0$ and $\omega_0$. Within this high frequency range ($\omega_0$-$\omega_0$) waves I and II are propagated with complex propagation constants of the type: $b_1 = \epsilon(\beta(\pm 1) f) = (\beta(\pm 1) f)$ which means that one wave is propagated with an increasing amplitude and the other with an amplitude which decreases by an amount equal to the in-
increasing amplitude. It is within this frequency range that the antenna and wave propagation restricting device according to the invention shall operate and is dimensioned for. The antenna and wave propagation restricting device according to the invention shall thus be composed of a periodic structure \( I \) of the high pass filter type according to FIG. 5, which propagates electromagnetic waves with opposed phase and group velocity along the conductor, and shall be so dimensioned that the electromagnetic waves to be transmitted received or arrested are propagated with a phase velocity \( v_p \) which is close to, equal to or higher than the phase velocity \( v_p \) for those waves which can be propagated between the structure \( I \) and the surfaces 2, 5 and which have a frequency between close to the frequencies \( \omega_1, \omega_2 \) as shown in curve \( a \) in FIG. 7, i.e. waves having a complex propagation constant within the non-shaded area of the graph illustrated in FIG. 8.

Under these conditions, an electromagnetic wave \( II \) is propagated between the extension surfaces 3 and 4 in a direction towards the periodic structure \( I \) at decreasing amplitude within the boundaries of the same, while on the structure \( I \) a wave \( I \) occurs which is propagated in the opposite direction with a correspondingly increasing amplitude and which at the end of the structure \( I \) nearest the extension surfaces 3, 4 is coupled out through the conductors 6, 7. Conversely, an electromagnetic wave \( I \) entering at the said end of the structure \( I \) is propagated with a decreasing amplitude, at the same time as an electromagnetic wave \( II \) appears between the surface 2 and the structure \( I \), this wave being propagated in the opposite direction and at increasing amplitude, i.e. in a direction towards the surfaces 3, 4, where the wave \( II \) continues to be propagated. If the periodic structure \( I \) is of sufficient length, it would suffice to arrange only six period lengths \( L \), to transfer in this way practically all energy from the conductors 6, 7 to the space between the extension surfaces 3, 4 or vice versa. When it is desired to restrict wave propagation only, it is not necessary to connect the conductor 6, 7 to the periodic structure \( I \), which then operates only as a choke. An electromagnetic wave \( II \), which is propagated between the surfaces 3, 4 towards the periodic structure \( I \), is coupled to the structure and is reflected at the ends thereof nearest the extension surfaces 3, 4, whereas wave \( I \) on the structure \( I \) is coupled to a wave \( II \) propagating in the opposite direction, which is thus transferred to the space between the surfaces 3, 4 but with an opposite direction of propagation, thus from the structure \( I \). Very good antenna and choke effects can be obtained with a structure having a plurality of period lengths \( L \). The number of period lengths \( L \) may be at a minimum if the characteristic wave propagation impedance of the periodic structure is selected equal to corresponding impedance between the surface 2 and the periodic structure \( I \).

The antenna and wave propagation restricting device according to the invention can be constructed in a number of different ways, a number of different, conceivable embodiments being illustrated in FIG. 9, 10, 11 and 12. FIG. 9 illustrates a high-pass filter comprising T-shaped conductors or conductive elements 14 which extend from a surface 5 and between which are arranged walls 15, the surface 5 presenting openings for receiving conductor connectors. Without the walls 15 the structure 1 becomes a structure which only propagate waves whose phase and group velocities are in the same direction. The walls 15 are consequently necessary in this type of structure if the structure is to fulfill the requirements of the invention. The lower portion of the walls 14, 15 may preferably constitute coaxial conductors which are short circuited by surface 5 at the lower end as shown in FIG. 9 and merge at the upper end into a central end body which presents rectangular surfaces and which forms gap walls and an upper surface of the plate 5. It will be seen from the section A—A that the structure can be made as wide as desired, although the structure shall preferably be divided at walls 14 with slots 16 arranged within each quarter wavelength of the width of the structure. High frequency absorbing materials can be inserted in the slots 16 for the purpose of preventing electromagnetic waves with small losses from propagating along the walls 14, 15. Coupling to one or more coaxial conductors, strip conductors or wave conductors 6, 7 can be arranged for example by connecting to the conductor or wall 14 nearest the surfaces 3, 4.

