A Technique for Stable Tuning of High Q Loads

Many processes involve the heating of materials that do not easily absorb microwave energy due to their low dielectric loss characteristics. Such low loss materials often require high efficiency microwave cavities in order to achieve adequate heating. The heating of low loss materials in high efficiency cavities can be somewhat unstable due to the difficulties associated with impedance matching (tuning) and frequency shifting.

Load Q and Power Coupling

Relating the difficulties and instabilities of tuning to low loss materials in high efficiency cavities is done by defining a quality factor, Q, in terms of the amount of energy stored in and lost to the loaded cavity. The loaded cavity can be described as a resonant circuit element in a microwave network whereby its resonant frequency is a function of its complex characteristic impedance. The Q of a circuit at its resonant frequency is defined as

$$Q \equiv 2p\left(\frac{\text{Energy Stored}}{\text{Energy Dissipated}}\right) \qquad (1)$$

Low loss loads in high efficiency cavities result in reduced energy dissipation compared to energy stored, thus resulting is high Q as defined in equation 1. The Q of a resonant circuit can also be described in terms of its resonance bandwidth as

$$Q = \frac{\text{Resonant Frequency}}{\text{Half - Power Bandwidth}} = \frac{f_r}{f_2 - f_1} \qquad (2)$$

Microwave Generator Spectral Output

The importance of the relationship in equation 2 becomes apparent when related to the spectral output of common sources of microwave power. Microwave generators operate within a band of output frequencies depending on the type of power supply it utilizes. Noting that most industrial generators use magnetrons for high frequency oscillation, their output spectral bandwidth typically ranges from 5 MHz or more for high ripple power sources to less than 100 kHz for low ripple sources.

Figure 1a compares the output spectral bandwidth of a high ripple generator with the coupling bandwidth of a high Q load. In this situation much of the power generated will not be coupled to the load no matter how well the impedance is matched. By contrast, it can be seen in Figure 1b that all of the power generated by a low ripple generator can be coupled to a low Q load.

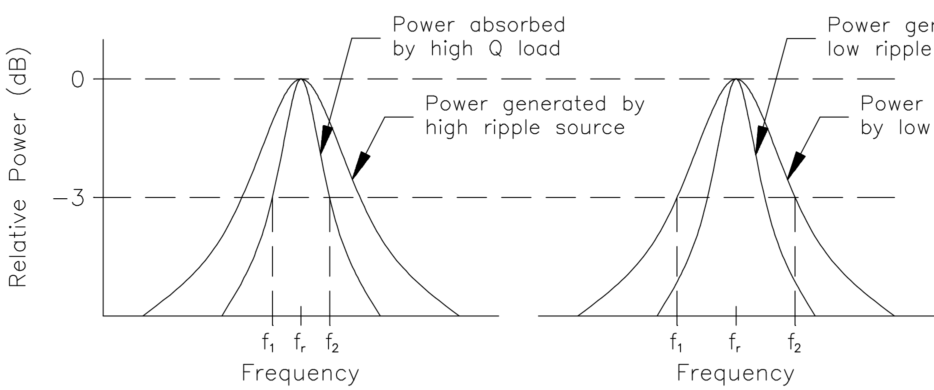

FIGURE 1a — Not all power generated can be absorbed.

FIGURE 1b — Power generated is easily absorbed by load.

A characteristic common with all magnetrons is the shifting of its operating center frequency as the output power changes. The center frequency of a typical 3kW magnetron can shift as much as 50 MHz from zero to full output. The affect this characteristic has on load impedance matching can be seen in Figure 2. The load impedance can be tuned for operation at a given generator output power level, but if the power is raised or lowered the resulting frequency shift of the microwave generator causes a loss of power coupling to the load.

GERLING APPLIED ENGINEERING, INC.

