# Basic and Advanced Training

# Microwave Appliance Basics

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# Physical principles

## Heat as an energy form

In terms of physical principles, heat is produced in conjunction with the kinetic energy inherent in the particles **(molecules)** of a solid, liquid or gaseous substance. In solid bodies, exerting forces upon each other **(inertia or gravity)**, the molecules are arranged in a rigid order. They nonetheless oscillate in place about their rest position, as shown in the following schematic (Fig. 1.)

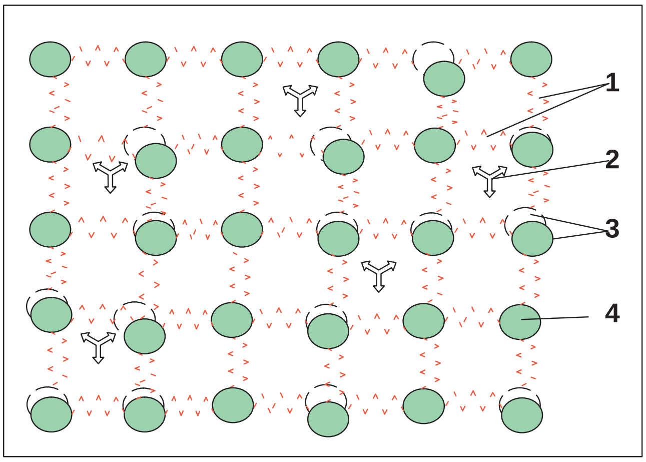



**Fig. 1 Time-slice illustration of motion in a molecular structure**

**1 Forces of gravity**
**2 Possible directions of movement**
**3 Molecule deflected from neutral position**
**4 Molecule in neutral position**

The continuous motion may also be stimulated by introducing external forces. For example, mechanically by means of friction or thermally by introducing heat. This will cause the molecules to oscillate more intensely, while also stirring particles in their proximity into more intense motion.

**Stronger motion is connected with an increase in thermal content.**

The change in the **kinetic energy** of a material is measurable by means of the change in its temperature.

The transfer of heat may be achieved:

(1) by direct contact as thermal **conduction** (Fig. 2.)

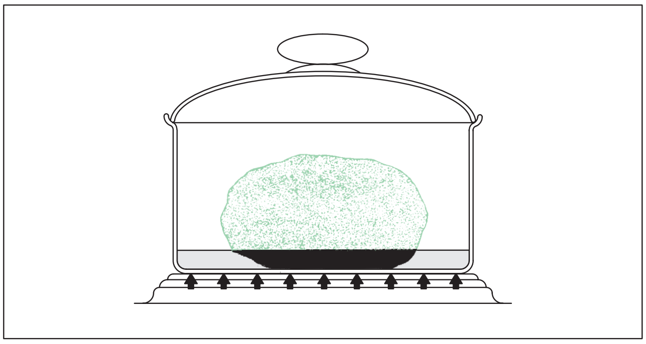


**Fig. 2 Thermal conduction for an electric hotplate with food**

or (2) by means of air as a medium for heat flow **(forced convection)** (Fig. 3.)

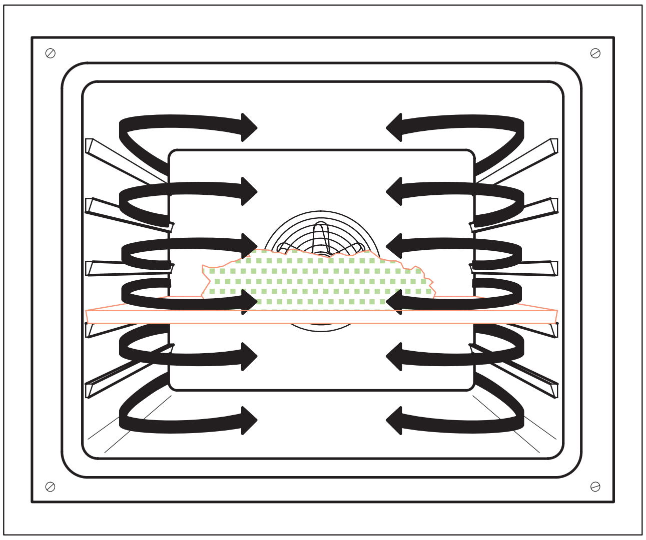


**Fig. 3 Heat flow by means of forced convection for a fan-assisted oven**

It is known that heat is a form of energy which cannot be produced per se, but which requires conversion from another form of energy. (Fig. 4.)


**Fig. 4 Example of energy conversion into heat**

As shown by the examples in Fig. 2 and Fig. 3, a transfer medium is normally required to accomplish any type of thermal transfer, and especially in cooking and baking.

However, if the degree of heat, i.e., the **temperature**, is steadily increased by adding energy, this increases the kinetic energy of the molecules to a point where they commence electromagnetic oscillations. Examples are the glowing heating spiral of the incandescent lamp or the grill element of an oven. (Fig. 5.)

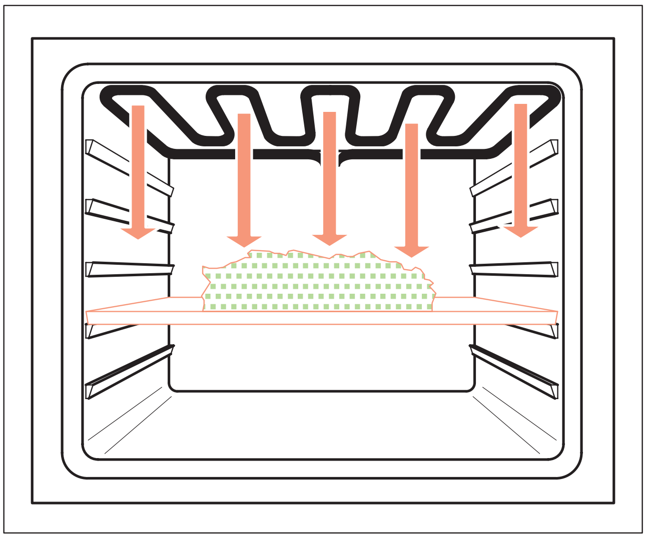


**Fig. 5 Thermal radiation from a grill element**

In accordance with the frequency range of the oscillations, the resulting emissions are known as infrared radiation. The oscillations are emitted into space, and at this point no longer require a medium to effect thermal transfer.

In the grill element example, the food absorbs the infrared radiation of the glowing grill element on its facing surface. This results in the required heating and degree of browning.

## Microwaves as thermal energy

In this energy form, **high frequency energy is converted directly into heat.**

For microwave appliances, the high frequency energy in the appliance is produced as an electromagnetic alternating field by a kind of ”transmitter”, and injected into the cooking compartment. The conversion into heat occurs within the food, i.e., the electromagnetic oscillations are transferred directly and without the need of an intermediate medium into kinetic energy, and thereby into heat. (Fig. 6.)

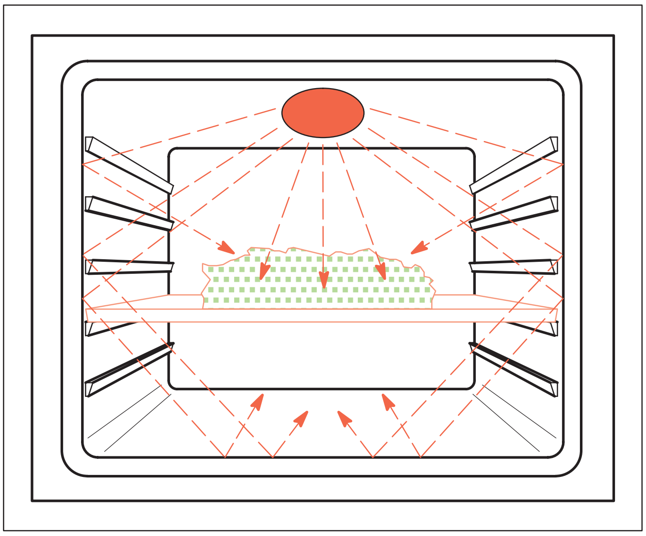


**Fig. 6 Heat from microwaves**

For household use a frequency of **2450 MHz** has been designated for microwave emissions.

Other application areas such as in medicine, radio relay systems, radar and industry, use various and differing frequency ranges.

## Microwaves in the frequency spectrum

There is a multitude of electromagnetic waves which continuously surround us and to which we are constantly exposed. There are, for instance, cosmic and UV radiation, visible sunlight, thermal (infrared) radiation and waves emitted by radio and television stations. While X-rays are used in medicine, we use electromagnetic waves to transmit news texts and images, to make objects visible on a cathode ray tube (radar screen), to make phone calls, to create lighting, and to cook foods with heat (infrared grill). (Fig. 7.)

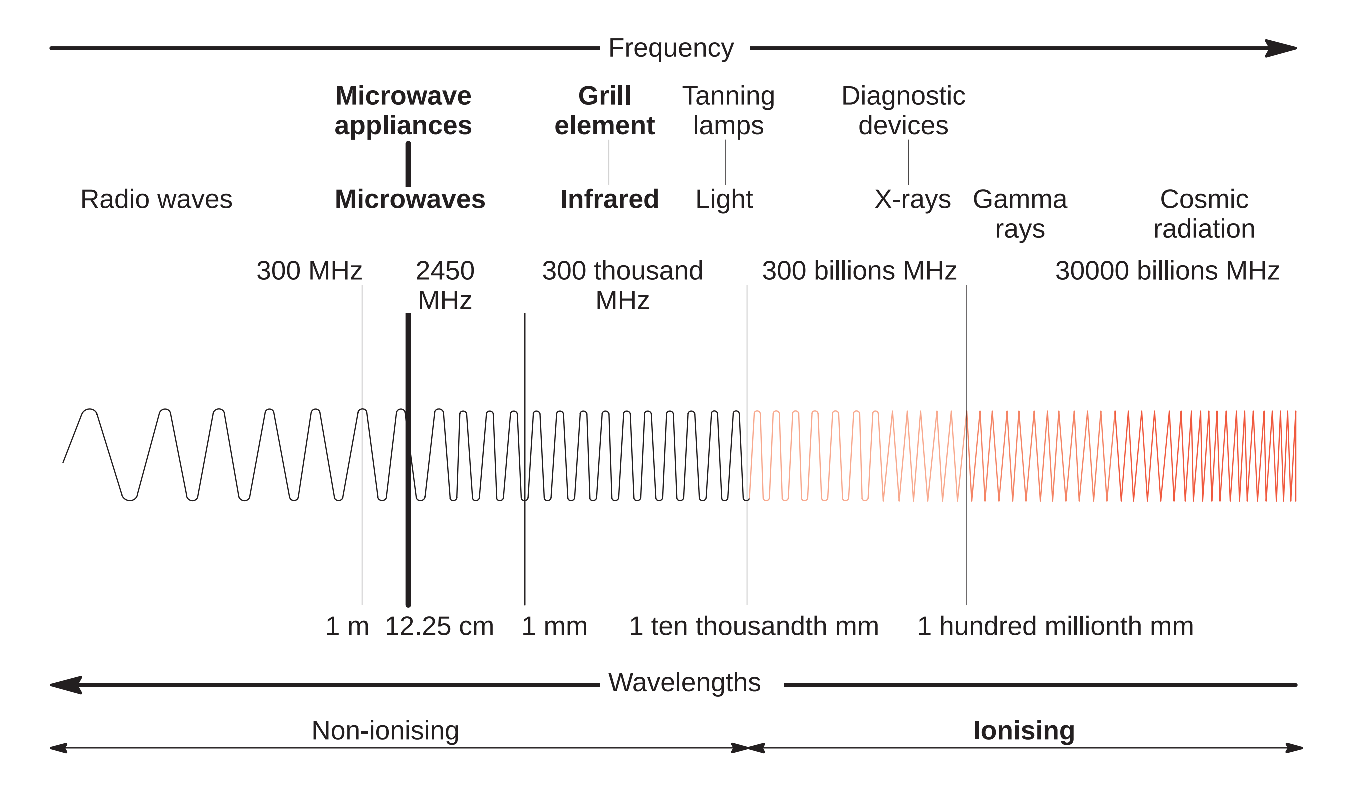



**Fig. 7 Application areas for electromagnetic waves**

Similar to thermal radiation, microwaves are electromagnetic waves, the dispersion mechanism of which is based on a continuous alternation between an electrical and a magnetic field.

On the spectrum of electromagnetic waves, the wavelength of microwaves is located between the frequency bands assigned to radio transmission and that of infrared radiation.

As shown in Fig. 7, certain electromagnetic waves are ionised, each according to wavelength and frequency. Waves up to the range of X-rays are **non-ionised**. This applies to radio, television, visible light and **microwaves**.

The energy content, and with it the actual radiation risk to humans, increases with a shorter wavelength and an increased frequency.

In other words, the higher the frequency of the electromagnetic wave and the shorter the individual wave, the more energy it contains.

The ionisation effect of radiation starts in the range of X-rays and gamma rays, which may lead to a chemical change of the radiation-exposed substance (ionisation). Such changes are not possible for electromagnetic waves such as radio, radar and microwaves.

## Microwave characteristics

Dependent upon the types of substances exposed to microwaves, the latter exhibit the following characteristics:

**Microwaves are reflected**

Metals reduce the degree of penetration to a few thousandths of a millimeter (skin effect) of microwaves owing to their high electrical conductivity.
**That means in practice they are reflected from the surface.** (Fig. 8.)

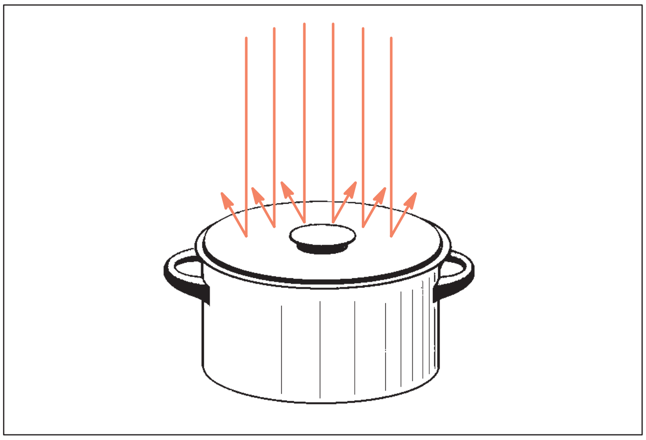


**Fig. 8 Reflection on metal surfaces**

However, if metallic containers are used that partially shield the substance to be heated, the heating time increases and the efficiency is reduced correspondingly. (Fig. 9.)

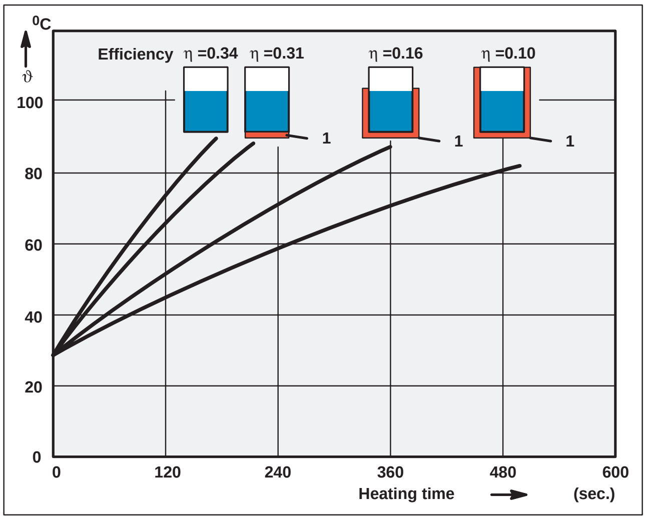



**Fig. 9 Influence of metal screening on heating, time and efficiency**

**1 Metal**

In addition to the disadvantages previously described, metals may also cause spark-over to the oven compartment walls.

Eddy currents may appear on the surfaces of metal due to the high conductivity and extremely low penetration depth. These mainly appear on metallised decoration of cookware components.

Due to the high current density and the geometric shape, sparking or glowing may result, thereby possibly removing parts of metallic decoration by burning. As this occurs on the metal surface it is referred to as ”skin effect”.

For these reasons, containers of this type must not be used in microwave appliances. (Fig. 10.)

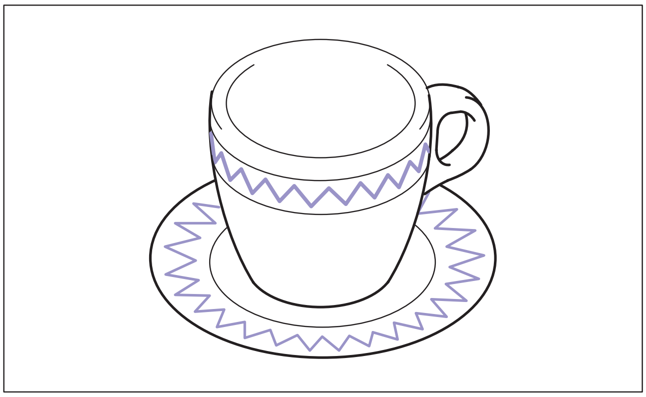


**Fig. 10 Utensils with metallic decoration must not be used in microwave ovens!**

## Microwaves penetrate certain materials

Electrical insulating substances allow microwave energy through **almost completely unhindered**. While they themselves heat up only nominally, they are **penetrated** by microwaves **like glass by visible light**. (Fig. 11.)

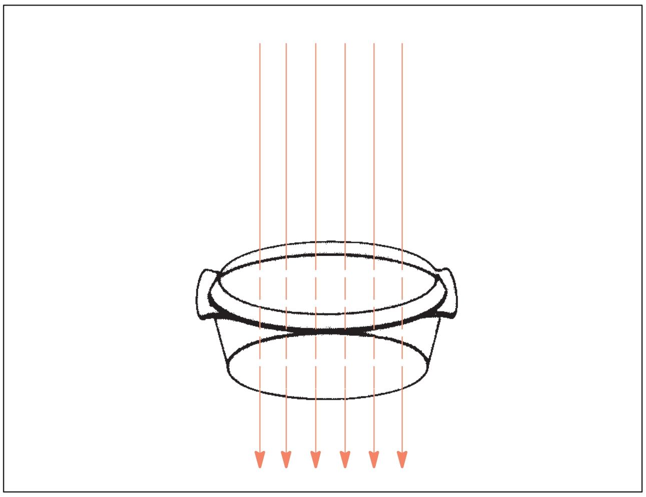


**Fig. 11 Penetrating glass, porcelain and ceramic**

Due to the physical properties and structure of individual materials, a small amount of the available microwave energy is actually absorbed by the cookware. For your information, the following are approximate values in % of the microwave power absorbed by the materials currently available for microwave cookware:

| | |
|---|---|
| **Plastic** | **approx. 3 %** |
| **Glass** | **approx. 7 %** |
| **Glass ceramic** | **approx. 12 %** |
| **Ceramic** | **approx. 18 %** |

In cases of doubt this simple test may be explained to the user to determine if the utensil is suitable for use in a microwave:

Place the empty utensil in the cooking compartment of the microwave appliance and operate for half a minute at the 600 W power setting.
**If it is warmer than ”hand warm”, it will not be suitable as a microwave utensil.**

## Absorbed microwaves

A large number of substances, in particular water and food, contain components which react to the microwaves by taking the energy **through absorption** and converting it into heat. (Fig. 12.)