FIG. 10 illustrates a biperiodic structure which instead of walls 15 has an inductive coupling, or preferably a so-called strap connection 17, 18, between conductors or walls 14. The inductively coupled or strap connected structure can be connected to coaxial conductors, which may comprise an extension of the couplings or strap conductors or be connected to wave conductors having openings between the walls 14 nearest the surface 4 and this surface.

FIG. 11 illustrates another biperiodic structure which comprises only walls 14 which, through slots 16, have a restricted width and which are alternately displaced in relation to each other to define periodic conductive elements. The wall width may be approximately one quarter of a wavelength. The height of the walls may be approximately a quarter of a wavelength with structures such as those illustrated in FIGS. 10 and 11, and may be slightly lower with structures of the type illustrated in FIG. 9. The biperiodic structure can be joined to surface 4, for example, with connections 20.

FIG. 12 illustrates a biperiodic structure corresponding to that illustrated in FIG. 11 but without walls 14 and merely comprised of photoetched or otherwise arranged conducting surfaces 19 on a dielectric substrate between the surfaces and a surface 5 to define periodic conductive elements. These surfaces 19 shall be approximately \( \frac{1}{2} \) to \( \frac{3}{4} \) wave-length long and may be alternately displaced by half this length in the manner illustrated in FIG. 12. The biperiodic structure can be joined to surface 4 by, for example, connections 20 located between the structure 1, surface 19 and the surface 4.

FIG. 13 illustrates a convoyer type microwave furnace. The furnace comprises an electrically conductive or non-conductive belt 21 driven between rollers 22, 23 by means, for example, of a motor 24. The belt passes an elongated cavity or passage 25, 26 having end openings 27, 28, or in the simplest case a surface 33 arranged over the belt and defining only a cavity 25 above the belt (or beneath). Close to the end-openings 27, 28 are arranged antenna and/or wave restricting devices 29, 30 according to the invention. Connected to the devices, via conductor 31, are one or more high frequency generators 32, which may be triode-, magnetron- or, e.g. semi-conductor oscillators. Antenna and wave propagation restricting devices 29, 30 can be an-
ranged at said openings 27, 28 on all surfaces which within this region embrace the belt 21. If the furnace is open, i.e., if only one surface 33 is arranged above the belt 21, a broader surface 34 can be arranged to advantage above the surface 33, the surface 34 being well insulated from the surface 33 but preferably also close to the same. This surface can thus prevent radiation from the other surfaces. In this instance the surface 21 (the belt) and the surface 34 shall be wider than the surface 33. Supply of electrical high frequency energy can take place at several regions within the cavity 25, 26 but perhaps only at one side 25 of the two cavities and adjacent perhaps only one of the two end openings 27, 28, in which case only wave propagation restricting devices 30 according to the invention are suitably arranged close to the opposite opening. When high frequency energy is applied to the antenna 29, the energy is propagated between the antenna, the surface 21 (2, 3) and 33 (4) and opposing or controlling means 30 which operate perhaps only as a choke. At the means 30 energy which has not been absorbed is reflected when said means 30 is passed by material located on the belt 21 and intended to be heated. The energy reflected by the means 30, is used e.g. to control by means of an indication signal the output of the high frequency generator 32. In this instance, conductors 31 shall also be arranged on this side. The distance between the coupling positions 29, 30 can, to advantage, be so great that the largest portion of the applied high frequency energy can be absorbed by the material charged on the belt 21 before the energy reaches the opposite end of the belt. It will be understood that if the furnace is sufficiently long and is charged with material which absorbs energy in this manner, high frequency energy can suitably best be supplied to the arrangement at both ends thereof or alternatively at several positions between the ends. Due to the antenna and wave restricting devices 29, 30 of the present invention, high frequency electrical energy is effectively prevented from leaving the furnace openings 27, 28 and thus larger quantities of high frequency electrical energy can be supplied without the personnel in the proximity of the furnace being exposed to harmful radiation. If the goods to be heated in the furnace illustrated in FIG. 13 are charged into the furnace from its sides and removed from its sides, e.g. through openings and tubes, tunnels or the like or feed and discharging members arranged in the vicinity of the device 29, 30, the distance between surface 33 (4) and the belt 21 may be greater in this region than between the devices 29, 30 and the belt 31. In this instance, the change in height shall take place successively in the vicinity of the devices 29, 30.