PO Box 580816 ▪ Modesto, CA 95358 ▪ USA
Phone: +1-209-527-8960 ▪ Fax: +1-209-527-5385
E-mail: sales@5800MHz.com ▪ Web: www.5800MHz.com

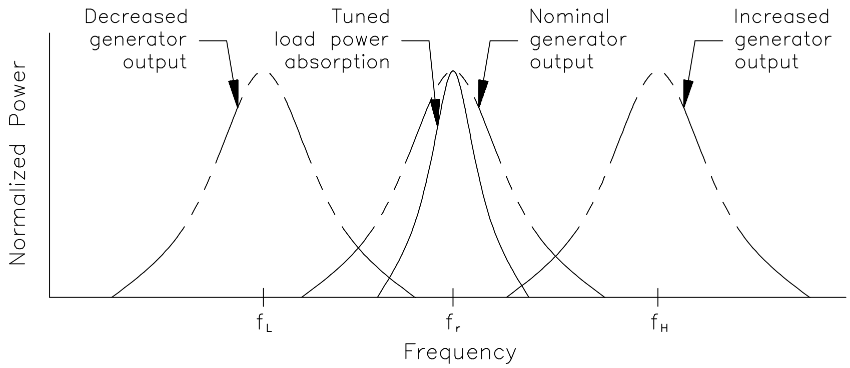

FIGURE 2 — Output frequency shifting with changes in output power.

That is, the load impedance is no longer matched when microwave output power is changed and heating is reduced. While Figure 2 may represent an extreme case, it illustrates a common phenomenon occurring when heating a high Q load with a low ripple microwave generator. It should also be noted that this example assumes stable impedance characteristics of the load during heating. Load impedance often shifts with increased temperature, thus shifting the coupling frequency and further necessitating retuning.

Typical Waveguide Configuration

Figure 3 illustrates a typical waveguide configuration for microwave heating using a waveguide applicator cavity. In this configuration the only means to vary power delivered to the applicator load, once impedances are matched, is to vary the output power of the microwave generator. If the load is frequency sensitive (I.e. high Q) then the result is the phenomenon described above in Figure 2. This can be observed by monitoring microwave power reflected from the applicator load.

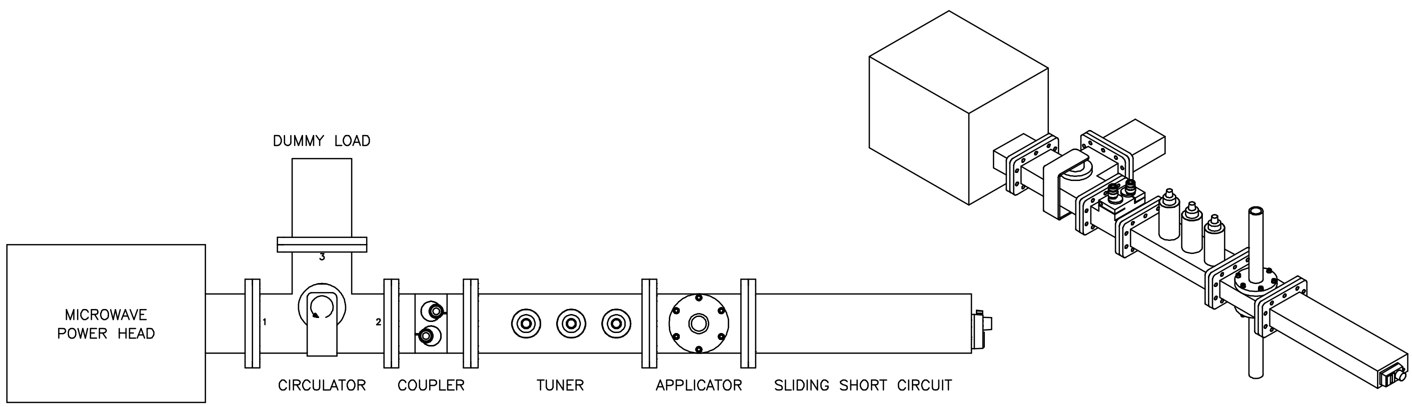

FIGURE 3 — Typical waveguide configuration for microwave heating.

Once the load impedance is tuned at a given power level, reflected power as a percentage of forward power will behave in a manner as shown in Figure 4. This is true whether the initial tuning is done at low or high output power. Note that in the case where initial tuning is done at high forward power, decreasing forward power will still yield a drop in reflected power, but reflected power will increase as a percentage of forward power.