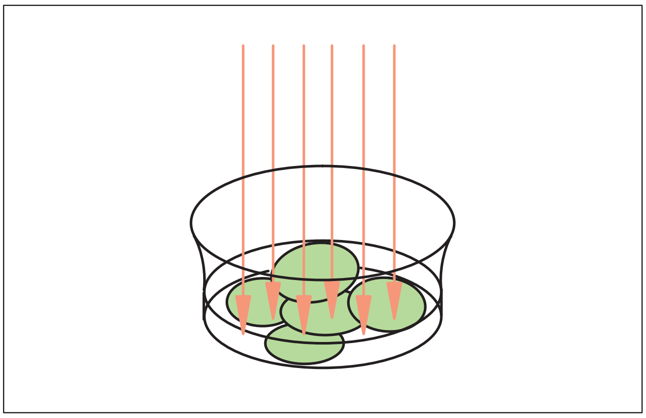


**Fig. 12 Absorption by food and water**

**Relationship between frequency, penetration depth and temperature gain** (Fig. 13.)

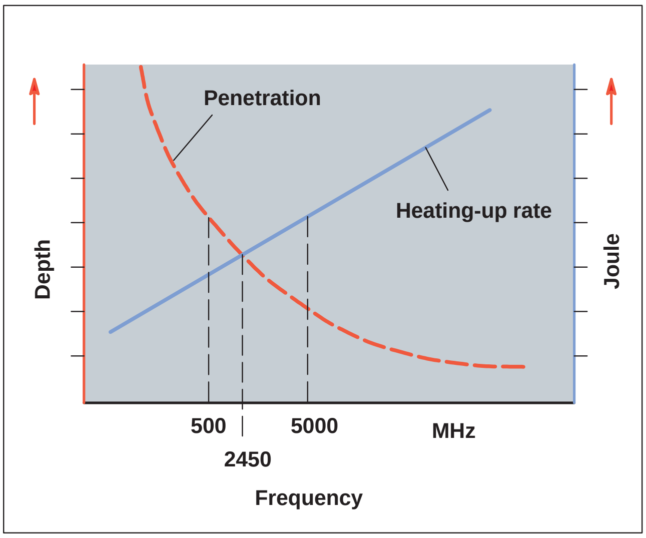



**Fig. 13 Penetration depth and temperature gain as a function of frequency**

As already mentioned, household microwave appliances work with a frequency of **2450 MHz.**

The figure also illustrates other areas of application, like **500 MHz** for medicine and **5000 Mhz for industrial use**.

For a substance which absorbs microwaves, the penetration depth falls with an increase in frequency, and the temperature gain increases.

The frequencies are allocated with a view to the needs of the user.

**Medicine**

Large depth penetration in tissue layers
with mild temperature gain (short-wave therapy).

**Household**

Compromise between sufficient
penetration depths and temperature gain.

**Industrial**

Low penetration depths with high temperature gain for vulcanising and drying of materials with corresponding measurements.

## Penetration depth and absorption capacity at a given frequency

The penetration depth at a specified frequency, i.e., **2450 MHz**, is defined as the depth at which approx. **86 %** of the microwave energy in a substance has been converted into heat. (Fig. 14.)

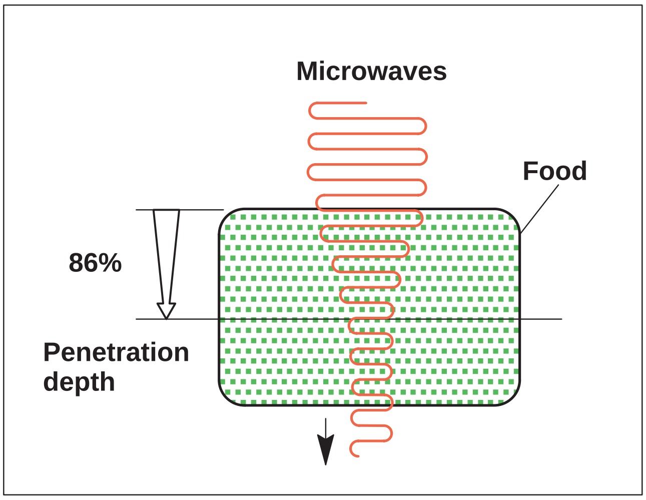



**Fig. 14 Penetration depth**

The penetration depths in foods are different:

| | |
|---|---|
| **Meat** | **approx. 2–3 cm** |
| **Other foods** | **approx. 5–7 cm** |

The absorption capacity comprises the capacity for absorbing microwave energy, plus its conversion into heat. It varies with different materials and foods. **Penetration depths and absorption capacities work in opposite directions**. (Fig. 15.)

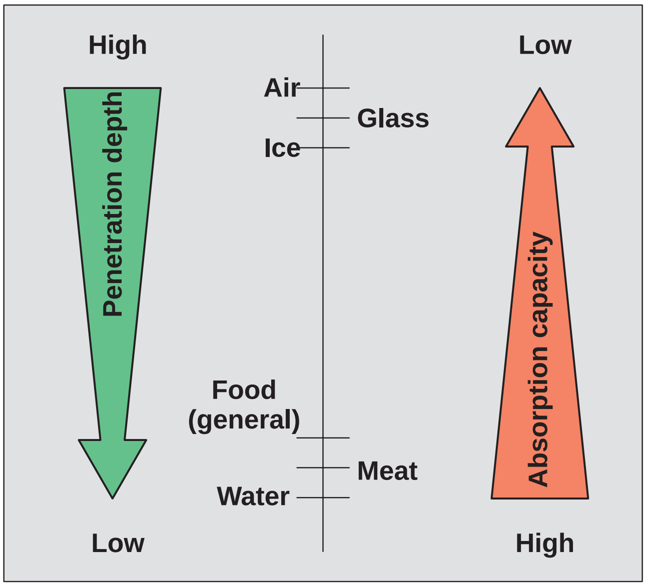



**Fig. 15 Penetration depth and absorption**

The following sections discuss the various processes occurring in food due to microwave absorption during warming and cooking.

## Molecular polarisation in an electrostatic field

All substance consists of very small parts, called molecules, which in turn comprise of atoms.

Every substance which may be heated by microwaves consists of **polarised molecules**. This means, that one side of every molecule carries a positive charge and the other side a negative charge. Water, for example, is a substance with molecules of different atoms. This chemical connection consists of two hydrogen atoms and an oxygen atom, **$H_2O$** :

The oxygen atom forms the central core of the molecule and is charged with positive energy **(protons)**. The hydrogen atoms are charged with negative energy, **(electrons)**. (Fig. 16.)

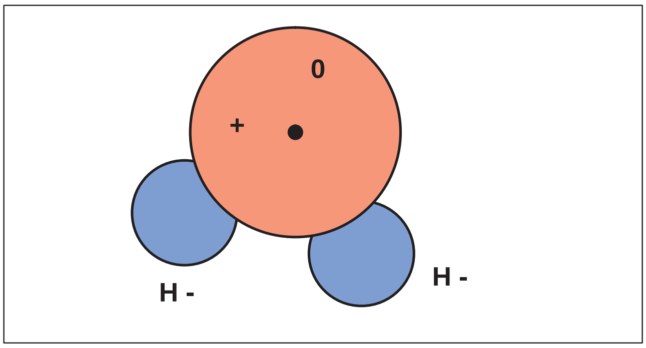



**Fig. 16 Structural model of water**

It is therefore clear that a water molecule is charged with positive (+) and negative energy (-). For this reason, as seen from an electrical standpoint, the water molecules, as do certain molecules of the food, exhibit a dipole character. (Fig. 17.)

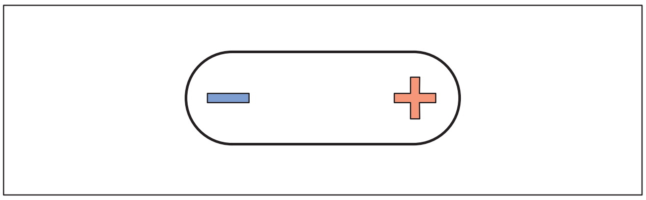


**Fig. 17 Dipole character of a water molecule**

If a polarised molecule is exposed to an electrostatic field, it will align itself as shown in Fig. 18.

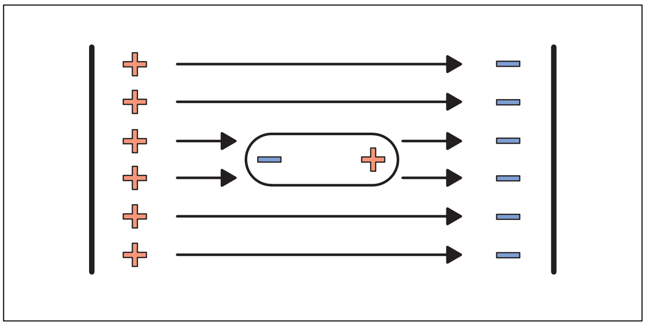


**Fig. 18 Dipole in an electrostatic field**

Under normal conditions in a glass of water or in food, the molecules are arranged in complete disorder. (Fig. 19.)

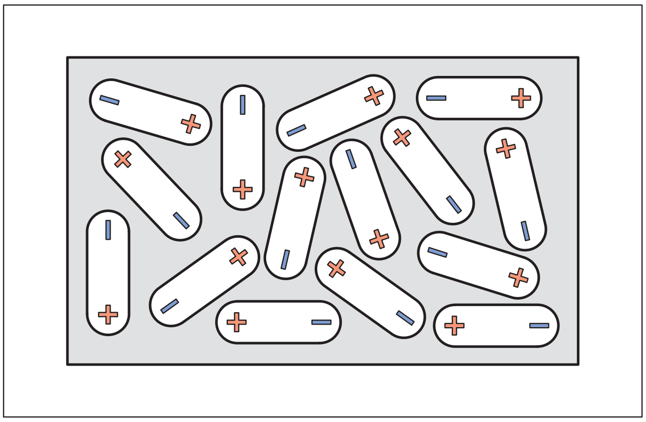


**Fig. 19 Molecules in normal position**

If this dipole medium is placed in a sufficiently strong electrostatic field, the molecules will align themselves so that their positive charges point in the same direction as the electrostatic field. (Fig. 20.)

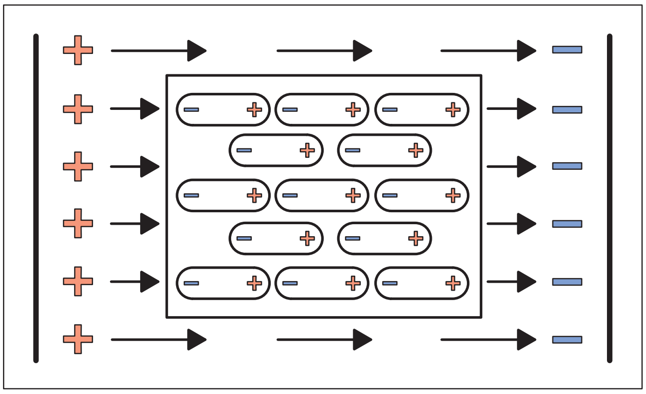


**Fig. 20 Dipoles in an electrostatic field**

If the electrostatic field reverses its direction, the molecules will also turn accordingly. If the field polarises very quickly the molecules follow just as quickly and produce heat as a result of friction against each other. (Fig. 21.)

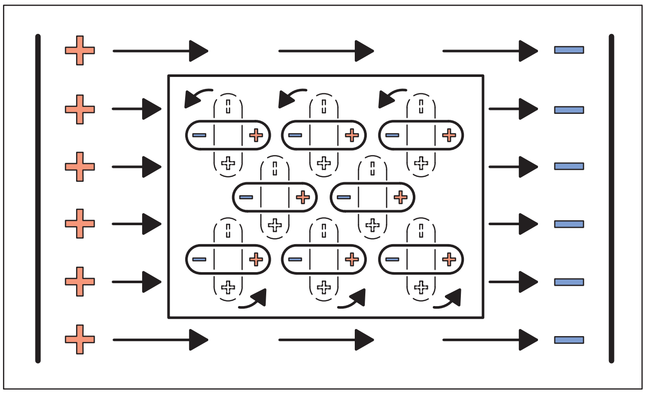


**Fig. 21 Dipoles in an alternating field**

As discussed in the foregoing, microwave appliances work with a frequency of 2450 MHz. That means, that the electrostatic field **changes polarity 2450 million times per second**.

## Heat generation and distribution in foods

In conventional heating procedures, foods are heated up by an external source through thermal conduction or thermal radiation. In this manner the molecules first move against the molecule situated closest and pass the motion further inwards. However, for cooking with microwaves the heat is produced in the food.

The microwave energy can penetrate as far as allowed by the characteristic properties of the food. Of prime importance are the electrical and thermal characteristics of the product to be heated. They determine to what extent the applied energy may be changed into heat.

The intensive interrelation with polarised molecules means that substances with an unequal load distribution produce heat quickly. With high electrical conductivity the penetration depth of the microwave is reduced, so that a lot of energy is transferred in the boundary layer of the product and results in high or excessively high temperatures. The temperature difference between the layer and the core then appears intensified.

The saline content of a food increases the electrical conductivity by producing ions, and thereby influences the transfer of microwave energy into heat. In order to obtain even and hygienically safe temperature distribution in salty products, less power and proportionate compensating times should be used for thermal conduction.

Among the thermal characteristics of substances which are of importance in conjunction with microwave cooking, are the specific thermal capacity (c) and the heat quantity which is necessary to heat 1g of a substance by1 K. Despite a lower polarity, fat molecules, for example, may be heated in a microwave field relatively quickly due to the lower specific heat ($C_{oil}$ = 1.9 J/gK and $C_{water}$ = 4.19 J/gK)

The geometry of products to be heated and cookware plays a large part in heat distribution. The energy tends to concentrate at corners and edges or onto protruding parts, so at these points overheating and in particular drying out may easily occur. As the energy cores are mainly distributed in the horizontal plane of the cooking compartment and have a distance of approximately 6 cm, they may be more effective on flat, wide products (Fig. 22.)

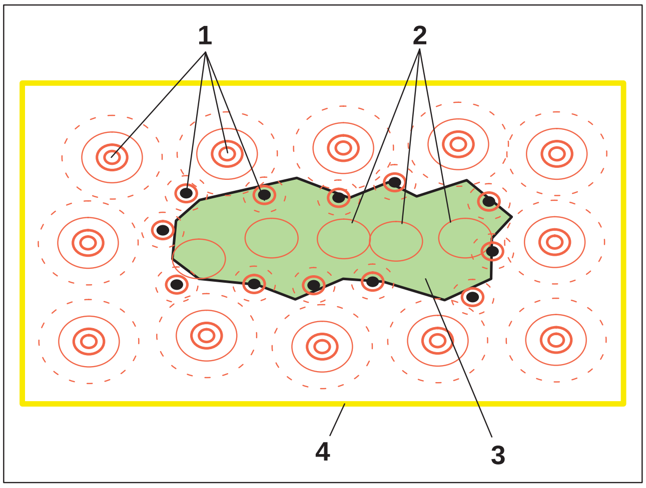



**Fig. 22 Energy distribution on a cooking compartment plane, with food**

**1 Locations of higher energy density**
**2 Locations of lower energy density**
**3 Food**
**4 Cooking compartment wall**

In addition, the penetrating capacity of the microwaves should still be considered (Refer to 14 and 15). Products with a large volume should be heat-soaked with a maximum penetration depth of 1-2 cm in the core by means of thermal conduction.

The material characteristics of the food to be heated and their effect have been shown in isolation here. Foods are not homogeneous but are together subject to very different reacting molecules, i.e. water, egg white, fat, mineral substances etc. Therefore high temperature differences in the food may occur during microwave heating due to the different material qualities in a product, and the field distribution.

All factors contributing to the heating of a product treated with microwave energy are contained in the following schematic (Fig. 23.)

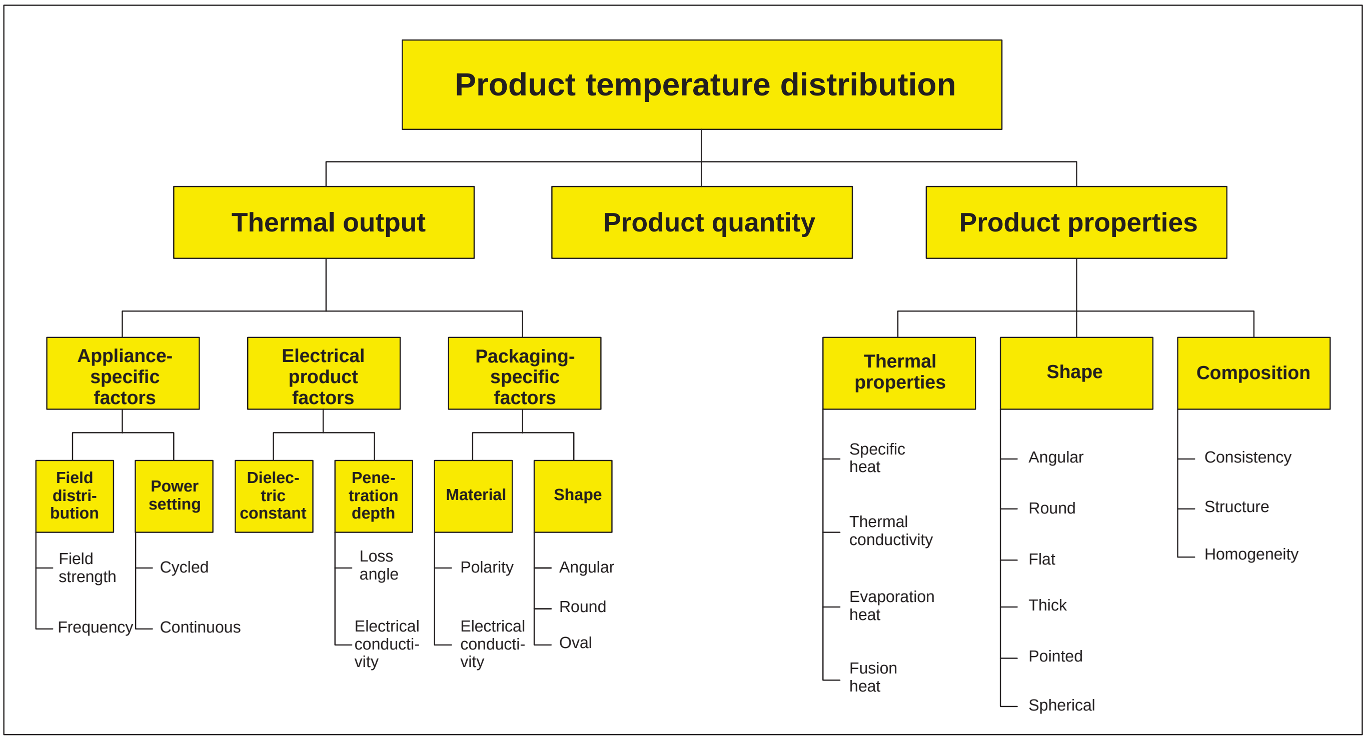



**Fig. 23 Factors which influence the temperature distribution in products**

Microwave energy is **one** of **many types of energy** which may be converted to heat.

Already known is the frequency of 2450 Mhz at which household appliances work, and their position in the frequency spectrum.

It is also known that microwaves, due to their wavelength, do not harm the human organism (with the exception of the heating effect).

Also known are the properties of microwaves and their effect on the different substances and materials, as well as the relationships and influences on the cooking process.

The next chapter discusses the generation of microwaves, the required components and electrical circuits, pertinent appliance technology and designs, plus many essential notes on handling microwave appliances.

# Generating electromagnetic oscillations

## Oscillating circuit

The basic circuit for the generation of electromagnetic oscillations is the oscillating circuit. It consists of, for example, the parallel connection of a coil and a capacitor (Fig. 24.)

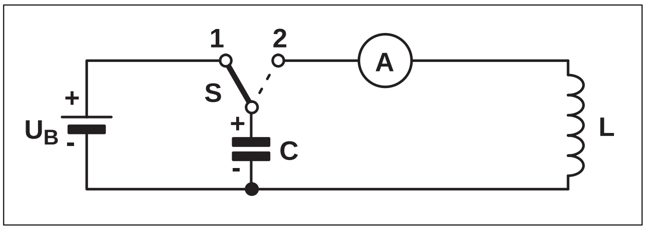



**Fig. 24 Anti-resonant circuit**

**$U_B$ Battery voltage**
**S Switch**
**A Ammeter**
**L Inductance (coil)**
**C Capacity (capacitor)**

To start an oscillating circuit, it must be supplied with energy in a fashion similar to a pendulum. In the present circuit arrangement, this occurs by charging the capacitor on the battery voltage, in switch position 1. In this way an **electric field** is produced in the capacitor.

Afterwards the switch may be changed to position 2. This moment is the **starting point** for the following oscillation. (Fig. 25.)