Another type of belt furnace or tunnel furnace according to the invention is illustrated in FIG. 14. In the case of this furnace, high frequency electrical energy is supplied transversely of the direction in which the goods 37 to be heated are moved. The movement may also be caused in this case by a belt having a surface 21 although is also caused by relative movement of the furnace with a surface which will preferably conduct electric current. The furnace 33 illustrated in FIG. 14 may also be stationary in relation to the surface 21, the goods 37 being charged and discharged to and from the furnace in containers or in carriages, which may be connected together and advanced along the outside of the furnace by a drive means associated therewith. The furnace may alternatively be raised out of contact with the surface 21, the wave propagation restricting means 30 of the invention being arranged around the complete periphery of the furnace and directed towards and located adjacent to the surface 21, or be arranged on wheels and capable of moving over the surface 21. When the goods 37 are charged in this manner the furnace may be higher at the centre thereof than at its sides 35, 36, where antenna and wave propagation restricting devices according to the invention shall be arranged. Furnaces of this type can be used in particular when large objects 37 are to be heated, e.g. wagons containing such objects as stone to be disintegrated by high frequency energy or other substances 33. Also in the case of this furnace, high frequency electrical energy can be applied at several regions at the sides of the furnace along the whole length thereof, and antenna 29 and wave propagation restricting devices 30 according to the invention are arranged along the sides and also at the in-feed and out-feed ends 37, 38 thereof, although in this latter instance the devices shall be oriented in a suitable direction.

With high frequency furnaces according to the invention, the belt surfaces 21 may be provided with sealing walls of conductive material transversely arranged in a known manner and provided with planar surfaces which extend at right angles from the edges of the walls and which in the conveying direction shall preferably be of such length that they cover approximately six period lengths L of the wave restricting devices adjacent the furnace openings 27, 28, the length of the wave propagation restricting devices being of the same order as half the distance between the aforementioned walls. In a modification, the wave propagation restricting devices may be arranged on all the surfaces extending from the aforementioned walls. If the material 37 is charged between such walls or in containers, wagons or the like, the high frequency energy should only be applied when these separate units are located opposite an energy transmitting antenna constructed in accordance with the invention.

In the case of stationary microwave furnaces for heating food, microwave energy may be supplied through antennas constructed in accordance with the invention, the surface 2 (see FIGS. 1, 11, 12) being used as one of the inner walls of the furnace or a separate surface 2 of conducting material being arranged adjacent the inner walls of the furnace and which may be curved and arranged so that the distance from the furnace wall through which the high frequency energy is supplied by the antenna of the invention to the furnace gradually increases. Such furnaces often have a furnace door through which goods to be heated are charged into the furnace. This door must be sealed so that high frequency energy does not escape when the door is closed and this can be achieved by arranging wave propagation restricting devices according to the invention around all edge surfaces of the door, and a space should be arranged between the door and the wave propagation restricting devices, close to the furnace cavity, and, if desired, the door and the furnace can be joined together outside the furnace and the door by bringing them into engagement with each other. Antenna and chokes (wave propagation restricting devices) according to the invention may also be used with high frequency apparatus other than microwave furnaces. For example, the invention can be used with different types of conductors for transmitting, receiving
and restricting therein be propagation of electromagnetic waves having frequencies within the frequency band according to the invention. The invention is also applicable to wave propagation along planar conductors, tubular wave conductors and coaxial conductors and can also apply to wave propagations in azimuth direction and in annular structures (space) or helical spaces.

