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"RF Heaters - Watts to Heat?"

Industrial Dielectric Heating Equipment and its possible effects on broadcast and other communication services

Today nearly every household has a microwave oven and most people are reasonably well aware of the advantages of microwaves in fast heating of foodstuffs. However, few are aware that Radio Frequency (RF) heating and drying has been used extensively in industry for many years. The first application of RF heating as far as the author is aware, was in 1943 and it was used for rapid curing of adhesive in the Mosquito Bomber.

Subsequently, a whole range of different applications have been developed including Textile drying (for bobbins after dyeing, loose fibre, hanks, ladies tights etc.), Plastic Welding (inflatable goods, medical bags, PVC stationery products etc.), Paper Converting (drying water based adhesives on items such as business forms, book spines, junk mail etc.) and Food processing. Indeed, if you eat Weetabix, then you will have eaten one of the many food products which have been dried using RF energy! There are thousands of these installations in the UK and hundreds of thousands worldwide.

A typical RF Tunnel Oven for Textile Drying (courtesy G3PJD)

No doubt, many of you have heard of or experienced interference problems (RFI) with transmitters or receivers. One of the main sources of RFI is due to RF Industrial Scientific and Medical (ISM) Equipment, and can originate from poorly constructed dielectric heaters (e.g. RF plastic welders, RF tunnel dryers etc.). This interference can usually be put down to the use of old, unfiltered designs, supplied by companies with a poor understanding of RF engineering who often are ignorant of the current legislation (specifically EN55011) or worse still, choose to ignore it entirely.

A lot of this equipment uses industrial vacuum triodes at the heart of the design. Often, the designs are designed to work with fundamental frequencies in the ITU bands allocated for ISM devices, the most commonly used of which are 13.56MHz +/- 0.05% (13.553MHz-13.567MHz), 27.12MHz +/- 0.6% (26.957MHz – 27.283MHz), and 40.68MHz +/- 0.05% (40.66MHz-40.70MHz). These fundamental frequencies are usually not a problem in their own right, provided they remain within the allocated bands. However, it is the harmonics of these frequencies which usually present the main problem areas. The harmonics are produced within the oscillator circuit, which typically operates under Class C conditions. The anode current waveform of a Class C oscillator is far from a perfect sine wave.

Mechanical element resonances within the triode itself and also within the components of the resonant circuit often cause certain harmonics to be produced, with some harmonics being:- considerably higher than others.

One of the decisions made by the ITU which is extremely difficult to understand, was why they chose to specify these particular ISM frequency bands whilst also allocating frequencies of 108MHz to 112 MHz for Instrument Landing Systems (ILS) and 117.975 MHz to 137 MHz for VHF Aircraft Communications. It can be clearly seen that these very important frequency bands lie almost exactly at the 8th and 10th harmonics of 13.56MHz and 4th and 5th harmonics of 27.12MHz. A worse choice of frequencies is very hard to imagine!

A further complication introduced in many dielectric heating installations is that the operating frequency is not fixed, rather it usually sweeps downwards as the oscillator is loaded.

The reason for this “moving frequency” is explained below

A simple dielectric heater consists of two tuned circuits, the oscillator circuit (C1/L1) and the applicator/oven circuit (C2/L2) which are closely coupled. A typical basic circuit of such a machine is shown in Fig 1below:

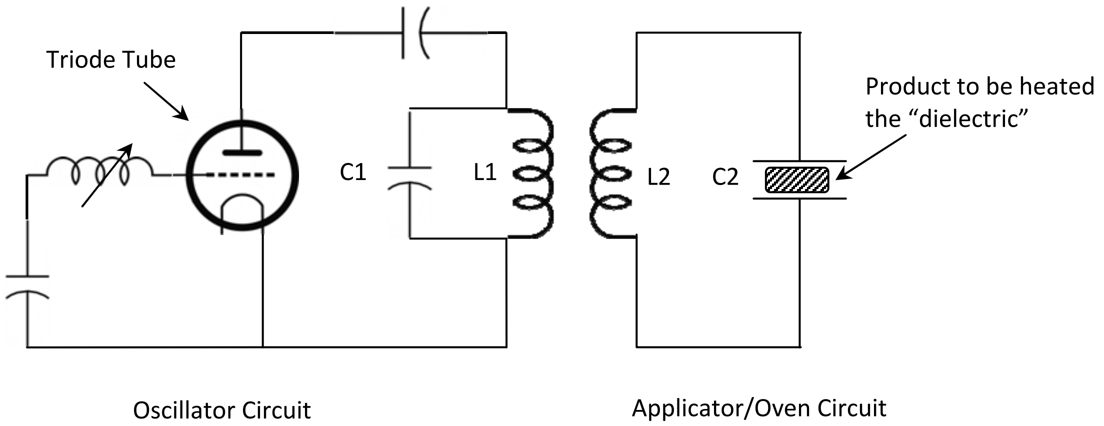

Fig 1 – Typical circuit diagram of a dielectric heater

For a parallel resonant circuit such as C1/L1 or C2/L2, the frequency of resonance is determined by the formula:

$$F = 1/(2\pi\sqrt{LC})$$

Where

F= Frequency in Hz
L= Inductance in Henries
C = Capacitance in Farads

Therefore it can be seen that by adjusting the values of L1 and C1 in the oscillator we can determine the required frequency (e.g. 27.12MHz in this example). A parallel resonant circuit such as this will have a frequency response as shown in the diagram Fig 2 below:

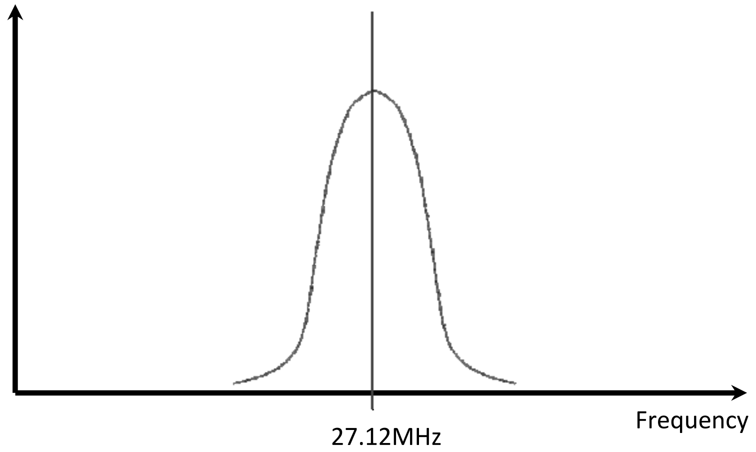

Fig 2 – Resonance curve of Oscillator Circuit (C1/L1)

Similarly, the applicator/oven circuit can be arranged to have a corresponding frequency resonance as indicated in Fig 3 below. This is usually slightly higher in frequency (say 31MHz) than the oscillator circuit (say 27MHz):

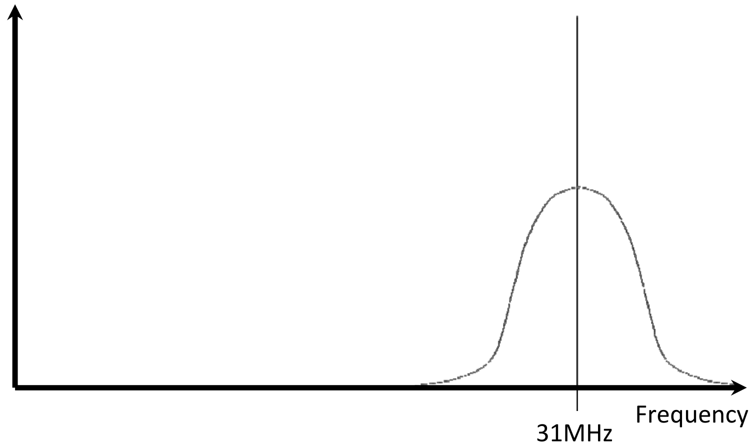

Fig 3 – Resonance curve of Applicator/Oven Circuit (C2/L2)

It is the relationship between these two frequencies which is very important and this determines the amount of power transferred to the product. It also determines the resultant frequency of operation for the machine, the harmonics of which can cause interference (RFI) to occur.