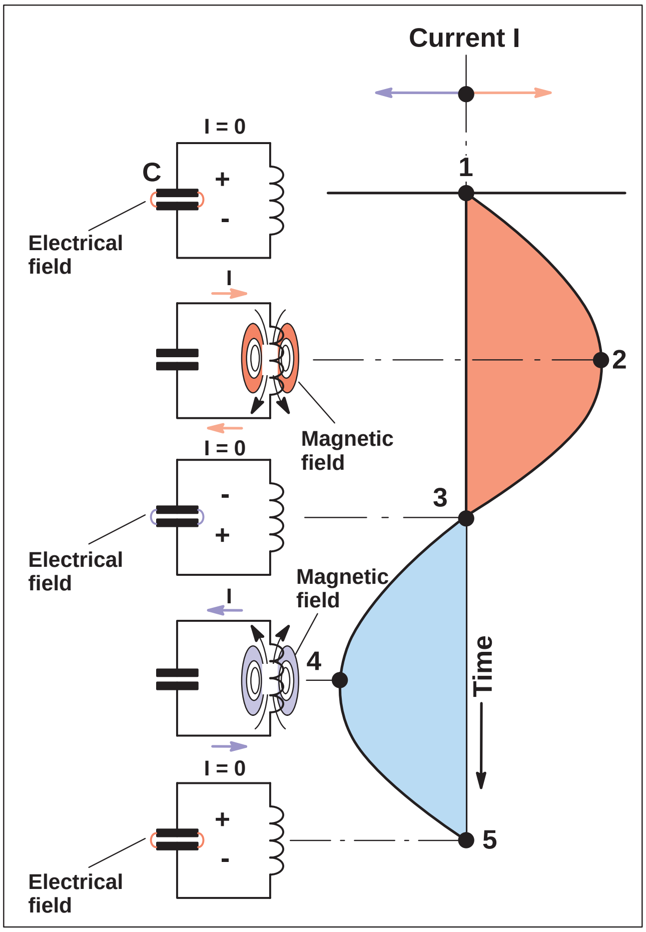



**Fig. 25 Progress of an oscillation**

Along a timeline, the progress of an oscillation occurs as follows:

If the charged capacitor is connected to the coil, the capacitor discharges. The discharging current flows through the coil and causes a **magnetic field** to be built up in the coil. **(Pos. 1 and 2.)**

When the capacitor is discharged, the magnetic field collapses. This change in the magnetic field **induces** a voltage in the coil, which again effects a current. **(Pos. 2 and 3.)** According to **Lenz's law**, the current has the same direction as the capacitor discharging current. Thereby the capacitor is again charged, but now with **reversed** polarity. **(Pos. 3.)**

The process repeats itself. The current direction has reversed by the reversed polarity at the capacitor, i.e. the current curve now runs below the neutral axis. **(Pos. 3 to 5.)**

**The process in brief**

The alternating electrical fields in capacitor and magnetic fields in the coil induce a current. Theoretically this process repeats itself continually with changing polarity, without having to apply a voltage from an external source.

In reality, however, the alternating current in the oscillating circuit generates heat in the non-reactive resistance of the coil. The oscillations become smaller and finally subside. The energy of the electrical and/or magnetic fields is converted to heat. The subsiding oscillation is termed a **damped oscillation**. (Fig. 26.)

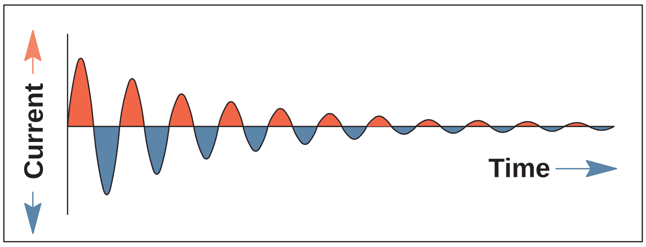



**Fig. 26 Damped oscillation**

## Resonance

Damped oscillations are unsuitable as microwaves. In order to produce a corresponding heat effect, microwave energy of the same level should be continuously supplied.

To prevent the cessation of oscillations as a result of damping, the oscillating circuit must be continually excited with a voltage having a frequency that corresponds to its natural frequency. In this case the oscillation circuit may ’covibrate’. This covibration is called **resonance**. In the discussion of the functional principle of the magnetron, we shall briefly make reference to this fact.

For those who wishing to work with exact figures, the resonance frequency for an oscillating circuit may be calculated. It was named after the discoverer, and is called Thomson’s oscillation formula. (Fig. 27.)

$$f_{res} = \frac{1}{2 \cdot \pi \cdot \sqrt{L \cdot C}}$$

**Fig. 27 Thomson’s oscillation formula**

| | | | |
|---|---|---|---|
| **fres** | **=** | **resonance frequency** | **Hz (hertz)** |
| **L** | **=** | **inductivity** | **H (henry)** |
| **C** | **=** | **capacitance** | **F (farad)** |

## Frequency and wavelength

The wavelength is obtained by dividing the speed of light by the frequency. The wavelength symbol is $\lambda$ (lambda).

If the formula is applied to the microwave frequency of 2450 MHz, the wavelength is produced as shown in Fig. 28.

$$\text{Wavelength } \lambda = \frac{30\,000\,000\,000 \text{ cm/sec.}}{2\,450\,000\,000 \text{ oscillations/sec.}} = 12.25 \text{ cm}$$

**Fig. 28 Wavelength formula**

Similar to the waveform of standard alternating current, the microwave oscillation exhibits sinewave characteristics. The measurement $\lambda/4$ has a particular significance for the design of door seals and shielding. This will be discussed within the framework of the appropriate topic. (Fig. 29.)

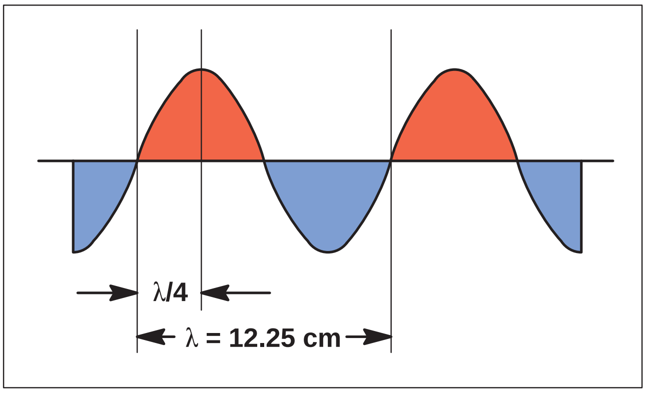



**Fig. 29 Microwave**

# Microwave generation

## Construction of a magnetron

In our example oscillation circuit, the frequency of 2450 MHz or 2 450 000 000 oscillations per second denotes a very high value. Oscillations at this frequency may not be reached with the use of traditionally dimensioned components, i.e., coil and capacitor.

Microwaves are therefore generated by a magnetron. Its construction is designed to simulate the function of a coil and capacitor. The function of a magnetron may be traced back to that of an oscillating circuit.

The construction and function of a magnetron, as well as the required principal circuits, will be discussed in the following section.

Modern magnetron construction is similar to that described here, and comprises individual components as shown in Fig. 30.

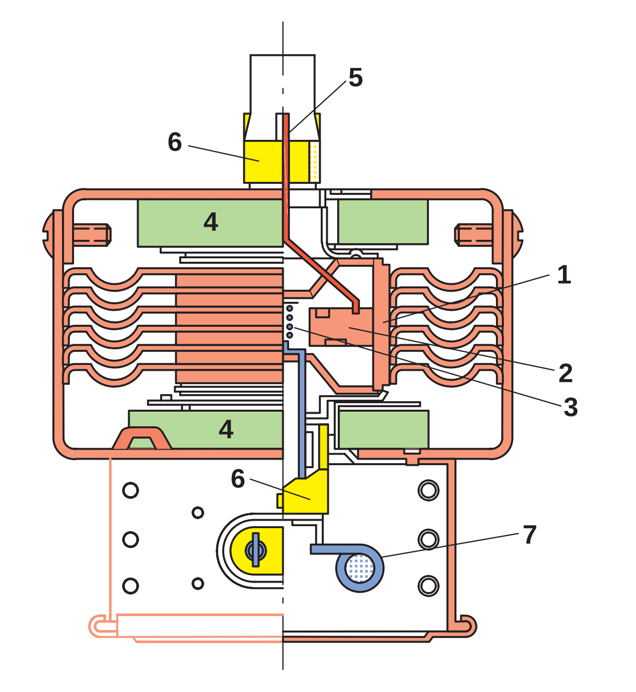



Fig. 30 Magnetron design

**1 Anode**
**2 Anode segments**
**3 Cathode (filament)**
**4 Permanent magnets**
**5 Antenna**
**6 Isolating clearances**
**7 Reactance coil**

The anode segments, cathode and antenna are in a vacuum. The insulating bushings for the cathode terminal and antenna are formed by ceramic insulating pieces.

The next figure shows a top view of the anode body, anode segments and cathode (Fig. 31.)

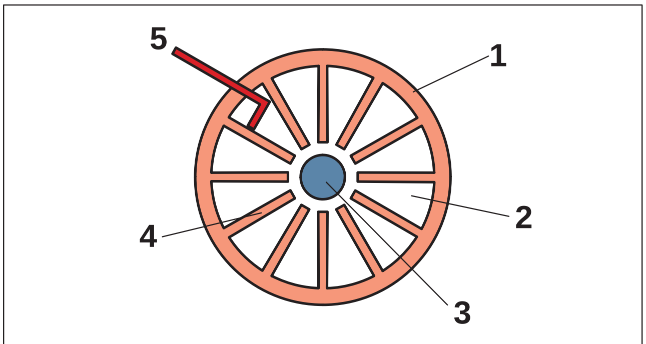



Fig. 31 Anode body

**1 Anode body**
**2 Hollow space (vacuum)**
**3 Cathode**
**4 Anode segments**
**5 Antenna**

The magnetron anode is a metal hollow body with open hollow spaces which are formed by an even number of anode segments. The anode segments point from the start of the anode to the heating filament. The antenna is connected to an anode segment.

An anode current only flows during the functioning of the magnetron so that the wall of the hollow space acts as a coil and the open side of the chamber as a capacitor, thereby simulating the function of the oscillating circuit.

Here inductance and capacitance are very small values, enabling a rapid change between electrical and magnetic fields, thereby creating a very high frequency. (Fig. 32.)

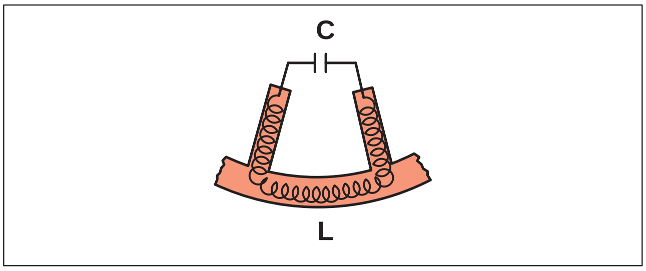



Fig. 32 Simulation of an oscillating circuit

## Functional principle of a magnetron

To enable a magnetron to generate microwaves, two voltages must be applied simultaneously to its terminals, as shown in Fig. 33:

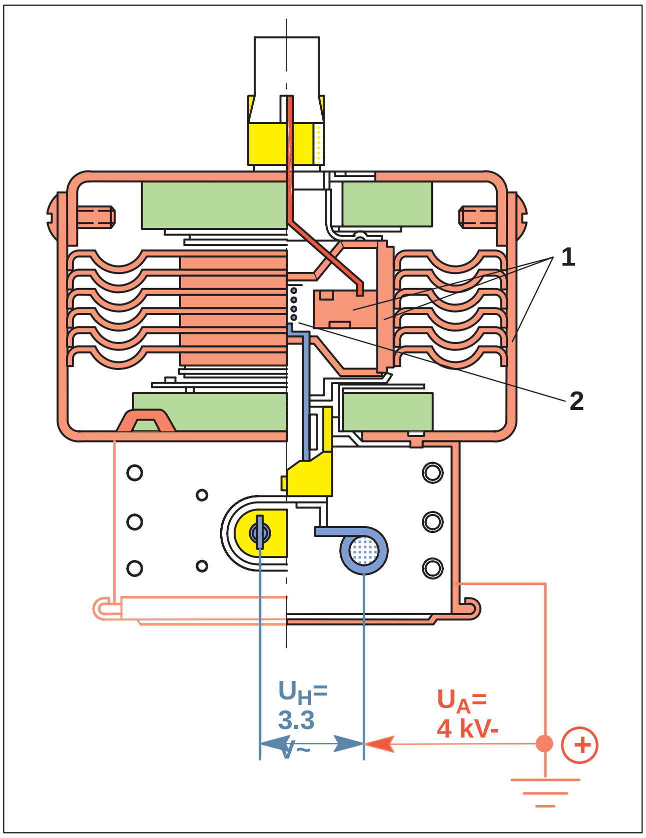



Fig 33 Magnetron voltage supply

– **approx. 3.3 V alternating current on the cathode connections (filament winding)**

– **approx. 4 kV as the positive wave of an alternating current at the anode connections**

**1 Anode**
**2 Cathode (filament winding)**

As shown in the illustration the anode body and anode segments are connected to the magnetron housing via the cooling plate. In turn, the housing is connected to the appliance chassis by means of the mounting screws.

In this manner, the appliance chassis constitutes the anode terminal.
**This is a special feature of microwave appliances.**

The voltages are produced in a high-voltage transformer with galvanically separated windings and a subsequent doubler connection. A complete description of this circuit follows later.

By heating the cathode in the vacuum, electrons escape and, in this example, fly directly to the positively biased anode. (Fig. 34.)

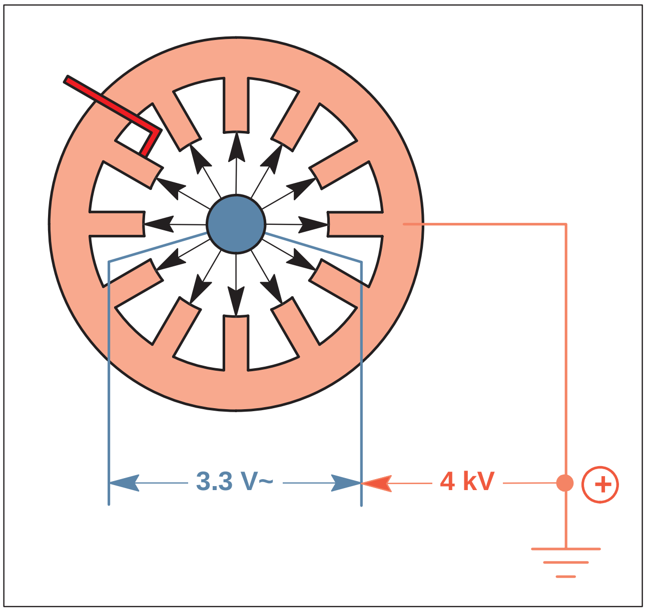



**Fig. 34 Flow of electrons**

If there exists a sufficiently strong magnetic field between cathode and anode due to the two permanent magnets, the electrons are deflected at right angles from their original direction of movement. The result is that the electrons reach the anode in a spiral path (Fig. 35.)

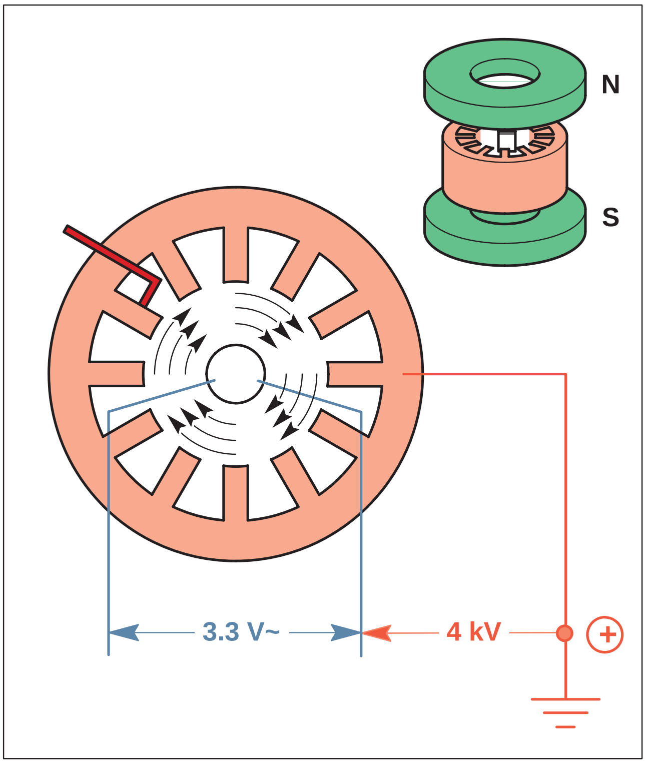



**Fig. 35 Electron deflection**

This circular motion of the electrons induces alternating currents in the hollow spaces of the anode. If an electron approaches an anode segment, a positive charge will be induced in this segment. If the electron now passes this segment its positive charge diminishes, while the electron induces a positive charge in the next segment. (Fig. 36.)

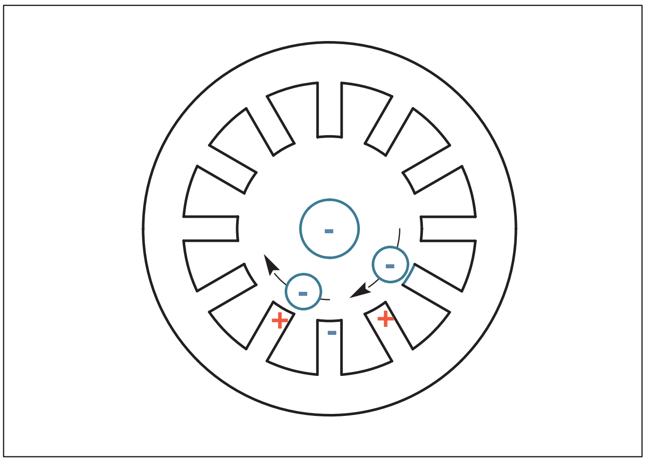



**Fig. 36 Induction by alternating current**

The induction of alternating current in the hollow spaces of the anode may best be illustrated if the oscillating circuit is viewed stationary as a unit (Fig. 37.)

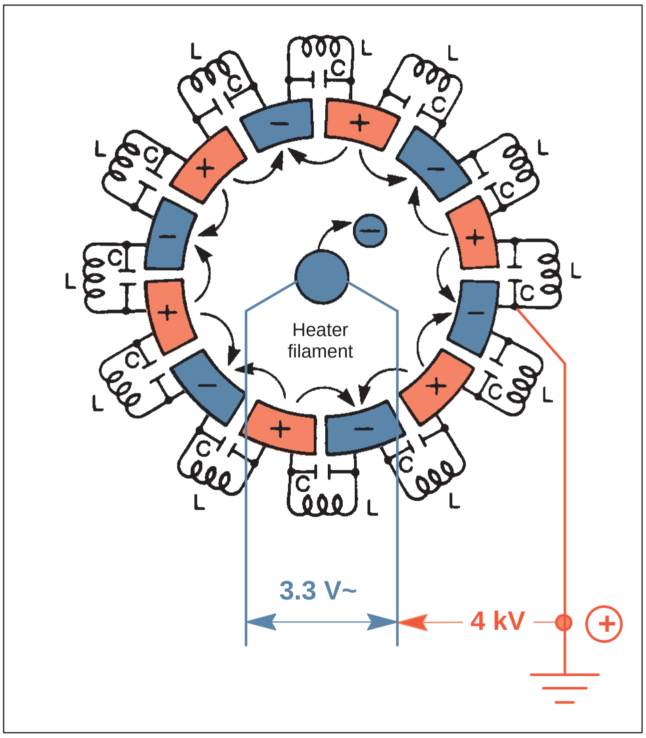



**Fig. 37 Oscillating circuit**

During normal operation of the magnetron, a concentration of electrons takes place, forming an electron cloud. Under the influence of the high anode voltage and strong magnetic fields, the electron cloud takes on the shape of a spoked wheel, which passes the anode segments with the resonance frequency of the oscillating circuit (Fig. 38.)

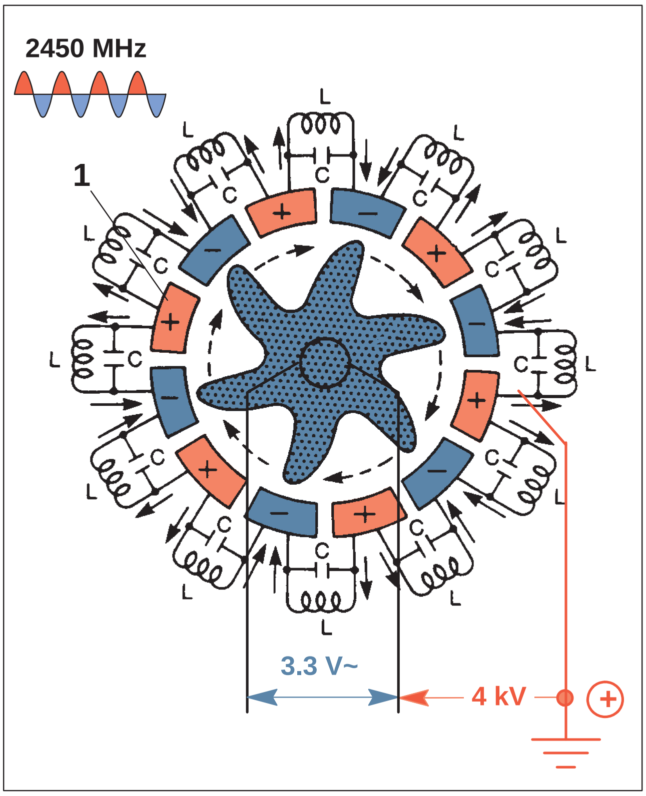



**Fig. 38 Electron cloud**

**1. Antenna**

In this fashion, a continuous oscillation of the oscillating circuit is generated.