Antenna and chokes constructed in accordance with the invention may also be used to close and brake electric high frequency energy at angular frequencies in the proximity of and higher than \( \omega_c \), but lower than the angular frequency at which the phase velocity along the structure is close to or equal to the speed of light \( c \), by arranging the surface 2 close to or remote from the structure 1 or completely removing the surface from the structure. Such a possibility of braking the electric high frequency energy is particularly desired in high frequency apparatus with which personnel are liable to be in the vicinity of the apparatus being for instance, a microwave oven or a furnace.

An example of how the braking possibility can be utilized, but primarily also a further example of how microwave furnaces having devices according to the invention can be used, is illustrated in FIGS. 15, 16.

The microwave furnace or apparatus according to FIGS. 15, 16 comprises a rectangular cavity having conducting walls 10 and an opening 41, although the cavity may perhaps have a smoother geometrical configuration e.g. may be super-elliptical. Arranged preferably in the bottom surface 42 of the furnace, or on any of the side surfaces 43, 44, 45, are one or more antenna 48 according to the invention, which are oriented so that electromagnetic waves can be transmitted only in the cross direction, i.e. along the sides 42, 43, 44, 45 and not across the side 46 or opening 41. High frequency electrical energy or microwave energy is applied to the antenna 48 from one or more high frequency generators 47 arranged adjacent the furnace, preferably beneath the furnace. With the simplest conceivable embodiment, the material to be heated can be charged into the furnace on a conducting surface 48 positioned above the antenna so that high frequency electrical energy, from and to the antenna, can be conducted between the underside of the surface and antenna 48, to its upper side where the goods to be heated are located and subjected to the high frequency energy. The surface 48 thus functions as surface 2 and 3 in the embodiment of FIG. 1. Energy which is either reflected or is not absorbed by the goods continues around the plate 48 to its underside and is there either reflected at the rear end of the antenna 48 or, if the ends of the antenna are also in the form of antenna, is received there and possibly absorbed in a high frequency load, arranged at this position and/or utilized as a signal to control the output of the high frequency generator. The unused energy may alternatively be coupled back over single-wave attenuation means, for example, to transmitting antenna 48. The surface 48 is preferably mounted or suspended on insulated supports 49 made of a dielectric material with low high frequency losses. The conducting surface 48 may, in the simplest instance, comprises a metallic plate, e.g. of aluminium, but is preferably made of a dielectric material of very low high-frequency losses, e.g. a plastic or ceramic material, and surface coated by photoetching technique or in some other appropriate manner with electrically conductive, mutually insulated strips or filamentary coils 50 (see FIG. 16,) which are either connected to themselves or form one or more spirals surrounding the surface 48 in a manner whereby only electromagnetic waves propagated in the cross direction of the furnace, i.e. only waves going along the sides 43, 44, 45, can be propagated along the conducting strips 50. In this way it is ensured that propagation of electromagnetic waves in other directions is as low as possible. If the conducting strips form a helix, the antenna which transmit electromagnetic energy can be arranged on one side of the surface, e.g. nearest the surface 46, the strips over the antenna preferably being as wide as the antenna and after a turn, being possibly of substantially reduced width and so displaced in relation to the antenna 46 that it can not appreciably be coupled to said turn. A similar arrangement can be made at the opposite end of the helix so that energy which is not absorbed by the goods on the helix is received by an antenna arranged on said side, preferably nearest the opening 41. The high frequency electrical energy can also be reflected on said side, e.g. by causing the last turn of the helix to be connected to itself or by arranging at this point a choke in accordance with the invention. The plate 48, which is made completely of metal or of a dielectric material having a surface 50 conducting in only one direction or in the helix direction, can be attached to the cover used to close the opening 41.