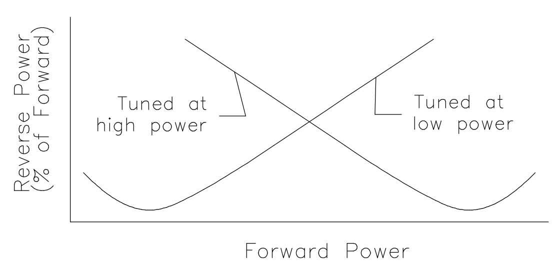

FIGURE 4 — Reverse power as percentage of forward power for tuned high Q load.

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PO Box 580816 ▪ Modesto, CA 95358 ▪ USA
Phone: +1-209-527-8960 ▪ Fax: +1-209-527-5385
E-mail: sales@5800MHz.com ▪ Web: www.5800MHz.com

Constant Frequency Waveguide Configuration

A means to stabilize power coupling while varying power delivered to a frequency sensitive load is, of course, to stabilize the operating frequency of the microwave generator. But the inherent characteristics of magnetrons require that the output power from the generator remain constant. Therefore, a separate means for varying delivered power must be provided.

Figure 5 below is a variation of the typical waveguide configuration having an additional circulator and dummy load with a power reflecting stub. Generated microwave power is diverted before it reaches the applicator cavity and directed towards the additional dummy load with reflecting stub. When the reflecting stub is fully retracted from the waveguide, all of the diverted microwave power is absorbed by the dummy load and none is delivered to the applicator cavity. By inserting the stub causes the diverted power to be reflected back towards Circulator 2 which then directs the power towards the applicator and the load to be heated. By operating the generator at constant full output, the power reflecting stub can be used to continuously vary the power delivered to the load from zero to full without change in generator output frequency. Motorizing this stub allows its use in process control systems in the same manner as controlling the microwave generator output power.

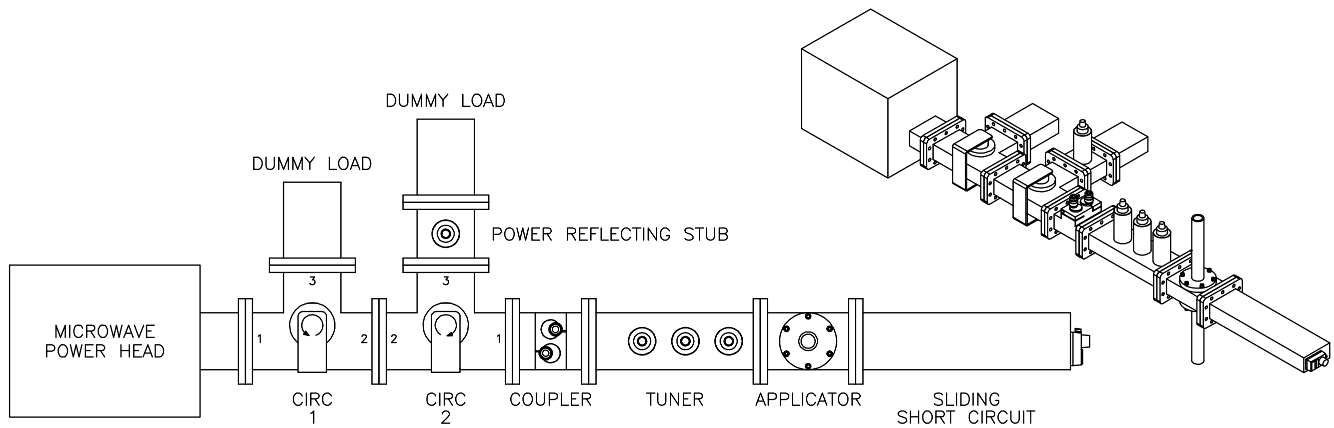

FIGURE 5 — Waveguide Configuration for variable microwave power at constant frequency.

Although the technique described above is very useful in certain situations, the following should also be considered:

- Stable operation at constant frequency requires the load impedance to be relatively stable. The dielectric properties of many materials change with varying temperature, resulting in impedance changes and a possible shift in resonant frequency. In such cases the advantages of the above technique may be limited.
- The waveguide configuration shown in Figure 5 is recommended for laboratory use only. While it may have some advantage is production systems, alternate methods of providing operational stability may be more practical and less costly.

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PO Box 580816 ▪ Modesto, CA 95358 ▪ USA
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