The high-frequency electromagnetic oscillations produced within the chamber, i.e., the microwaves, are transmitted via the antenna and introduced to the cooking compartment by means of a waveguide.

**Summary of important points**

The magnetron consists of the cathode (filament), anode, antenna and two powerful permanent magnets.

The cathode, anode cavities and antenna are contained in a vacuum.

The components, such as coil and capacitor familiar from the oscillating circuit, are simulated by the anode cavities.

A magnetron only sends out microwaves, if 3 conditions are met at the same time:

– approx. 3.3 V applied to the cathode (filament)

– anode is at earth potential therefore voltage is –4 kV which is positive only in respect to EARTH

– approx. 4 kV positive AC applied to anode

– anode body contains a vacuum

## Voltage doubler circuit

The circuit specified for magnetron operation is a standardised electrical arrangement. It uses a similar principle in all microwave appliances, and differs merely in terms of component dimensioning as dictated by performance requirements. In accordance with its operational principle, the subject arrangement is termed **voltage doubler circuit**. Figure 39 shows the basic circuit containing graphical component symbols.

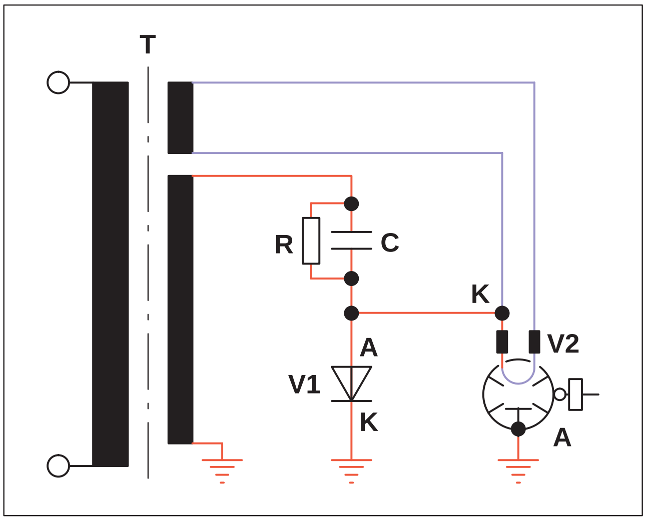



**Fig. 39 Voltage doubler circuit**

| | |
|---|---|
| **T** | **Transformer** |
| **C** | **High-voltage capacitor** |
| **R** | **Discharge resistor** |
| **V1** | **High voltage diode** |
| **V2** | **Magnetron** |
| **blue** | **Filament voltage circuit** |
| **red** | **High-voltage circuit** |
| ⏚ | **Earth connection** |
| **K** | **Cathode** |
| **A** | **Anode** |

The cathode of the high voltage diode, the magnetron anode and one one side of the high-voltage winding of the transformer are electrically connected to the appliance housing.

For reasons of electrical safety, the transformer primary and secondary coils are galvanically separated.

For radio interference suppression, two ferrite core inductor coils are situated downstream of the magnetron terminals (not shown). (Refer to Fig. 30, Pos. 7.)

To discharge the capacitor after switching OFF the appliance, a resistor is connected in parallel with the capacitor.

## Functional principle of voltage doubler

The voltages required for magnetron operation is derived from the secondary windings of the transformer. The filament voltage of approx. 3.3 V~ is permanently applied to the cathode terminal of the magnetron.

The high voltage of approx. 4 kV for the anode of the magnetron is obtained by connecting the negative half-wave of the transformer voltage in series with the capacitor voltage. The progression, commencing with the 1st positive half-wave of the secondary voltage, is shown in Fig. 40.

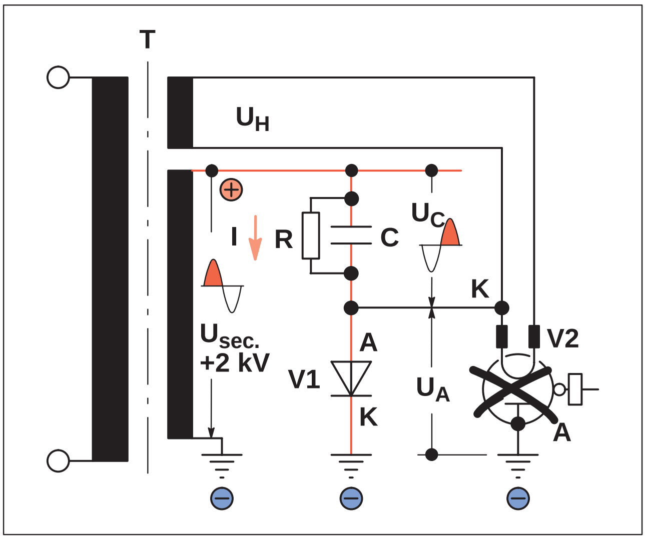



**Fig. 40 Doubler circuit during 1st positive half-wave**

| | |
|---|---|
| $U_H$ | **Filament voltage 3.3 V** |
| $U_{sec.}$ | **+2 kV** |
| **V1** | **Diode in forward direction** |
| **C** | **Capacitor is charged $U_{sec}$** |
| $U_C$ | **Capacitor voltage +2 kV** |
| $U_A$ | **Anode voltage, magnetron approx. 0 V** |
| **V2** | **Not in operation** |
| **I** | **Capacitor charging current** |

**Important Note:**

- The voltage specifications are RMS values.
- The starting points of the voltage arrows determine the polarity of the voltage specification.

**Negative half-wave (Fig. 41.)**

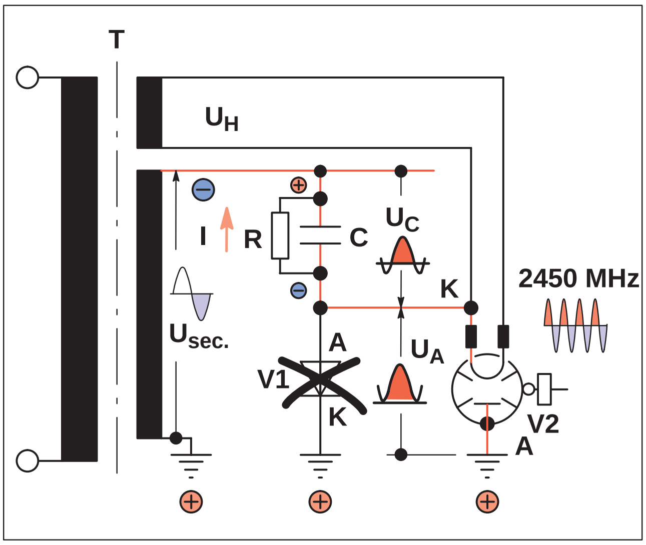



**Fig. 41 Negative half-wave**

| | |
|---|---|
| $U_H$ | **3.3 V** |
| $U_{sec.}$ | **+2 kV** |
| **V1** | **Closed** |
| **C** | **Capacitor** |
| $U_C$ | **Capacitor voltage approx. +3.3 kV** |
| $U_A$ | **Anode voltage, magnetron approx. +4 kV** |
| **V2** | **In operation** |
| **I** | **Magnetron anode current** |

As the sequence progresses, it yields the waveshape at the components as shown in Fig. 42.

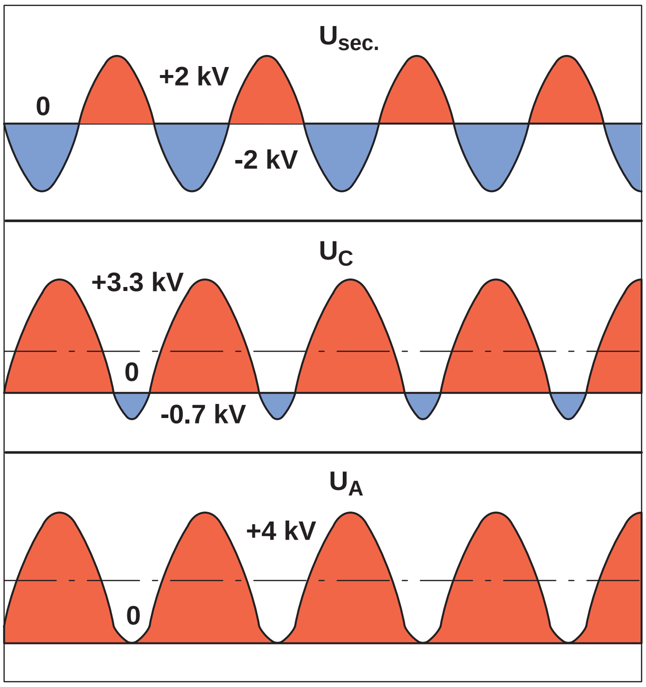



**Fig. 42 Voltage waveshape during microwave operation**

### Capacitor voltage $U_C$

The negative half-wave of the transformer voltage causes the neutral axis of the capacitor voltage to shift downward. The result is the waveshape which adheres to the timing of the secondary voltage, i.e., indicated between U1 = +3.3 kV and U2 = –0.7 kV.

### Anode voltage $U_A$

As with the series connection of two batteries, the transformer voltage and capacitor voltage between anode and cathode of the magnetron add up to the **summated voltage of approx. +4 kV**. As demonstrated by the voltage waveshape, this occurs during each high-voltage oscillation, and thereby in sync with the mains power frequency.

Accordingly, the conditions for operation of a magnetron are fulfilled:

1. A constant filament voltage of approx. 3.3 V at the cathode heating element.
2. Simultaneously a constant, pulsating direct voltage of approx. +4 kV from anode to cathode.

The processes occur within the magnetron as described (Refer to figs. 34 to 38.)
**The magnetron emits microwaves.**

### Safety considerations

As stated previously, the voltage specifications are RMS values. However, in the case of a possible contact with the terminals, the **maximum values** apply. It must be considered that, in the case of an alternating current half-wave, these values are increased by a factor of 1.41. **This results in an anode voltage of approx. 5.66 kV**.

This is one of the reasons why microwave appliances may **only be repaired by trained, authorised personnel**.

**Specification summary, high-voltage circuit** (Fig. 43.)

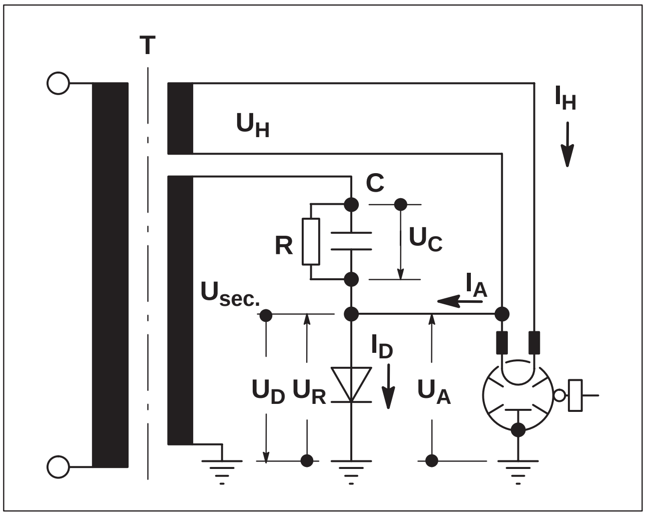



**Fig. 43 High voltage circuit specifications**

The specified values are approximate only, and merely intend to illustrate orders of magnitude. They are dependent upon appliance power ratings.

| | | | |
|---|---|---|---|
| Primary voltage $U_{prim}$ | | = | 230 V |
| Secondary voltage | $U_{sec}$ | = | 2 kV |
| Filament voltage | $U_H$ | = | 3.3 V |
| High voltage capacitor | C | = | 0.8–1.3 µF |
| Capacitor voltage | $U_C$ | | |
| | U1 | = | +3.3 kV |
| | U2 | = | –0.7 kV |
| Discharge resistor | R | = | 9 MOhm |
| Forward voltage, diode | $U_D$ | = | +15 V |
| Forward current, diode | $I_D$ | = | 0.3–0.4 A |
| Reverse voltage, diode | $U_R$ | = | +8 kV |
| Anode voltage, magnetron | $U_A$ | = | +4 kV |
| Anode current, magnetron | $I_A$ | = | 0.3–0.4 A |

## Protective devices for high-voltage transformer

A short-circuit on the high voltage side due to a defective diode, a punctured capacitor or a sparkover on the magnetron, leads to a voltage build-up of the secondary current circuit of the transformer (Fig. 44.)

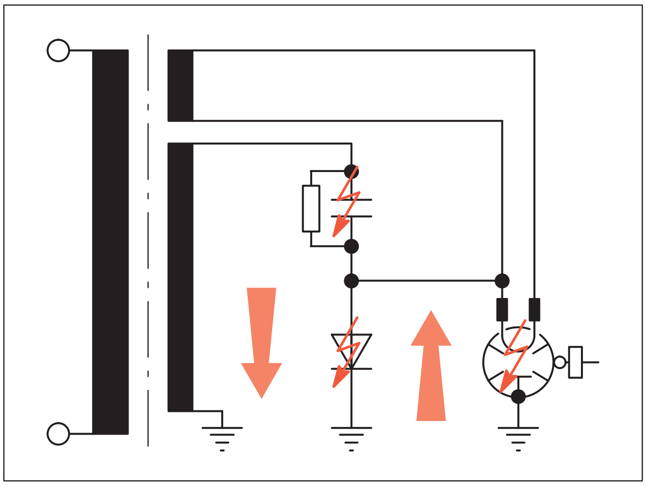


**Fig. 44 Short-circuit on the secondary side**

To protect the transformer from becoming too hot, different protective measures and circuit arrangements are applied:

- short-circuit-proof transformer designs with correspondingly thick wire cross-sections
- Wire fuses/temperature fuses
- High-voltage fuses in the diode and anode current circuits of the magnetron
- Use of a protective diode

These protective measures are used singularly or combined according to the appliance design and model variant.

## Short-circuit proof transformer designs

These measures are mainly used for appliances with electromechanical control. These appliances have a maximum operating time of 1 hour.

The installed transformers are sufficiently short-circuit proof for this duration.

**Wire fuses and temperature fuses** (Fig. 45)

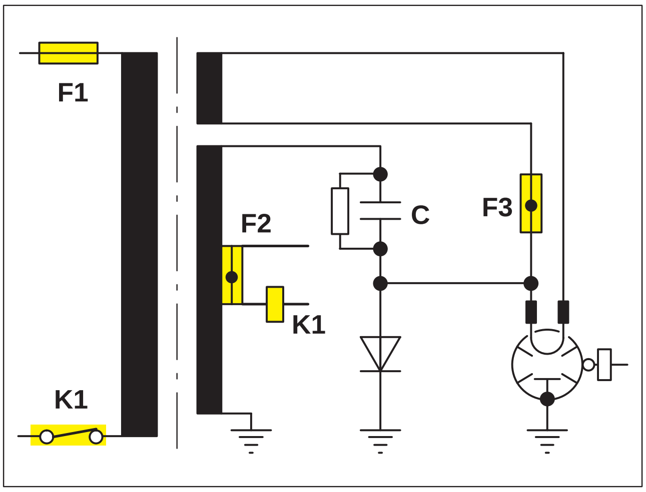



**Fig. 45 Protective circuit by means of transformer fuses and wire fuses**

**F1** **Primary side minature fuse**
**F2** **Temperature fuse (compound-moulded with the transformer winding)**
**F3** **Wire fuse in heating circuit**
**Length and cross-section of this fusible wire are based upon the respective short-circuit current.**
**K1** **Cut-OFF relay**

**F1** Tripped by a short-circuited high-voltage capacitor. This causes the primary current to rise, tripping the F 1 appliance fuse.

**F2** Tripped by excessive heat accumulation in the high-voltage winding of the transformer. At the same time, the primary side of the transformer is switched OFF by the K 1 relay.

**F3** Melts when a short-circuit is detected in the heater circuit. Blow-out response time is current-dependent.

**Fuses in the diode and anode current circuits** (Fig. 46.)

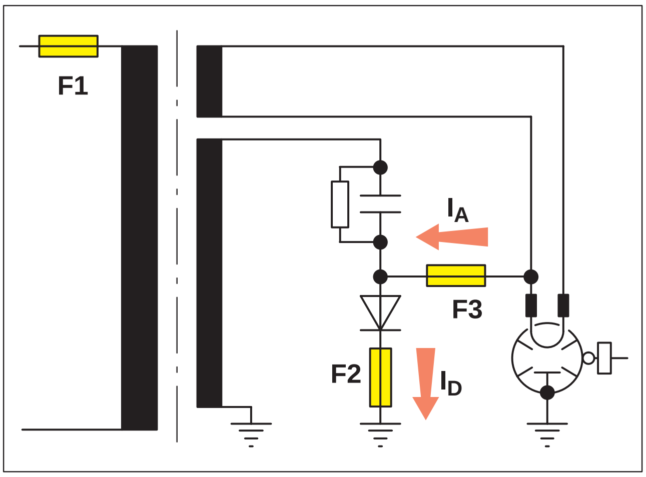


**Fig. 46 Fuses in the diode and anode current circuits**

**F1 Primary side appliance fuse**
**F2 Diode current circuit fuse**
**F3 Anode current circuit fuse**

**F1** has the same function as already described for the circuit arrangement using fusible links.

**F2** and **F3** are determined for the corresponding currents. If the value of the tripping current is exceeded, the corresponding fuse is triggered.

## Protective diodes

The protective diode consists of two diodes connected back to back with different reverse voltages. It is connected in parallel to the high voltage capacitor and forms, together with the F1 primary side fuse, the protective cut-off. (Fig. 47.)

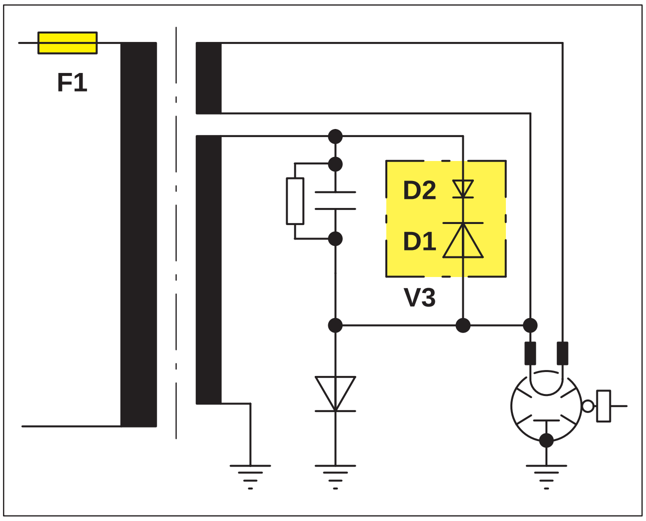



**Fig. 47 Protective diode**

**F1 Primary fuse**
**V3 Protective diode**

Both back to back connected diodes carry the following reverse voltages:

**D1 = 6 kV**
**D2 = 1.7 kV**

Since the protective diode is connected in parallel with the high-voltage capacitor, normal operation will yield the voltage waveshapes as shown in Fig. 42. (Again, please observe the voltage directional arrows.)

**Normal situation: capacitor voltage $U_C$= +3.3 kV** (Fig. 48.)

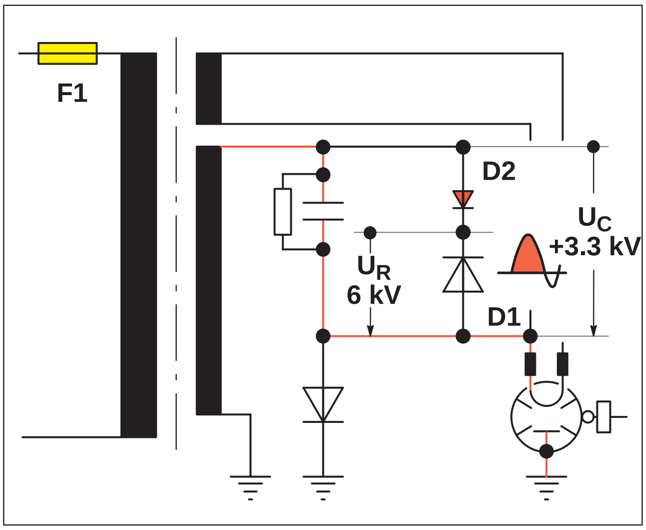



**Fig. 48 Normal situation: $U_C$ = +3.3 kV**

D2 in the forward direction. D1 is in the reverse direction and is not destroyed because the reverse voltage of 6 kV is greater than the applied voltage of 3.3 kV. The capacitor is not bridged. The protective circuit has no effect.