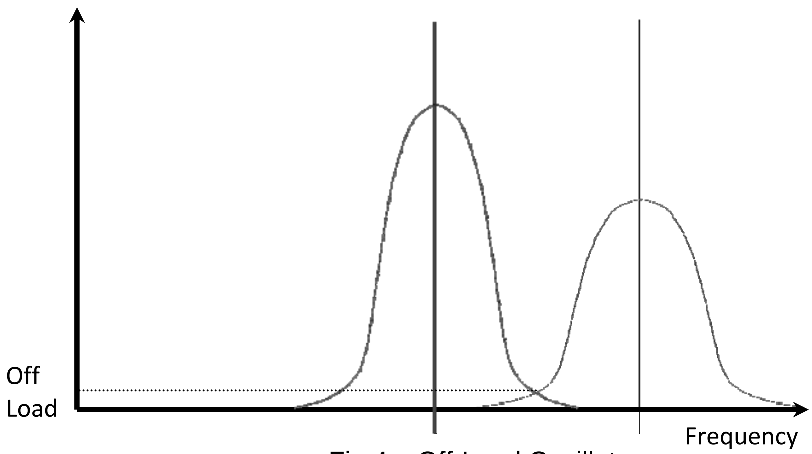

Fig 4 – Off-Load Oscillator

In the diagram Fig 4 above, the frequency curves are someway apart, so that the overlap is minimal. The power transfer to the product load is therefore also minimal. However if the frequencies are moved closer together as in the diagram below, Fig 5, then the power transfer is increased. This can be achieved by increasing C2 or L2 (as C,L increase, frequency drops), or it can be due to a change in the properties of the load (increasing C due to higher moisture content, increased volume/density of product, increased dielectric loss factor etc.).

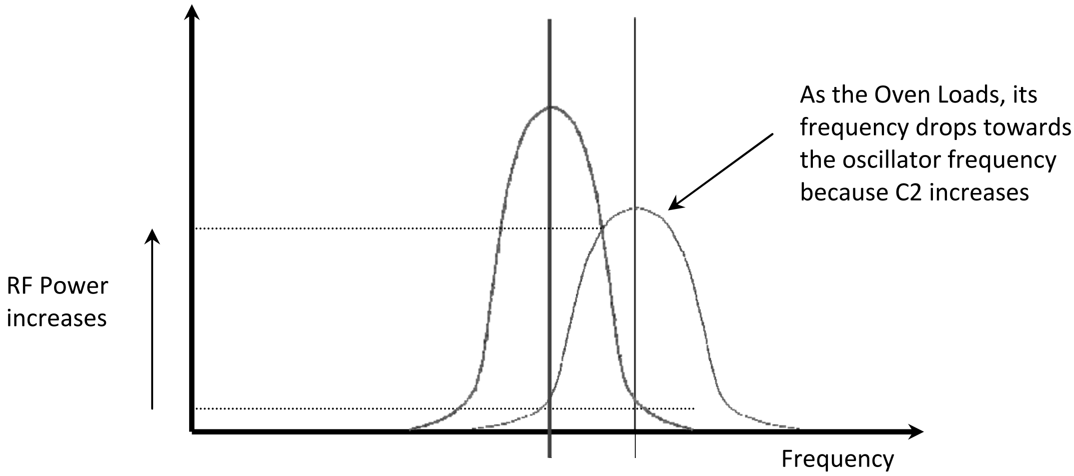

Fig 5 – Fully-Loaded Oscillator

This ability to change the amount of power is an important and unique feature of some dielectric dryers, because, with careful design, it enables the dryer to use the moisture in the product to control the amount of RF power delivered to it, thereby allowing the power level to auto-regulate depending upon the moisture content of the product: If the product contains high moisture, then the power delivered to is increased due to the increase in capacitance of the oven which lowers the oven frequency, but if the moisture level in the product reduces, then the capacitance reduces and the amount of power delivered also reduces. Thus we have an ideal moisture profiling dryer which adjusts itself instantaneously to the moisture level of the product in the dryer. This effect cannot be achieved by conventional dryers.
As the power increases, due to the drop in frequency, the resultant frequency can be seen to reduce. Depending upon the type of machine, this sweep cycle can be repeated regularly if the machine operates cyclically (as a plastic welder would function), or at breaks in the product when a machine such as a tunnel oven loads up and empties out.

Furthermore, if the tuned circuit of the oscillator has a relatively low ‘Q’ the frequency sweep is significantly greater as can be seen from diagram 6 below and may cause the frequency to travel outside the allocated ISM band.