When the cover is opened, the plate 48 is simultaneously moved away from the antenna 46 wherewith these can be arranged so that they are unable to transmit high frequency energy.

In accordance with a further modification of the invention, there can be arranged in microwave and high frequency furnaces provided with the system of the invention, insulated highly conductive mutually interconnected surface 52 which are located preferably very close to but spaced from the inner surfaces 42, 43, 44 and 45. The surface 52 can then operate in the same manner as surface 48 spaced from the walls of the furnace, in accordance with FIG. 1. The surface 52 is insulated from the inner surface of the furnace (42-45) by a dielectric material having low high-frequency losses. The surface 52 can advantageously be made of a dielectric material having low high frequency losses and on which the conductive strips, produced by photoetching technique or in some other appropriate manner are preferably connected to themselves or possibly caused to form a helix, in relation to the surfaces (42-45) situated nearest the central inner cavity of the furnace and surface 48. In this way, it is ensured that high frequency electrical energy is only propagated between the conducting strips and surfaces therefore, e.g. surface 48 in FIGS. 15, 16.

Since the antennas according to the invention only receive and transmit electrical high frequency energy in one direction, microwave furnaces, for example, which are equipped with such devices can be constructed so as to be substantially non-resonant i.e. electromagnetic waves can be transmitted and propagated in only one direction and received at the ends thereof, possibly to be absorbed there or to be returned to the input end over a second conductor or path.