**Normal situation: capacitor voltage $U_C$= –0.7 kV** (Fig. 49.)

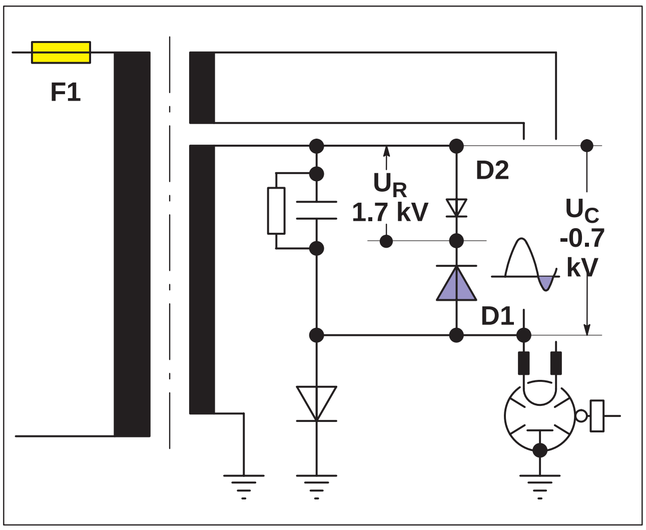



**Fig. 49 Normal situation: capacitor voltage $U_C$ = –0.7 kV**

D1 is now in forward direction and the voltage of 0.7 kV is in the reverse direction at D2. The protective circuit again has no effect because the reverse voltage of 1.7 kV is higher.

**Fault situation: Diode V 1 short-circuited** (Fig. 50.)

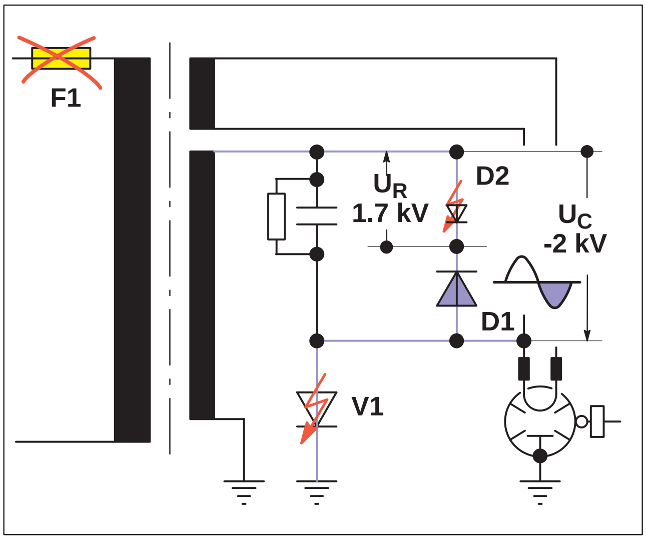



**Fig. 50 Fault situation: short-circuit in high voltage circuit**

By way of an example, due to a short-circuit of the diode or the magnetron the capacitor lies directly on the secondary voltage of 2 kV, respectively. This means that the neutral axis of the capacitor voltage is now again in the centre.

If the negative half-wave is currently active, this causes diode D1 to switch to forward-bias. The entire voltage of 2 kV is now present with reverse-bias on D2. Since the applied voltage of 2 kV exceeds the 1.7 kV reverse-bias voltage of D2, a break-through of D2 occurs.

This causes capacitor C to be bridged and a complete short-circuit of the high-voltage winding of the transformer. Triggered by the rise in current on the secondary side and dependent upon the transformer transmission ratio, the primary fuse F 1 is tripped immediately.

Due to the break-through of D2, the semiconductor junctions of D1 and D2 are flooded with charge carriers (avalanche effect), resulting in their destruction. Accordingly, the protective diode must be replaced together with the component initiating the fault, and with fuse F 1.

The essential points about the function of the protective diode are summarised in a data table (Fig. 51.):

| | **D1** | **D2** | **F1** |
|---|---|---|---|
| **$U_R$** | **6 kV** | **1.7 kV** | |
| **$U_C$ +3.3 kV** | **$U_C < U_R$** | **Forward** | |
| **$U_C$ –0.7 kV** | **Forward** | **$U_C < U_R$** | |
| **$U_C$ –2 kV** | **Forward** | **$U_C > U_R$** | |

**Fig. 51 Protective diode data table**

## Controlling output power

The output power is the microwave power which is used for heating foods in the cooking compartment. The power is expressed in watts.

In accordance with the required microwave power, several levels of output power may be selected. (Fig. 52.)

| **Power level** | **Application** |
|---|---|
| **max.<br>i.e., 1100 W** | **Rapid heating** |
| **600 W** | **Cooking** |
| **360 W** | **Heating up** |
| **180 W** | **Defrosting** |
| **90 W** | **Warming** |

**Fig. 52 Microwave oven power levels**

Our appliances utilise two methods of controlling output power:

– Changing the capacity of the high-voltage capacitor

– Varying ON and OFF times (cycling) of the magnetron

**Controlling power by changing the capacity of the high-voltage capacitor**

This method is mainly utilised in appliances with only two power levels (Fig. 53.)

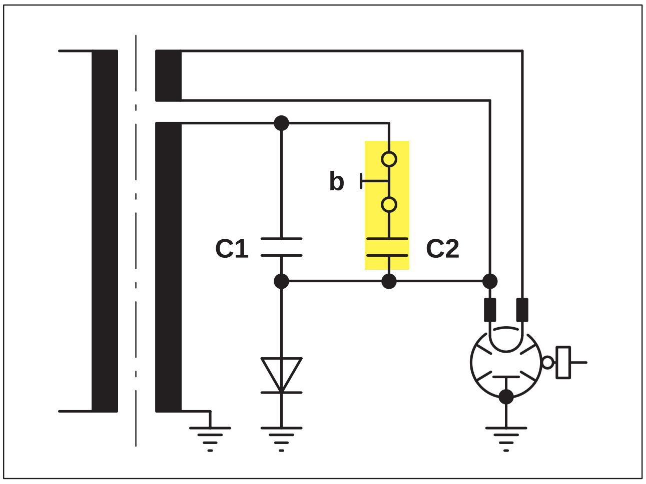



**Fig. 53 Power control by changing the capacity of the high-voltage capacitor**

**b switch**

Electrical isolation of capacitor C 2 results in a reduction of the anode current and thereby of the output power.

**Power control via different magnetron ON and OFF-times (cycling)**

With this method the magnetron always works with full power = 100 %. The various power levels are mathematically derived from the following formula (Fig. 54.):

$$P_2\,[\text{Watt}] = P_{max} \cdot \frac{ED}{ED+AD}$$

**or**

$$P_2\,[\%\,P_{max}] = \frac{ED}{ED+AD} \cdot 100$$

**Fig. 54 Formula for output power**

**$P_2$ = output power**
**$P_{max}$ = maximum power**
**ED = Operating time**
**AD = OFF cycle duration**

A sample calculation:

$P_{max}$ = 600 W
ED = 18 sec.
AD = 12 sec.

$$P_2 = 600 \times \frac{18}{18 + 12} = \mathbf{360\ W}$$

or

$$P_2 = \frac{18}{18 + 12} \times 100 = \mathbf{60\ \%\ P_{max}}$$

Again, the appliances operating according to this principle may be divided into two groups:

– cycling on the primary side
– cycling on the secondary side

**Cycling on the primary side** (Fig. 55.)

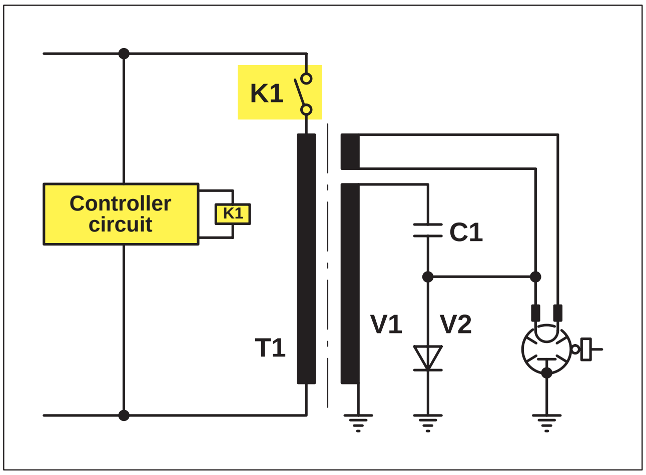



**Fig. 55 Cycling on the primary side**

**K1: Cycling relay**

With this principle the switch contact lies on the primary side. Thereby no particular demands are made on the insulation of the switch. The timing ratio determines the nature of the controller circuit. This may be an electronic or an external electromechanical timer. Since the ON/OFF cycling also includes disabling the magnetron heater filament, the magnetron requires a transient recovery interval of approx. 1 to 2 seconds before it can deliver full output.

**Cycling on the secondary side:** (Fig. 56.)

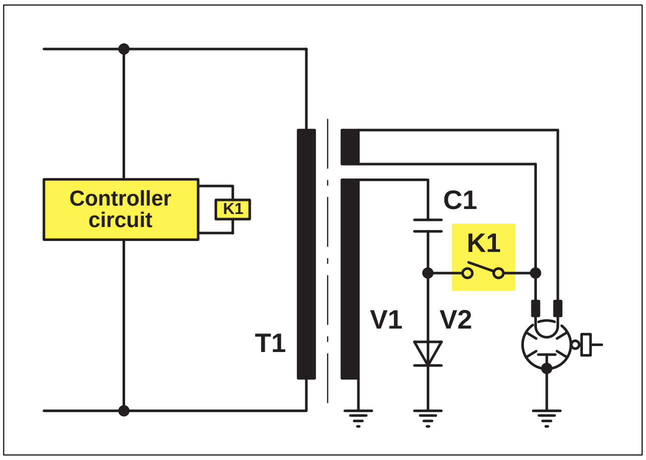



**Fig. 56 Cycling on the secondary side**

In contrast to the previous circuit, the switching contact is situated on the high-voltage side, and as a consequence is subjected to heavy use. For this reason, a special high-voltage relay with a reed contact is used.

As depicted by the circuit diagram, this arrangement does not switch OFF the magnetron heater during cycling. Accordingly, the magnetron delivers full power immediately upon being switched ON again.

In accordance with the selected power level, the controller circuit switches the timer relay ON and OFF. Using the example of a microwave appliance with a power rating of 600 W, the relationship between output power and associated cycle times is described in the following diagram (Fig. 57.)

| Setting $P_2$ | $P_2$ ($\%P_{max}$) | Clock times [sec.] On | Off |
|---|---|---|---|
| 600 W | 100 | 30 | |
| 360 W | 1) 2) 60/65 | 1) 2) 18/19.5 | 12/10.5 |
| 180 W | 30/35 | 9/10.5 | 21/19.5 |
| 90 W | 15/20 | 4.5/6 | 25.5/24 |

**Fig. 57 Clock times**

**1) Cycling on the secondary side**
**2) Cycling on the primary side**

For cycling on the primary side the clock times must be considered with the transient recovery time of approx. 1.5 seconds.

If a power budget is prepared for a microwave appliance, the components required for operation account for the following shares in % (Fig. 58.)

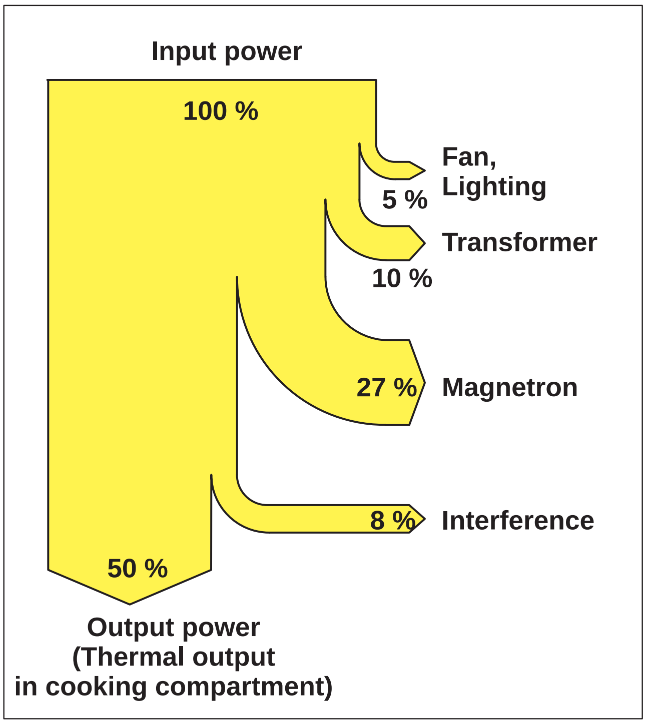



**Fig. 58 Power budget**

## Measuring the output power

The output power is calculated via the temperature increase of a prescribed water load at the maximum power stage and time.

The procedure is specified in the DIN regulations **(DIN 44566 Part 2)**. It is related to the standard issued by the "International Electrotechnical Commission" (IEC) and whose reference number is **IEC 705**.

For any deviating measuring procedures, appropriate methods are outlined in the respective service documentation.

## Limiting inrush current

Due to the initially minute internal resistance of the high-voltage transformer during the power-ON sequence, a high-current pulse may occur, thereby tripping the main fuse of the household.

To dampen this very short current pulse during the power-ON sequence, a series resistor is briefly introduced in series, and immediately afterwards again bridged by a relay contact.

Relays and damping resistors together comprise the inrush current limiter. It has a standard circuit arrangement which is installed in appliances with electromechanical and electronic control.

**Inrush current limiter for appliances with electromechanical control** (Fig. 59.)

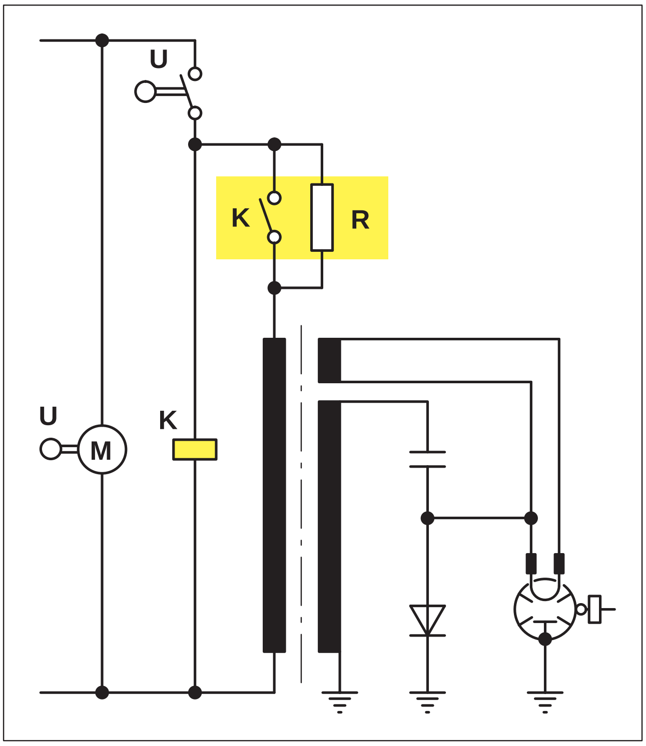



**Fig. 59 Inrush current limiter for appliances with electromechanical control**

**U Electromechanical power clock**
**K Limiting relay**
**R Damping resistor**

The clock times determine the power cycle. During the time differential, between triggering of the relay K and closing of the contacts, the power supply to the transformer ensues via the damping resistor. Afterwards the resistor is bridged by means of the contact assembly.

This time interval amounts to approx. 40 ms. The starting operation repeats itself at each power stroke.

**Inrush current limiter for appliances with electronic control** (Fig. 60.)

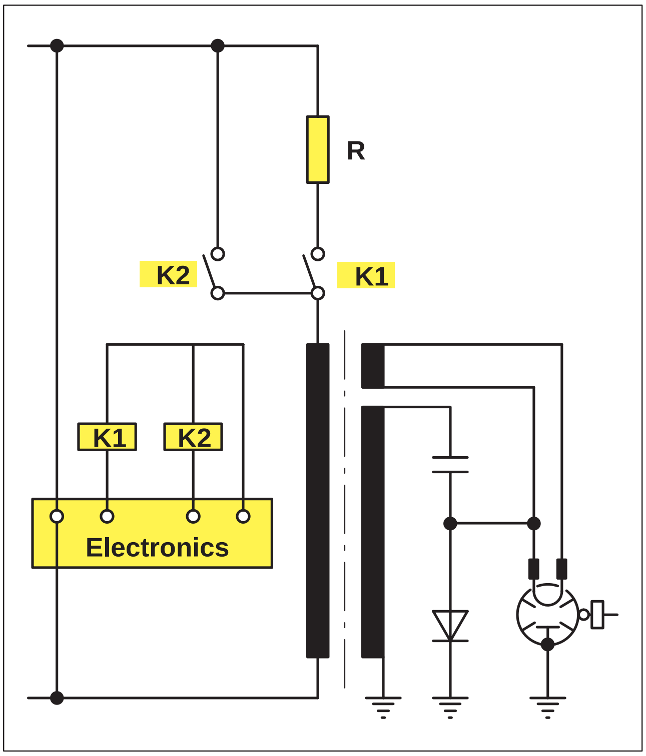



**Fig. 60 Inrush current limiter for appliances with electronic control**

**K 1 Limiting relay**
**K 2 Timing relay**
**R Damping resistor**

With every starting operation, the temporary operating sequence of the relay is electronically determined (Fig. 61.)

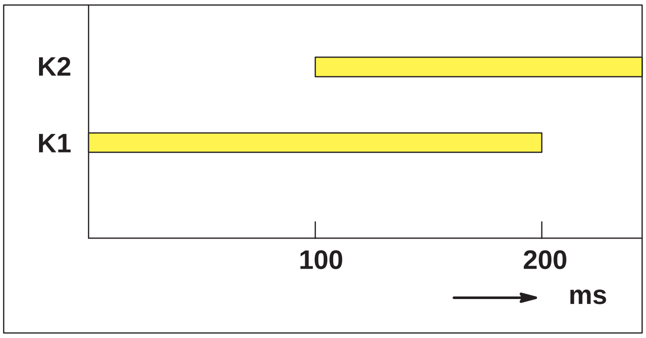



**Fig. 61 Starting sequence**

A safe power-ON sequence is ensured by the temporary time coverage of approx. 100 ms.

This sequence repeats itself with every timing sequence.

With appliances featuring electronic control, it is also possible to place the power-ON cycle in sync with the zero axis of the mains alternating current.

In this case a damping resistor may be omitted.

## Safety systems

The important and independently functioning safety systems are:

- **the door safety switch**
- **safety against over heating**
- **the sealing system.**

## Interlocking safety switches

Even in the presence of certain design variations, microwave ovens are equipped with a minimum of three safety switches. The switches are actuated by opening the oven door, with their basic function being the immediate interruption of microwave generation upon door opening. The third switch is a short-circuit switch. It monitors the remaining two switches, and trips the appliance fuse in the event that the switch being monitored should malfunction. In this case, the appliance is cut off from the mains power, and cannot again be switched ON. (Fig. 62.)