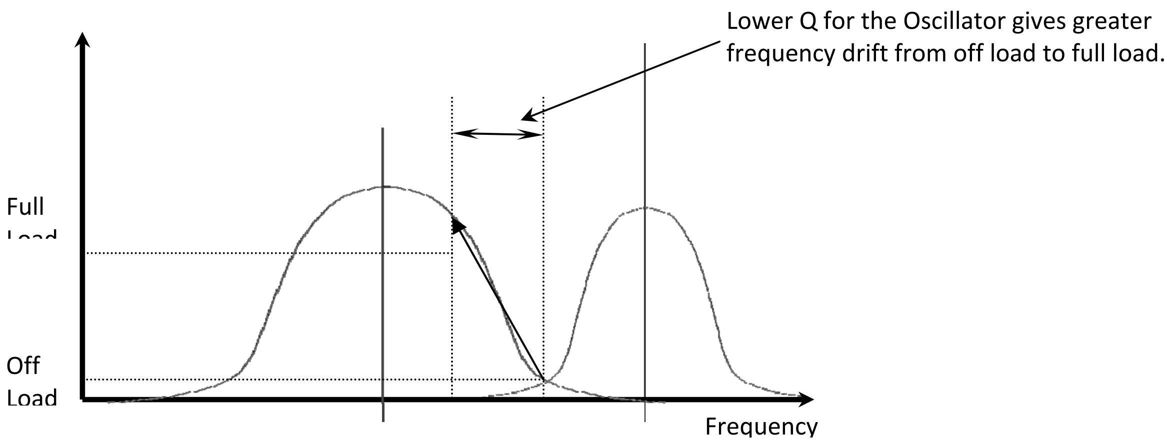

Fig 6 – Low - Q Oscillator

The circuit shown in Fig 1 and explained above is often referred to as a “Free Running Oscillator” (FRO). There are other similar dielectric heating circuits, based more on the lines of standard transmitters, known in industry as “50 Ohm” systems due to their characteristic impedance, but although filtering of the harmonics for EN55011 compliance is relatively easy, they do not have the ability of the FRO for moisture profiling. These “50 Ohm” systems consist of crystal controlled oscillators, driving 50 Ohm amplifiers, and they are matched to the product load for constant power by an appropriate impedance matching network, but in doing so, the ability to vary the power according to product moisture content is lost.

Compliance of FRO systems with EN55011

Older designs of FRO system may have gained somewhat of a reputation for non-compliance with EN55011. Contrary to much of the recently published academic literature, it is entirely feasible with good design, to product high power equipment which is fully compliant. However, unfortunately, much of the FRO equipment on the market today tends to be produced with scant regard to the regulations, and the alternative “50 Ohm” systems which have been strongly advocated by academics suffer from poor performance and low reliability under industrial conditions.

Additional Information on the Oscillator and other RF circuitry

For those interested in the design of the oscillator; typically, for industrial dryers with a free running oscillator, triode tubes are used (e.g. ITL12, RS3040, BW1184), operating in Class C, running at HT voltages of around 9kV to11kV, (derived from full wave rectified 3 phase AC). The anode currents are typically from 2 amps to 18 amps, giving RF outputs of 12kW to 120kW at a conversion efficiency of about 65% (DC input to useful RF output into the product).

The construction of the RF circuitry varies considerably from machine to machine, however many of the older designs tend to use low Q, lumped circuits (i.e. with discrete inductors and capacitors) and have fairly poor RFI shielding, with little attention being paid to reduction of harmonic emissions..

The newer, compliant designs, particularly for the 27.12 and 40.68MHz frequencies generally use aluminium resonant cavities, where the inductance and capacitance is not discrete (i.e. easily recognisable), but rather, it is distributed within the cavity structure. In order to achieve EMC compliance, it is usual to incorporate a high degree of filtering to the supply leads (for filament and HT) and, for those applications which cannot be confined within a Faraday Cage structure (e.g. Tunnel Ovens), it is essential to incorporate a suitable low-pass filter to reduce the levels of the harmonic emissions, and to utilise specially designed attenuation traps in the entrance and exit tunnels to the drying oven.

The author has designed many FRO systems for these applications which have passed independent compliance testing to EN55011. All that is required is the knowledge and experience of how to design an efficient, oscillator which incorporates a robust low-pass filter network which can be accurately reproduced by semi-skilled manufacturing processes.