Microwave and high frequency furnaces similar to that illustrated in FIGS. 15, 16 can also be constructed as tunnel furnaces, an opening being arranged also at the side 46. If the oven is long (deep) it can be used
even when the sides 46, 41 are open. Optionally, the
diameter of the furnace may be greater within the area
of the high frequency electrical energy, or smaller.
Furnace furnaces according to the invention may also be
constructed so that the high frequency electrical en-
city can be propagated also in its longitudinal di-
cbction, e.g. by arranging antenna and choke according to
the invention at the openings of the tunnel furnace
close to said openings and directed in towards the same
(FIG. 13). The plate 48 with the conducting surface 15
can in this instance, and also when the waves are propa-
gated in the cross direction, comprise an endless belt
21 extending through the furnace. It can be joined be-
hind the antenna and choke according to the invention
with the surface 2, or there can be arranged conven-
tional chokes and/or loss material which reflects and/or
absorbs electrical high frequency which may possibly
have reached this end. Otherwise, surface 2 need never
be connected with the rear ends of said devices.
An important advantage obtained with furnaces
equipped with devices constructed in accordance with
the invention is that the high frequency energy can be
permitted to be propagated in large furnace chambers
where no periodic structures are arranged and still be
reflectively transmitted and manipulated by such struc-
tures or devices installed at the ends of the furnace. In
large furnace chambers devoid of periodic structures,
electromagnetic energy can be propagated with consid-
erably lower losses and providing more uniform energy
distribution over wide surfaces; also bulkier goods can
be subjected to the h.f. energy than in furnaces where
energy transfer to said goods 37 takes place over peri-
odic structures, particularly if these goods in the fur-
nace chamber propagate electromagnetic waves of de-
layed phase velocity relative to the speed of light.
Microwave furnaces often operate at frequencies be-
tween 2,400-2,500 MHz but with devices according to
the invention can also operate at frequencies both
above and below this frequency range, e.g. 13-22,250
MHz or even lower than 10 kHz.
When electric high frequency energy is propagated
into space, for example the cavity of a microwave oven
or furnace, propagation of the energy often takes place
in different directions, depending greatly upon the
shape and position of the goods charged to the cavity.
Consequently it is impossible to restrict energy propa-
gation with devices which can only propagate electro-
magnetic waves in one direction.
In accordance with the subject of the present inven-
tion, antenna and wave propagation restricting devices
which are capable of propagating electromagnetic
waves in various directions consist of periodic struc-
tures operative in two dimensions, i.e. so-called two-
dimensional structures having the same form in two di-
0mensions and propagating electromagnetic wave in a
manner similar to periodic structures having only one
direction of propagation, as formerly described herein.
A description of the construction of such two-
dimensional periodic structures will now be given with
references to FIGS. 17-19.
The two-dimensional periodic structure of the pres-
ent invention may be similar to the structure 1 illus-
0rated in FIG. 9, but shall have the same structural form
even at right angles to the propagation direction ob-
tained therewith, as at section H—H in FIG. 17. That
is to say, the grooves 16 should preferably be as wide
as the gap between the T-shaped walls 14 in the Figure
to the left of the drawing and equally as densely placed,
and the walls 14 within the region of the walls 15 and
surface 5 should be similarly arranged and the lower
portions of the walls 14, 15 preferably comprise co-
axial conductors which are short circuited by
surface 5 at the lower end in FIG. 9 and merge at the
upper end into a central end body which presents rect-
angular surfaces and which forms gap walls and an
upper surface above the same.
It is not necessary for the structural dimensions of
the extensions of the structure to be identical to each
other. Although it is preferred that these extensions are
located at right angles to each other they can in prac-
tice extend at any angle in relation to one another.
Nor is it necessary for the two dimensional structures
to have exactly the form illustrated in FIG. 9; such struc-
tures can be of varied construction, although they must
be capable, in accordance with the invention, of propa-
gating electromagnetic waves with opposed phase and
group velocity in two-dimensional directions.
Devices constructed in accordance with the inven-
tion can be used as wave propagation restricting de-
vice in chambers having openings which are large in
relation to the wave length of the high frequency en-
ergy, even when the device lacks the surface 2. The
wave propagation device in such cases is also effective
if the frequency of the high frequency energy coincides
with frequency at which electromagnetic waves are
propagated along the aforementioned structures with
the phase velocity coinciding with the speed of light or
higher.
If the conductive surface 2 is an endless conveyor
belt, it may be made of an insulating material upon
which a conductive surface 30 is applied parallel with
a belt or perpendicular to the conveying direction of
the belt, according to FIG. 15. The periodic structures
in these instances can be of varied construction and
they can, for example, be arranged in level with a con-
ductive surface, in which openings are disposed for the
outermost surfaces of the central end bodies of the
structure 1. They can alternatively consist of two-di-
0mensional biperiodic structures, for instance accord-
ing to FIGS. 10-12.
What is claimed is: 1. A microwave oven comprising:
means for generating

microwave energy within a given frequency range;
a cavity for receiving material to be treated with
microwave energy, said cavity having conducting struc-
tures disposed therethrough, through which openings
said material to be treated is fed in and withdrawn; and
a plurality of devices for attenuating and restricting
microwave energy to prevent leakage through said
openings, at least one of said plurality of devices being
positioned within the cavity at each of said openings, each said de-
vice including: a base, and a plurality of parallel spaced
apart electrically conducting elements conductively
disposed on and supported by said base, said spaced
elements being arranged in groups and defining a struc-
ture which is periodic in the direction of wave propaga-
tion, said electrical conducting elements being shaped
and oriented with respect to one another so as to con-
stitute a predetermined mutual capacitance and induc-
tance defining a high-pass filter means which propa-
gates incoming microwave energy within the given fre-
quency range with counter-directional phase velocity and
group velocity, the phase velocity of the waves in
said high-pass filter means being greater than the phase
velocity at which the microwave energy is propa-
gated in the vicinity of said device within the cavity.
2. A microwave oven as claimed in claim 1 wherein
each said device is positioned to substantially surround
a respective one of said openings.
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