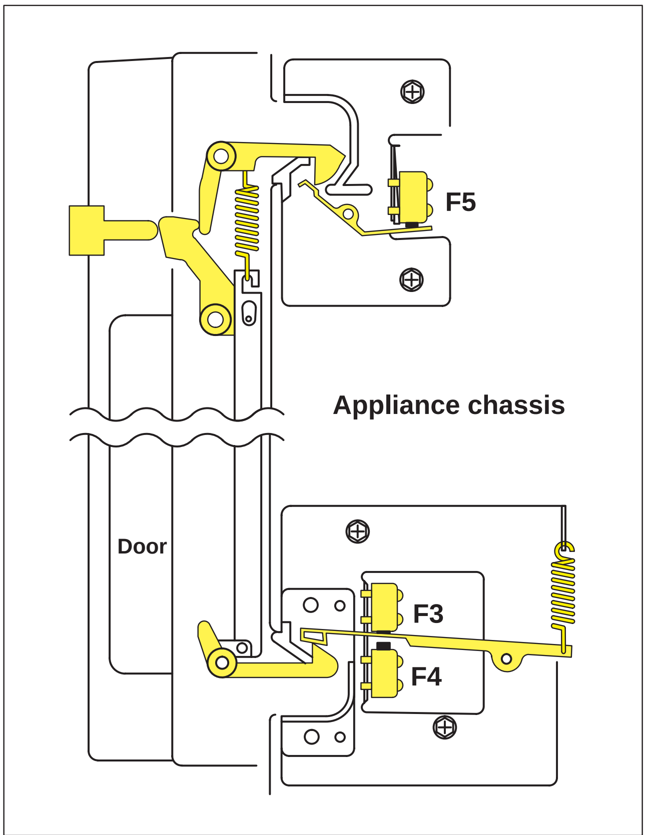



**Fig. 62 Door safety switch arrangement for a microwave appliance (door closed)**

**F3 Door safety switch**
**F4 Short-circuit switch**
**F5 Safety switch monitored by F4.**

In terms of circuits, the switches are arranged as follows: (Fig. 63.)

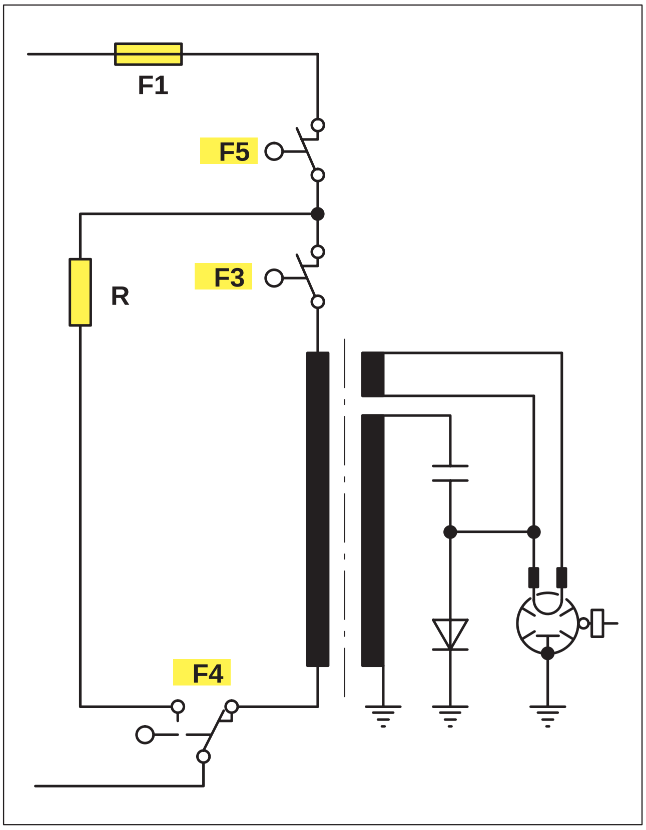



**Fig. 63 Safety circuit (door closed)**

**F1 Appliance fuse**
**R Series resistor**
**F3 Safety switch**
**F4 Short-circuit switch (monitors F5)**
**F5 Safety switch (monitored by F4)**

When the oven door is opened, each door switch disables the power supply to the microwave independently of the other switches. The switching sequence is dictated by the switch arrangement, as listed in the table in Fig. 64.

| Switch sequence | Door opened | Door closed |
|---|---|---|
| 1.) | F5 | F4 |
| 2.) | F3 | F3 |
| 3.) | F4 | F5 |

**Fig. 64 Switching sequence for door safety switch**

If the schematic in Fig. 63 is again examined with a view to switching sequence, it becomes apparent that, in the case of a failure of switch F5 **(contact fails to open upon when door is opened)**, a short-circuit occurs through F4 across the series resistor, with the result that the appliance fuse is tripped. This prevents the appliance from being switched ON again.

This is an automatic occurrence, although all switches disable the high-voltage transformer independently of this function. The result is a 3-way safety interlock which is used in a similar arrangement in all microwave appliances of our manufacture.

### Overheating protection

The very high density of high-frequency energy within the magnetron results in a significant rise in temperature during operation.

For this reason, the magnetron is equipped with cooling fins and is constantly cooled by a cooling fan.

In the event that the cooling fan power fails for some reason, the temperature limiter that is flange-mounted to the housing immediately cuts off the power supply to the magnetron. (Fig. 65.)

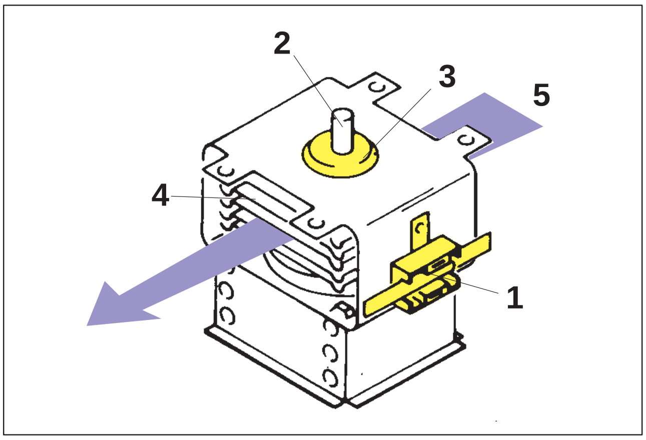



**Fig. 65 Magnetron with temperature limiter**

**1 Temperature limiter**
**2 Antenna**
**3 High-frequency seal**
**4 Cooling fins**
**5 Cooling fan air stream**

Another temperature limiter is situated on the appliance housing in the proximity of the air vent of the cooking compartment. It also monitors the presence of the cooling air stream and the temperature of the cooking compartment, and switches OFF the appliance if lack of ventilation or excessive temperature are detected.

Appliances with electronic control utilise NTC sensors for the temperature limiting function.

Reference to the placement of the temperature limiters within the appliance circuitry will again be made in the subsequent discussion of the overall appliance functions.

## Microwave appliance circuit arrangement

The operating method of the components and systems referred to up to now such as; magnetron, voltage doubler, power control, initial inrush current, overheating protection and door safety switch, are now seen in context with the help of a wiring diagram. The graphical symbols of the components with safety functions are marked in yellow (Fig. 66.)

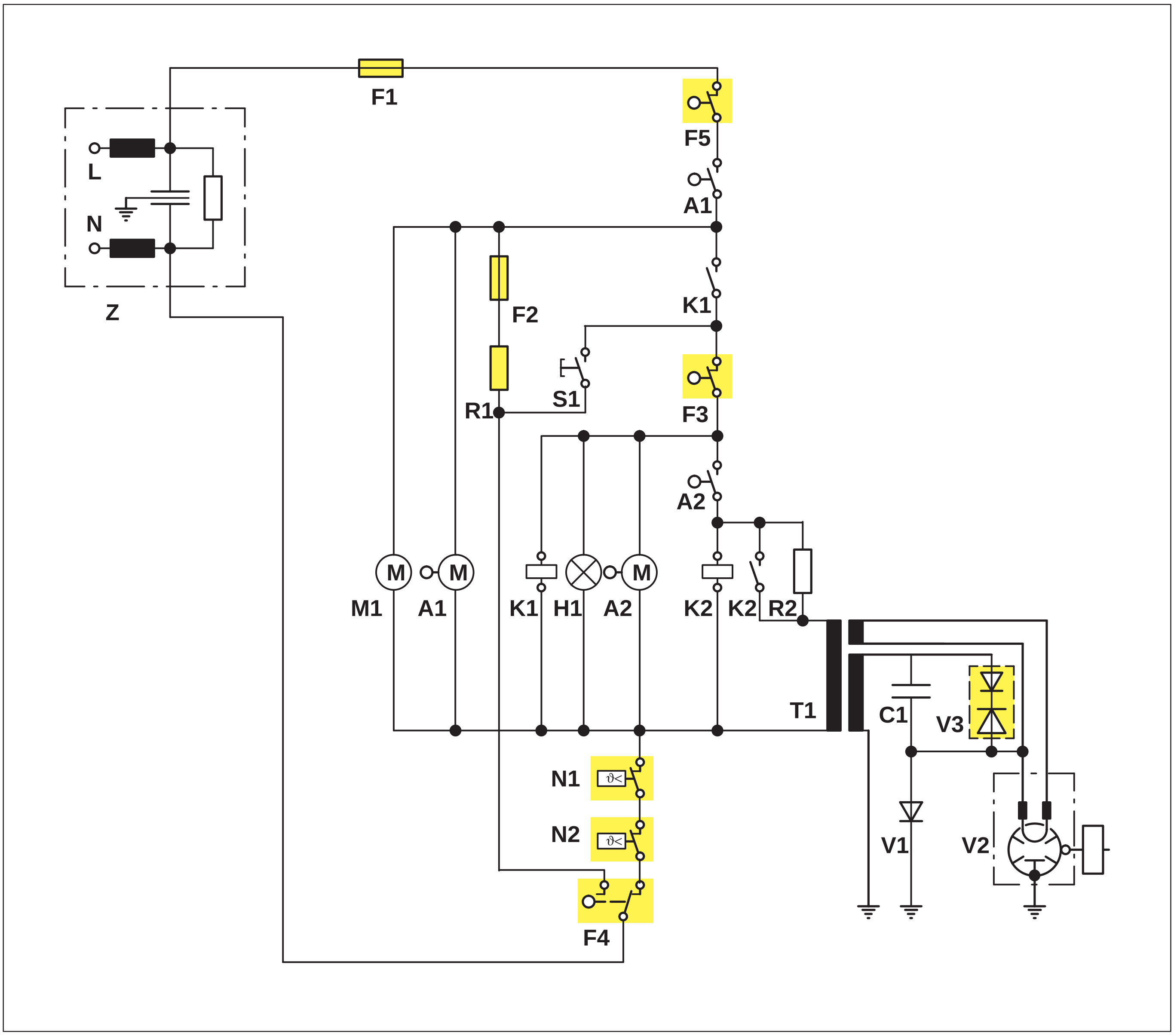



**Fig. 66 Main wiring diagram for a microwave appliance with electromechanical control**

**Z** **Radio interference suppression**
**F1** **Appliance fuse**
**F5** **Door safety switch (monitored)**
**A1** **Time clock/Time closing contact**
**M1** **Fan motor/antenna drive/rotary base**
**F2** **Short-circuit current fuse**
**R1** **Damping resistor**
**S1** **Start button**
**K1** **Start relay**
**F3** **Doorswitch**
**H1** **Cooking compartment lamp**
**A2** **Power timer/Contact**
**N1** **Magnetron overheating protection**
**N2** **Cooking compartment overheating prot.**
**F4** **Short-circuit switch (monitors F5)**
**K2** **Cycling relay**
**R2** **Damping resistor (inrush current limiter)**
**T1** **High-voltage transformer**
**C1** **High-voltage capacitor**
**V1** **High-voltage diode**
**V2** **Magnetron**
**V3** **Protective diode**

The at-rest position for all of our wiring diagrams, and therefore also for the contact position of door safety switches, is always the position with **door closed.**

In this example, further steps in the power-ON sequence require the setting of the timer, selection of power level, and pressing the start button. (Fig. 67.)

| | Door | Time A1 | Power timer A2 | Start button |
|---|---|---|---|---|
| Com-po-nent | Closed | Selected | Selected | Pressed |
| M1 | | On | On | On |
| A1 | | On | On | On |
| K1 | | | | On |
| H1 | | | | On |
| A2 | | | | On |
| K2 | | | | On (timed) |
| T1 | | | | On |

**Fig. 67 Component starting sequence**

## Safety sealing systems

Safety sealing systems prevent the escape of microwaves during appliance operation. The following sealing systems are used in combination with one another:

**Shielding (Faraday's cage)**
**Capacitive seals**
**Lambda trap**
**Ferrite seal**

## Shielding (Faraday's cage)

A fully enclosed metal housing provides additional shielding and provides protection against electric shock for all the microwave oven components, in particular for the high-voltage circuit components.

A perforated metal mask placed between the door wafers allows observation of the cooking compartment but simultaneously prevents the escape of microwaves by means of its screening effect (Fig. 68.)

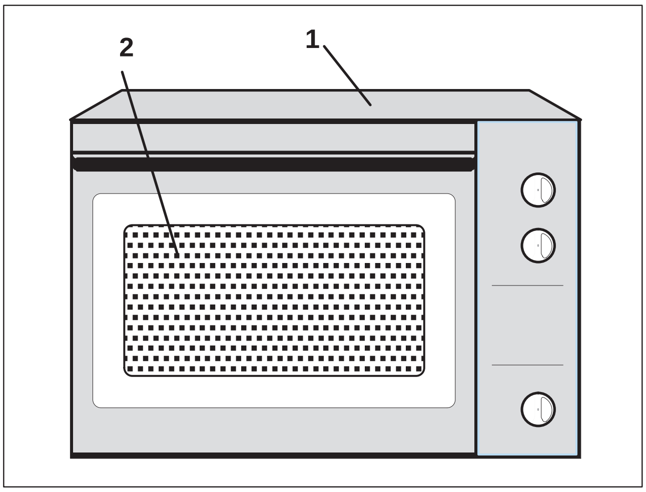



**Fig. 68 Shielding**

**1 Appliance housing**
**2 Perforated mask**

Together with the door shielding and the housing, the metallic cooking compartment or oven cavity comprise a closed, electrically conductive system. It serves to concentrate the microwave energy on the food being heated in the cooking compartment, while at the same time shielding against undesirable escape of microwave energy. The dimensions of the air vents in the cooking compartment as well as those of the perforations of the window mask constitute only a few percent of the Lambda wavelength. **They are therefore virtually impervious to microwave penetration**.

## Capacitive seals

From an electrical standpoint, with high-frequency operation the combination of the close tolerances between the cooking compartment wall and door, with an intermediate condensate seal, provides **capacitive properties** (Fig. 69.)

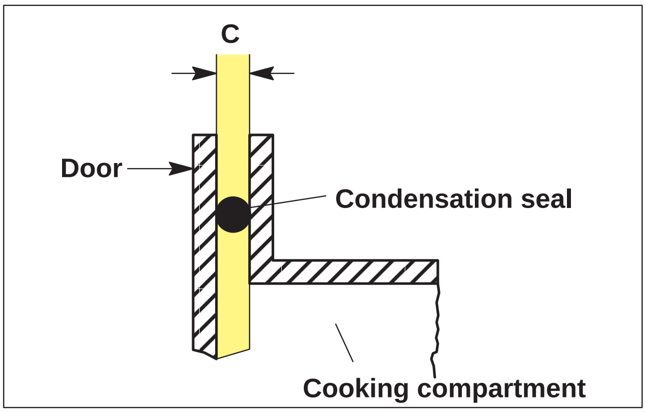



**Fig. 69 Capacitive seal**

The gap between cooking compartment flange and inside door surface may not exceed a specific dimension which is determined by the wavelength. In this case, the gap acts as a capacitor.

To the high-frequency microwaves, this simulated capacitor represents a short-circuit. It therefore has the same effect as if both surfaces are in metallic contact.

## Lambda trap

The lambda trap is a metal frame which is open on one side. In this example it is found on the internal side of the door and is dimensionally fixed at 1/4 lambda wavelength = **3.06 cm** (Fig. 70.)

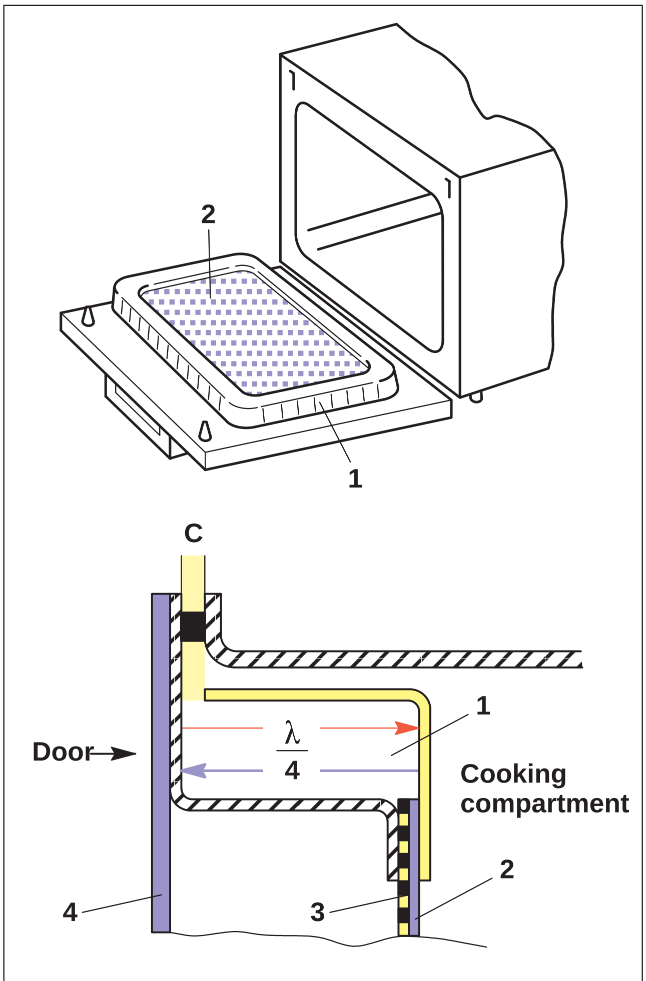



**Fig. 70 Sealing system with an internal, horizontal lambda trap**

**1 Lambda trap**
**2 Internal wafer**
**3 Perforated mask**
**4 External wafer**
**C Door gap with condensation seal**

Upon arrival from the cooking compartment, the microwaves enter the Lambda trap, and are reflected back to the entrance aperture in phase opposition. There they cancel further incoming microwaves. Up to this point, they have travelled 2 x 1/4 Lambda.

Since the door gap is designed to be adjacent to the entry aperture of the Lambda trap, any microwaves arriving in the area of the door gap are cancelled by the effect of the Lambda trap. Naturally, the additional function of capacitive seal C must also be considered, making certain that no microwaves can escape in the vicinity of the door area.

What exactly occurs in the lambda trap may be seen in Fig. 71.

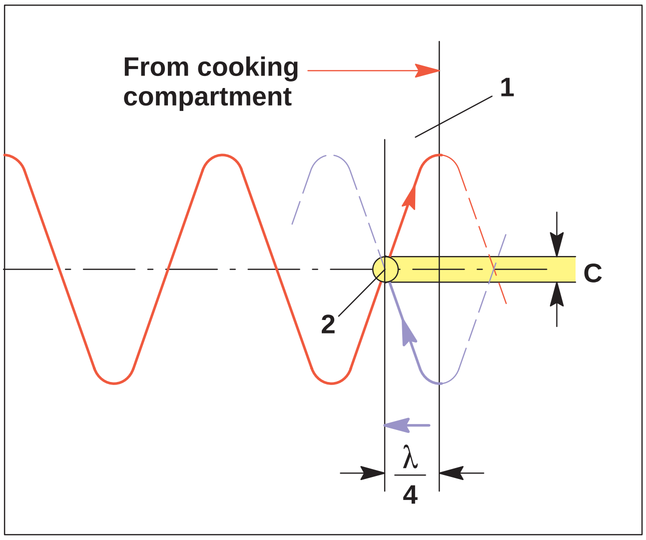



**Fig. 71 Lambda trap functional principle**

| | |
|---|---|
| **1** | **Lambda trap** |
| **2** | **Entry point** |
| **C** | **Door gap** |
| **Red** | **Incoming microwaves** |
| **Blue** | **Reflected microwaves** |

As shown above, the incoming microwaves at the point of entry are reflected back onto those which have left the cooking compartment. They arrive in phase opposition and thereby cancel out incoming oscillation.

## Ferrite seal

Ferrite seals consist of pure, soft carbon iron crystals which are embedded in rubber. Their physical properties cause them to absorb microwaves. They are commonly installed in addition to the door sealing systems discussed in the foregoing.

The following figure shows a ferrite seal for an appliance with a horiziontal lambda trap situated outside the cooking compartment (Fig. 72.)

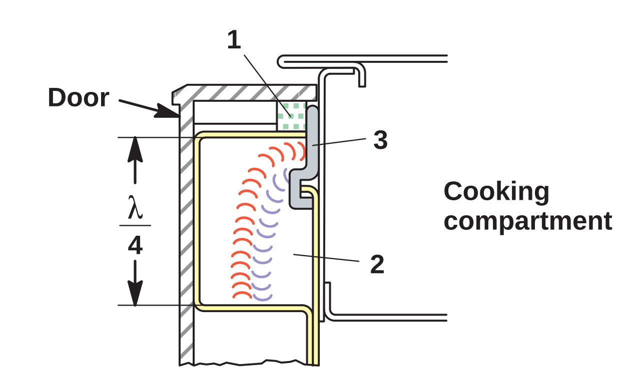



**Fig. 72 Ferrite seal and external Lambda trap**

1 **Ferrite seal**
2 **Lambda trap**
3 **Plastic seal**

The ferrite seal absorbs any possible microwave energy which may still be present in this area. The functional principle of the Lambda trap located outside the cooking compartment has been described in the foregoing.

The existing plastic cover protects the lambda trap from dirt accumulation.

**To summarise briefly**

Door switches, acting independently of each other but monitoring each other in an interlocking fashion, provide a safe power-OFF situation when the appliance door is opened.

The combination of several safety sealing systems, such as shielding, capacitive seals, Lambda trap and ferrite seal prevent the escape of microwaves while the appliance is operating.

## Microwave distribution

The microwaves generated within the magnetron are introduced to the cooking compartment either directly or via so-called waveguides.

Since the dispersion of the microwaves does not occur in free space but in an enclosed cooking compartment, the dimensions of the same are specified according to the wavelength of the microwave frequency.

The wavelengths and the cooking compartment dimensions lie in the same order of magnitude (in cm).

Viewed from the standpoint of physics, the resulting model would, in its idealised form and with an empty appliance, comprise a **standing wave** (Fig. 73.)

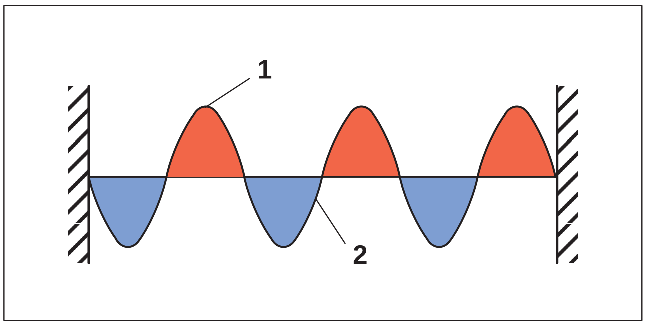



**Fig. 73 A standing microwave in the cooking compartment**

1 **Position with high field strength**
2 **Position with low field strength**

The figure shows that with this field distribution on the cooking compartment walls, the field strength is zero, and for this reason no heat can be generated there.

In reality, the dispersion of the microwave field in the cooking compartment exhibits a three-dimensional characteristic. (Fig. 74.)

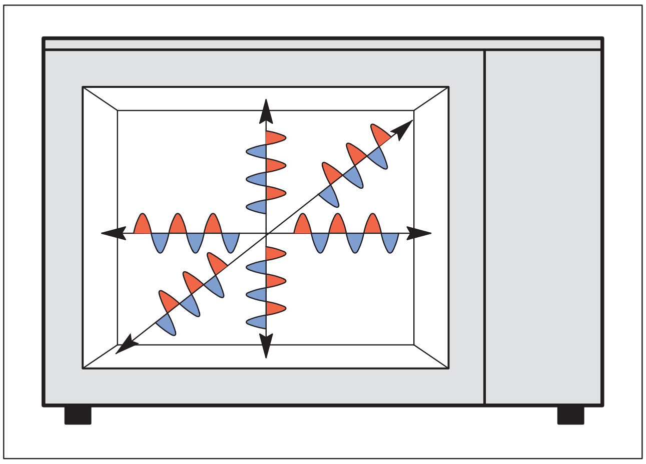


**Fig. 74 Three-dimensional microwave field**

If food is now added, the standing field will shift, resulting in varying field strengths and temperature distribution. We therefore utilise the following technical measures to optimise microwave distribution, and thereby also the temperature distribution:

**Rotary base**
**Wobbler**
**Rotating antenna**

## Rotary base

To reach uniform temperatures, the food is moved through the microwave field by a rotary base (Fig. 75.)

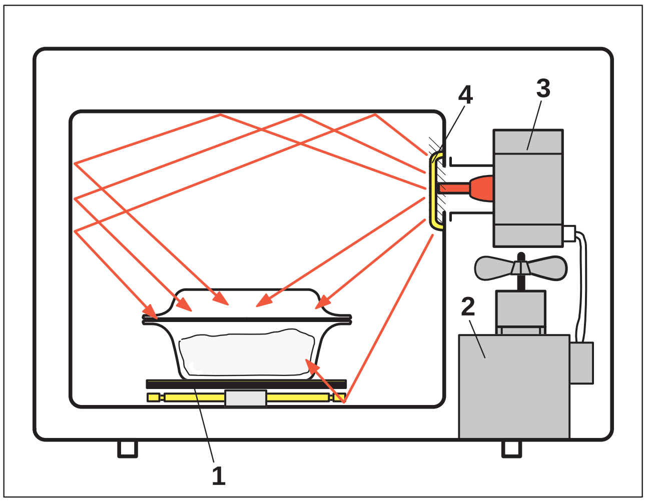



**Fig. 75 Microwave distribution with rotary base**

**1 Rotary base**
**2 Cooling fan**
**3 Magnetron**
**4 Input point**

The rotary base is continuously powered by a motor. In this example, the microwaves are input directly via the antenna post of the magnetron. A plastic cover protects against dirt contamination.

A rotary base consists of a special glass compound which absorbs a certain amount of microwaves and thereby warms up.

By improper use, without a load in the cooking compartment, the rotary base forms a base load. As a result it prevents the reflection of all the available microwave energy back to the magnetron. This could cause excessive internal temperatures in the magnetron, and subsequent operation of the protective temperature limiter.

## Wobbler (Reflector wing)

A metal wing on the cooking compartment ceiling reflects and distributes the microwaves in the cooking compartment (Fig. 76.)

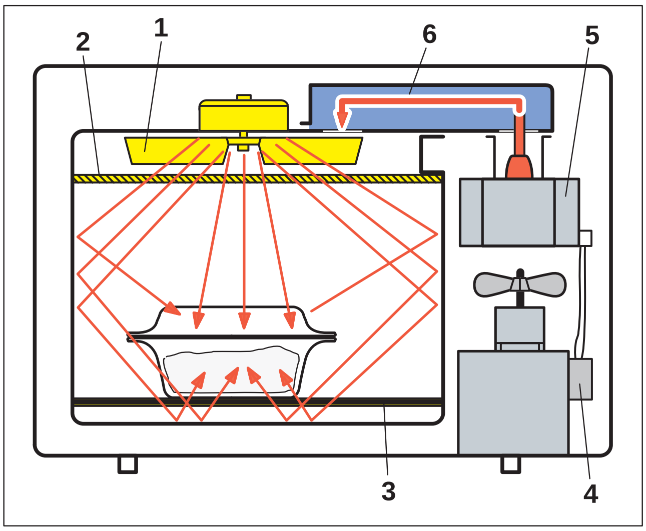



**Fig. 76 Microwave distribution with a wobbler**

**1 Wobbler**
**2 Cover**
**3 Glass plate**
**4 Fan**
**5 Magnetron**
**6 Waveguide**

In this example, the input from the antenna is directed at the wobbler via a waveguide, and is then deflected into the cooking compartment.

The wobbler is mainly driven by air from the cooling fan and is protected against dirt by the microwave permeable cover.

The glass plate on the cooking compartment floor forms the base load in a similar manner to the rotary base.

## Rotating antenna

This system is used in combined appliances, featuring conventional convection oven heating in addition to microwaves.

The input operates from the magnetron antenna via the waveguide to the antenna post of the rotating antenna and from there via the antenna wing into the cooking compartment. (Fig. 77.)

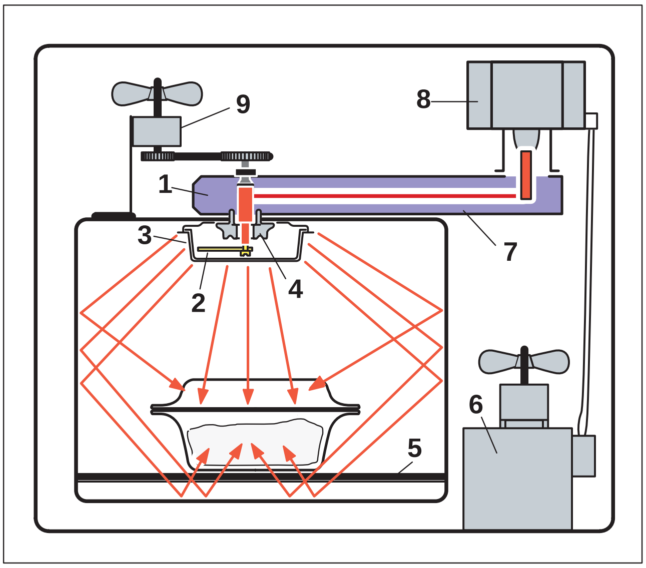



**Fig. 77 Distribution with a rotating antenna**

**1 Antenna post**
**2 Antenna wing**
**3 Glass cover**
**4 Antenna compartment**
**5 Compartment floor**
**6 Cooling fan**
**7 Waveguide**
**8 Magnetron**
**9 Antenna motor**

The rotating antenna has its own drive motor with a speed reduction gear. The antenna runs in a ceramic ring. The glass cover, which may be removed to allow cleaning, protects against dirt contamination and simultaneously serves as a base load.

## Safety tests

Conditional on the special characteristic features (in comparison to other household appliances), such as high frequency and high voltage, strict safety requirements are placed on microwave appliances with respect to sealing.
For example, the cooking compartment door is operated 100,000 times, and the door seals are contaminated with cooking oil after every 10,000 operating cycles, in order to simulate the worst operation conditions which may occur in practice during the appliance service life (Fig. 78.)

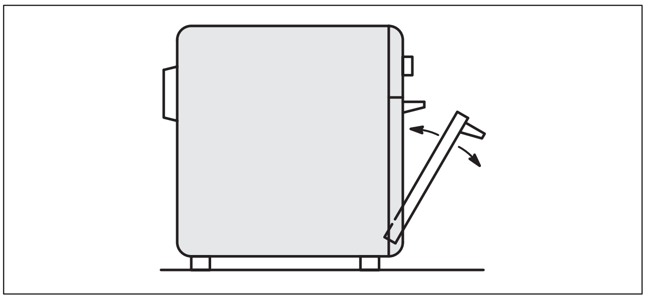


**Fig. 78 Door operation 100,000 times**

Furthermore, the open door is mechanically loaded with a test weight of 22.5 kg and/or with a test force of 140 N (Fig. 79.)

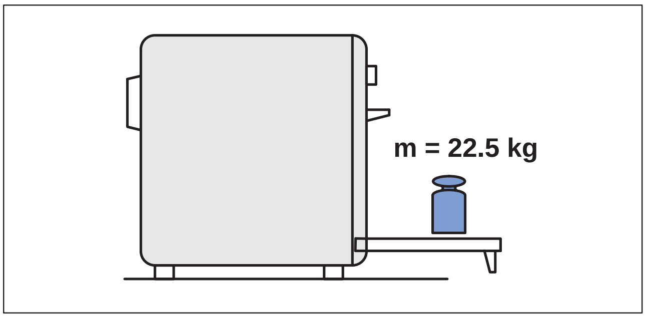



**Fig. 79 Mechanical loading of the door**

The door torsion is tested by clamping a bar and by then closing the door with a force of 90 N (Fig. 80.)

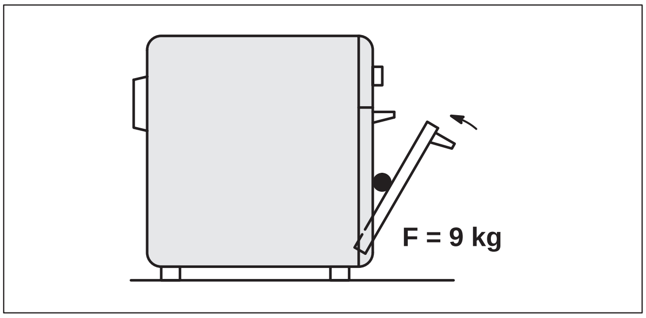



**Fig. 80 Torsion test**

Finally, all important parts, in particular the window, are subject to one of several impact tests (Fig. 81.)

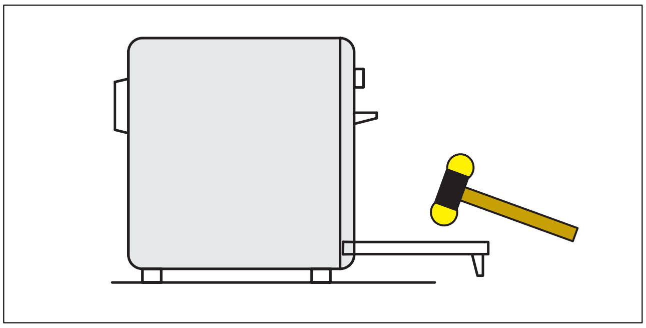


**Fig. 81 Impact test**

After these tests, the following described sealing tests are carried out, i.e., the appliance leakage rate is measured.

These tests are, among others, a requirement for obtaining certification, such as that issued by the German VDE or TÜV-GS institutes.

## Sealing test (leakage measurement)

The leakage rate refers to microwave energy which escapes despite intact sealing systems. It is measured as energy density, using suitable test equipment at a **distance of 5 cm**. The unit of measurement is **mW/cm²**.

The permitted maximum values for readings, as well as the measuring conditions, are specified in the VDE regulation **0700/Part 25**. They are specified below:

**Normal operation with load** (Fig. 82.)

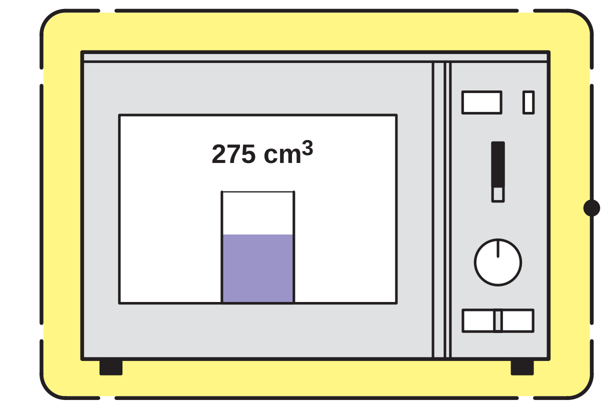



**Fig. 82 Normal operation with load**

| | |
|---|---|
| Setting: | maximum power level |
| Load: | 275 cm³ water |
| **Permissible MAX value:** | **5 mW/cm²** |
| Distance: | 5 cm |

**Abnormal operation (no-load)** (Fig. 83.)

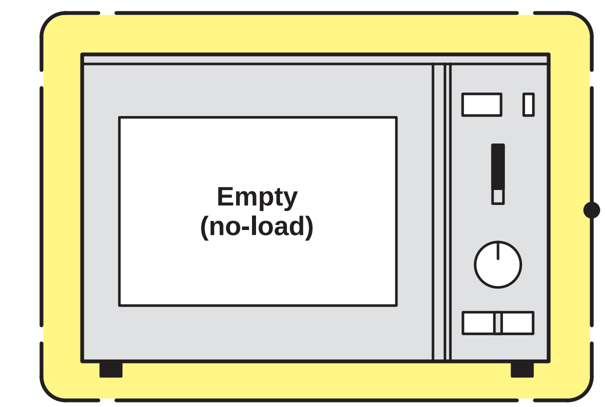



**Fig. 83 Abnormal operation (no-load)**

| | |
|---|---|
| Setting: | maximum power level |
| Load: | without (no-load) |
| **Permissible MAX value:** | **10 mW/cm²** |
| Distance: | 5 cm |

As a matter of course, customer service carefully performs the sealing test as part of the standard procedure after each repair. On the basis of a specified schedule, the measuring instruments used for this purpose are calibrated and certified by an independent authority, thereby excluding measuring errors.

The measuring instruments utilised in our facilities are fitted with a 5 cm spacer on the measurement probe, so that the prescribed test distance of 5 cm is automatically maintained, and that the probe may be directly placed onto the surface to be tested.(Fig. 84.)

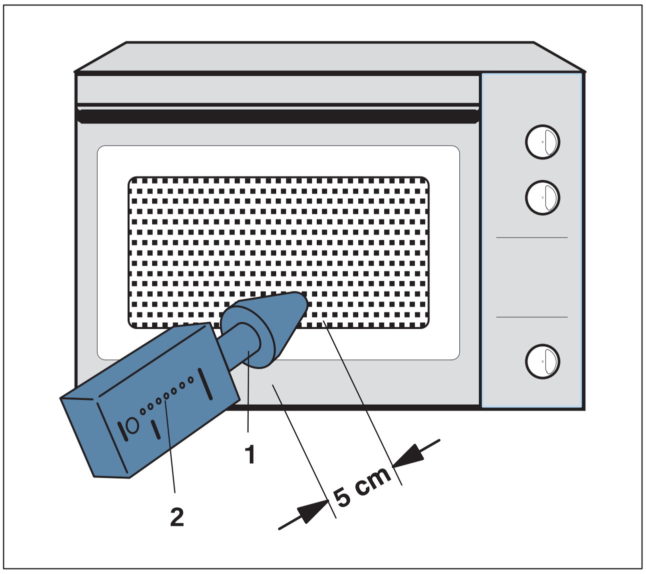



**Fig. 84 Example of a sealing test**

**1 Measurement probe with spacer tip**
**2 Display**

Measurement locations are the door area and/or the housing air vent.

Repeated tests from independent offices on appliances from all known manufacturers have established that, even for appliances which were used daily in the household for years, **the actual values were far below the permitted maximum values**.

Apart from the sealing test, it is understood that the appliances must also satisfy the requirements of all other electrical safety tests specified by the VDE regulations. This applies also to any repair work carried out on the appliances. **For this reason, microwave appliance must be repaired only by factory-trained customer service engineers**. An appropriate note is included in the instruction manuals accompanying our appliances.

# Design and model variants

## Designs

The microwave energy form is offered in different designs in our appliance range:

**as a microwave-only appliance, or**
**as a microwave combination appliance.**

A microwave-only appliance, commonly known as microwave oven, uses only microwave energy as a medium for heating.

Microwave combination appliances feature a microwave unit which is incorporated in an oven or the oven section of a cooker, using one or more of the conventional heating methods:

- **Top/bottom heat**
- **Circulating air**
- **Grill element**

In combination appliances, these heating methods may be operated individually or in combination with microwaves.

## Model variants

Microwave appliances are available in several model variants. Their designs differ with regard to their intended use and space requirements:

- **Table-top appliances**
- **Stand-alone appliances**
- **Built-in appliances**

## Table-top appliances

Table-top appliances are essentially self-contained, free-standing appliances which may be placed directly on a worktop or on another appliance. This ”portability” facilitates easy change of location. Due to suitable dimensioning, this category includes both ”microwave only” and microwave combination appliances. (Fig. 85.)

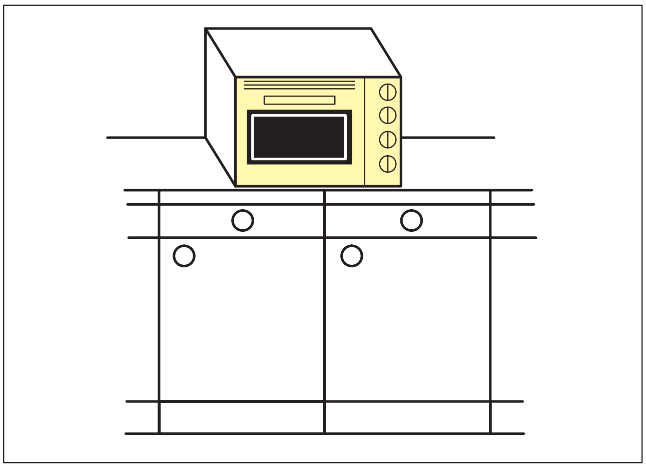


**Fig. 85 Table-top appliance**

Using special installation or mounting kits, suitably dimensioned table-top microwave combination and microwave-only appliances may be installed in top or bottom cabinets (see also Built-in appliances).

Due to their low weight, microwave-only appliances may be hung under top cabinets, and/or mounted directly on the wall. Special mounting kits are available for both purposes. (Fig. 86.)

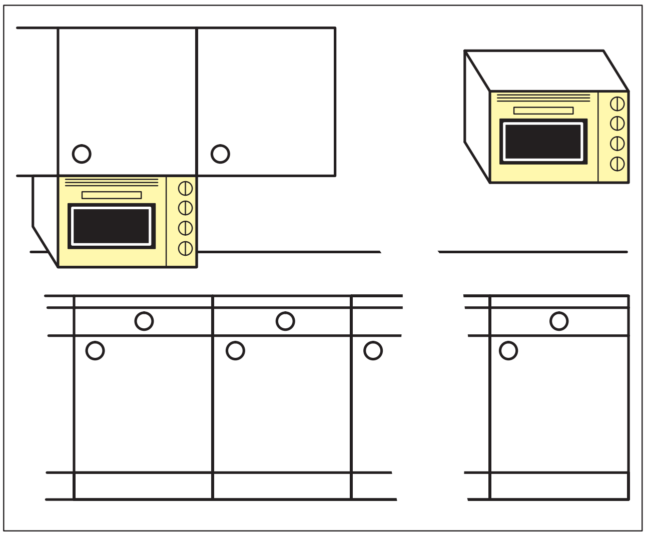


**Fig. 86 Top cabinet and wall mounting**

Note: Some microwave appliances are not suitable for built-in or hanging installation. The manufacturer’s instructions should be observed.

## Stand-alone appliances

Stand-alone appliance are free-standing and have standard table-top height. They are available as microwave ovens in combination with a conventional full-size cooker. The term full-size cooker indicates a stand-alone cooker with built-in oven and permanently mounted hotplates.

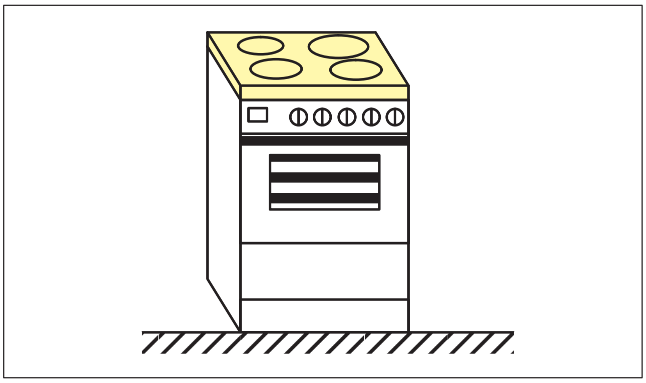


**Fig. 87 Stand-alone cooker with integrated microwave**

## Built-in and base unit appliances

Built-in appliances must be installed in specially provided conversion cabinets.

Base unit appliances are pushed beneath the work top. They do not require a conversion cupboard.

The group of built-in/base unit appliances includes all conceivable microwave appliance combinations, providing a large variety of choices. (Fig. 88.)

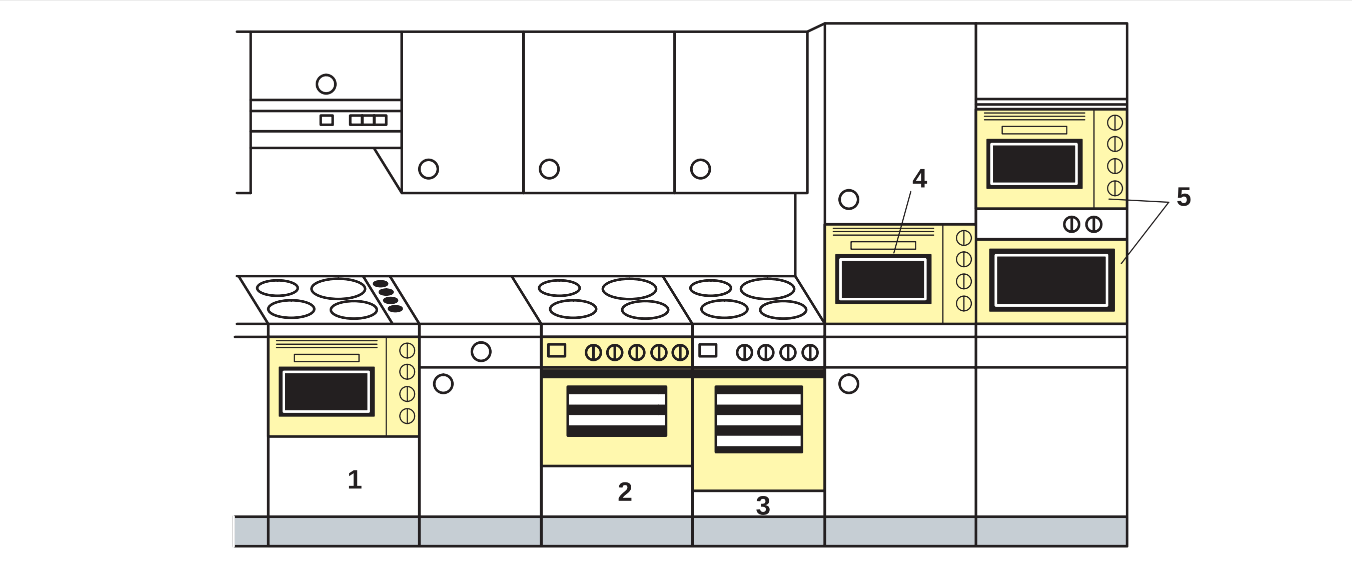



**Fig. 88 Installation options for microwave appliances**

1. **Microwave combination appliance with separate cooking section**
2. **Built-in cooker with integrated microwave, 60 cm wide**
3. **Base unit cooker with integrated microwave**
4. **Microwave combination appliance**
5. **Built-in oven and microwave oven**

## Installation and connection

When installing and connecting microwave appliances, the information in the installation instructions accompanying the appliance must be observed.

### Installation

With table-top appliances, the air vent opening must remain unobstructed. A suitable installation frame must be used if these appliances are built-in. Only then is adequate appliance ventilation guaranteed. The next figure shows an example of a frame mounting kit for a microwave combination appliance. (Fig. 89.)

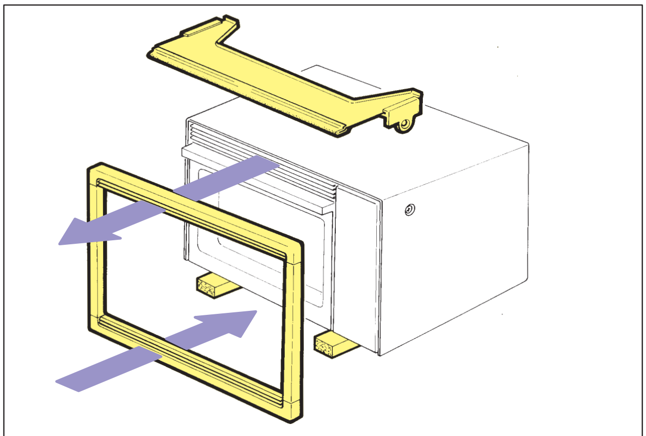


**Fig. 89 Frame mounting kit**

### Connection

Microwave ovens and combination appliances are supplied ”plug-in” ready. They may only be connected to an installed socket conforming to the regulations. Voltage, fuse protection and tripping characteristic of the fuses must correspond to the data on the nameplate and/or the installation and assembly manual.

Built-in/base unit cookers with integrated microwave and combined cooking sections are not supplied with an integral mains plug. Due to the high power absorption it is recommended that the appliance be connected to a three-phase alternating current in order to divide the power into the appropriate phases (not applicable to the U.K.). The connection diagram and terminal board are located on the rear of the appliance.

**Connection and commissioning may only be carried out by an authorised expert in accordance with the connection and installation instructions supplied with the appliance.**

**Special regulations issued by the electrical utility or power authority must be observed.**

# Safety instructions and user information

Due to the physical properties of the microwave and its effect upon foods and cookware (as compared with conventional cooking and baking), some special information should be observed.

Such information may also be found in the instruction manuals and cookbooks.

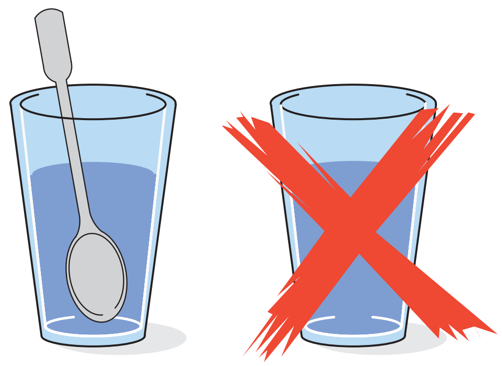
The advice listed here may be derived from the topics discussed throughout this brochure.

## Safety information

### Scalding hazard

#### Delayed boiling

With conventional heat transfer, steam bubbles are formed during heating up, in particular on specific flaws of the hot cookware (dents/depressions, scratches, hairline cracks). However, with heating by microwaves, the hot surfaces are missing and only the gases enclosed in the water form departure points for the steam bubbles. If after repeated heating these gas parts escape, strong retardation of boiling occurs, i.e., the temperature of the liquid is significantly higher than the environmental pressure would suggest. When removing the vessel from the cooking compartment (vibration or shock), this stored overheating energy may unexpectedly erupt in a steam explosion, expelling the hot liquid from the container. To prevent this from happening, we have included in our instruction manuals the warning note shown in Fig. 90.



**Scalding hazard!**
When heating liquids, always place a teaspoon into the container to prevent delayed boiling. Delayed boiling means that the liquid reaches the boiling temperature without steam bubbles rising to the surface. Even the slightest vibration of the container may then cause the hot liquid to boil over or erupt in a hot spray. This may cause severe scalding injuries.

**Fig. 90 How to prevent delayed boiling**

The spoon in the liquid causes a temperature compensation in the liquid column. It also acts as a kind of catalyst by stimulating the formation of steam bubbles with its large surface. Once steam bubbles are forming, delayed boiling can no longer occur.

#### Baby food

Baby food may be heated up in glasses or in bottles but **always without a lid or rubber teat**. After heating, the baby food must be stirred well or shaken so that the heat is uniformly distributed. Please check the temperature before giving the food to the child.

Foods that is heated via microwave transfers heat to the cookware. It may become **very hot**. Protect yourself by using pot handlers or oven gloves.

### Fire hazard

Please select always the microwave power levels and times suggested in the instruction manual. If you have selected a significantly excessive power level or time, the food may ignite, and the appliance may be damaged.

Monitor the drying of herbs, fruit, bread or mushrooms. Overdrying may lead to a **fire hazard**.

Foods wrapped in heat retaining packaging should not be heated up. **They may ignite**.

Cooking oil should not be heated up in a microwave. **It may ignite**.

## Bursting, breakage and explosion hazards

Foods and drinks in firmly closed containers should not be heated up. **Explosion hazard!**

Alcoholic drinks may not be heated up too much. **Risk of explosion!**

Foods in plastic foil may **blow up** and the foil may **melt**.

Eggs should not be cooked in the shell, and hard boiled eggs should not be heated up. They may **explode**. This also applies to shellfish and crustaceans. For fried eggs or eggs in a glass, pierce the yolk beforehand.

For foods with solid shells or skins, i.e., apples, tomatoes, potatoes and sausages, the shell may **split**. Pierce the skin before heating up.

Kitchen utensils made from porcelain and ceramic may have fine holes in the handle and lid. Hollow spaces are concealed behind these holes. Moisture which has penetrated the hollow space may cause the part **to burst. Therefore it is best to use dishwasher-safe cooking utensils.**

## Appliance safety

The microwave appliance should only be used for the preparation of foods.

Turn ON the microwave only while there is food in the cooking compartment. Without foods, the appliance could suffer an overload condition. The exception is a short-term cookware test (see Notes on cookware).

The cooking compartment or oven door must be properly closed. The door seal surfaces should be kept clean.

If the cooking compartment or oven door is damaged, the cooking compartment must only be used after it has been repaired by a customer service engineer. **Microwave energy may escape**.

# Notes on cookware

## Cookware materials

It has already been noted that microwave kitchen utensils made from glass, porcelain, ceramic or plastic material allow penetration, whereas metal containers reflect the waves. There are still some specific differences to be discussed in the following, but first, some essentials.

**The three basic rules:**

**Rule 1**
**Closed metal kitchen utensils are unsuitable.**

**Rule 2**
**Kitchen utensils with metal decor are unsuitable. This decor causes sparking in the cooking compartment.**

**Rule 3**
**Suitable kitchen utensils are those which are not heated up by microwaves.**

As already mentioned, the container is heated up due to the transmitted heat from food. However, some containers absorb the microwave energy and cause an increase in the cooking time.

In order to attain a reasonable degree of certainty as to whether cookware of unknown material composition is still suitable, simply perform the cookware test that was previously discussed in the section on Physical principles.

**Kitchen utensil test**

Place the empty container in the microwave appliance.

Set the microwave to the 600 W output and turn ON for approximately 20–30 seconds.

**Result:**

If the kitchen utensil is cold or only hand warm, it is suitable for use in a microwave appliance.

If the kitchen utensil is hot, particularly on the bottom, or if sparks emerge, it is not suitable.

**Glass, ceramic, earthenware and clay**

In principle, kitchen utensils made from these materials are suitable for microwave cooking. However, unglazed clay surfaces are less suitable, as they absorb moisture and consequently become too hot when cooking with microwaves.

There are some earthenware and clay kitchen utensils which, due to their special content or particular glaze (i.e., containing lead), become very hot (Cookware test). These kitchen utensils should not be used, as the glaze may crack.

### Plastic cookware

Plastic containers are generally composed of different base materials, and therefore behave differently during microwave operation. Some plastic materials deform and may melt. Plastic kitchen utensils made from melamine and ornamin become very hot, they store the microwave energy and therefore the cooking process takes longer. For this reason, containers made from these materials are not recommended. For cooking, plastic kitchen utensils are suitable which are heat resistant up to 200 $^{o}$C. There are special microwave kitchen utensils on the market which are suitable for cooking, freezing, defrosting and heating.

Low-temperature resistant plastics deform easily in microwave appliances. Therefore, do not overheat foods containing fat and sugar in these containers!

### Plastic foils

Some frozen foods are packaged in cooking bags made from plastic. In such instances the foods should be slowly and carefully defrosted and/or heated, as the bag may be melted by heating too quickly. It is better to transfer the still frozen food into a serving utensil and then heat. Roasting foil may also be used in microwave cooking (but without a metal cover). Plastic food wraps, on their own, are limited in use to covering containers. They are too thin and deform easily at high temperatures.
Microwave foil may be used to cover containers during heating and cooking of moist foods. However avoid direct contact with fat containing foods because fat can become very hot during microwave operation.

### Paper and cardboard

Paper and cardboard are suitable for short cooking and/or heating processes. Cardboard kitchen utensils may not be plastic coated, as the plastic melts at high food temperatures. Paper and cardboard may not be used in combination operations.
**Warning – Fire hazard!**

## Cookware for use in combination appliances

Only heat resistant and non-combustible materials may be used in combination operation, i.e., with top/bottom heat, circulating fan or grill heat, and activated microwaves.

With this operating method, open top metal containers may also be used. Because with our appliances input and distribution of the microwaves occurs from above, the microwaves can penetrate the container from the top.

The following table shows a summary of the possible applications of kitchen utensils with microwave appliances (Fig. 91.)

| Cookware/ utensil | Microwave-only applications | | | Combination appliances | | | | Comments |
|---|---|---|---|---|---|---|---|---|
| | De-frosting | Heat-ing | Cook-ing | Top and bottom heat | Grill element | Circu-lating air | Combina-tion operation | |
| Glass/porcelain | + | + | + | - | - | - | - | Refer to kitchen cookware supplier information |
| Glass/porcelain heat resistant | + | + | + | + | + | + | + | |
| Glass-ceramic | + | + | + | + | + | + | + | do. |
| Ceramic, earthenware, clay | (+) | (+) | (+) | + | + | + | + | do. |
| Plastic utensils | + | + | (+) | (+) | - | (+) | (+) (except grill) | do. |
| | + | + | + | - | - | - | - | Refer to supplier information |
| Freezer bags (boilproof) | + | + | + | - | - | - | - | Refer to supplier information, Freezer bags which are not boilproof are only for defrosting |
| Roasting foil | + | + | + | + | - | + | + (except grill) | Tie the bag with string instead of the metal clip |
| Metal baking forms | - | - | - | + | - | + | (+) | Take into account appliance enclosures |
| Metal utensils (flat form) | (+) | (+) | - | + | + | + | + | do. |
| Aluminium dishes | (+) | (+) | - | + | + | + | (+) | do. |
| Paper and cardboard | (+) | (+) | - | - | - | - | - | Paper utensils may not be plastic coated |
| * marked as microwaves | | | | | | | | + suitable<br>(+) conditionally suitable<br>- not suitable |

**Fig. 91 Possible applications for cookware materials**

## Cookware shapes

Next to the material selection, the shape and/or size of the cookware are decisive for optimum cooking.

Circular and oval forms are well suited for all long cooking operations. The microwaves are able to act on all sides of the food.

In angular forms the food may overheat in the corners (forming 'hot spots'), as at these points a concentration of microwaves may occur. As a precaution, the food should be stirred 1-2 times.

Large, flat containers are well suited for foods which may not be stirred, i.e., soufflé. The large top surface allows a good distribution of the microwaves.

In high containers the food should be stirred often so that a uniform heat distribution is ensured.

Firmly closed screw cap jars and bottles may not be put into microwave appliances. Through the quick heating of the contents, excessive steam pressure is generated, so that they easily burst.

For a good result the cookware height is also important. The capacity should roughly correspond to the food quantity (approximately 2/3 full). Larger, flatter containers are better than tall containers with a small diameter, because the large upper surface allows good penetration and/or impact of the microwaves.

Exception: Containers in which liquids are to be heated.

## Selecting power level and cooking time

The selected power level and cooking time are decisive factors in obtaining good cooking and defrosting results.

The information in our operating manuals and cookbooks describes reference values.

Although the experimental values established for electric cooker and oven cannot simply be applied to microwave appliances, such values should be still be used at least during the familiarisation period with the new appliances.

The microwave cooking time for food is dependent on the:

- **quantity**
- **initial temperature**
- **composition**
- **shape**
- **density**
- **structure**
- **selected power level**
- **cookware material.**

The following interdependence exists between time and quantity:

- Small quantities cook better than large quantities (it is better to heat two portions, one after the other, than to heat both at the same time)
- The larger the quantity, the longer the cooking or heating time
- Flat foods cook quicker than tall, narrow foods
- Rule of thumb: (Fig. 92.)

| | |
|---|---|
| **Double the quantity** | **= double the time** |
| **Half the quantity** | **= half the time** |

**Fig. 92 Rule of thumb**

## Selecting the power level

The composition and nature of the food determine the choice of the power stage. The overlaps of the areas are fluid (Fig. 93.)

| **Power level (watt)** | **Field of application** |
|---|---|
| max. i.e., 1100 W | This is the highest and consequently most intensive power stage. It is best used for very quick heating of liquids and drinks. A spoon should be placed in the container to avoid possible delay of boiling. **Power level for cookware test** |
| 600 W | This power stage is ideal for preparing many dishes. It is used for cooking, boiling, parboiling, heating and melting. **Power level for cookware test** |
| 360 W | This setting is the recommended value for the cooking of meat dishes, for heating larger quantities or for warming delicate dishes. |
| 180 W | This power stage is suitable for quick defrosting or for simmering specific foods. |
| 90 W | This low power stage is best used for careful defrosting, and also for keeping foods warm, and for simmering smaller quantities. |

**Fig. 93 Fields of application and power levels**

## Options for practical use

Essentially, microwave appliances may be used for defrosting, warming, cooking and heating foods. Defrosting uses low power levels. There is no better method which so swiftly, uniformly and carefully defrosts. A small disadvantage of microwave ovens is the absence of a browning effect.

The introduction of microwave combination appliances could contribute to a significant widening of applications. In a common cooking compartment, these appliances feature combinations of microwave cooking with the conventional heating methods, such as top and bottom heat, circulating-air heating and grilling. All cooking methods may be used singly or in random combinations with each other, providing the user with a large variety of cooking options.

## Consumption rates

Power consumption and cooking duration in microwave appliances are frequently compared with those of conventional hotplates and ovens.

Generally the consumption of electrical energy by microwave appliances in microwave-only operation lies under the comparable consumption of an electric cooker hotplate, but only by small quantities (up to approx. 500 g). The main advantage is the time saved.

However, with the use of a microwave combination appliance, and dependent upon the type of food, appliance and cooking volumes, considerable time and power may be saved even when preparing food in large quantities.