MUTUAL LOCKING OF QUASI IDENTICAL R.F. HEATING MAGNETRONS (PRELIMINARY RESULTS)

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ABSTRACT

The conditions for the mutual locking of two "canonically" coupled oscillators are established and the case of slightly different oscillators studied. The results are used to obtain preliminary data on the coupling of two r.f. heating magnetrons.

INTRODUCTION

The possibility of coherent operation of coupled oscillators is of interest in industrial microwave heating since it affects both the radiation from the applicators and the heat distribution in the materials.

We shall refer to the situation of fig. 1a with the simple reactive "canonical" coupling networks of fig. 1b. We define the per cent coupled power P_c as the fraction of the total power read by a matched meter that replaces one of the oscillators (fig. 2). For single tuned ones:

$$P_c = \frac{0,25k^2Q_{e1}Q_{e2}}{1+0,5k^2Q_{e1}Q_{e2}} \qquad (1)$$

We shall consider in the following any one of the two monoharmonic steady states of the coupled system.

STABILITY

It can be studied by assuming a small dynamic deviation from equilibrium of the form /1/-/3/:

$$v_i(t) = A_i(t)\exp(jwt-j\varphi_i(t)) \qquad (2)$$

which is equivalent to the introduction of a complex frequency:

$$\Omega_i \cong w+\delta\dot{\varphi}_i \ -j\delta\dot{A}_i/A_{io} \equiv w+\delta\Omega_i \qquad (3)$$

with A_{io} the equilibrium values.

It turns out that the minimum coupling for locking, k_m, is given by the condition:

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$$\frac{\partial k}{\partial w} = \frac{\partial k}{\partial A_i} = 0 \tag{4}$$

CIRCUIT FOR A MAGNETRON

A simple equivalent circuit for a magnetron is given in fig. 3 for which, under the approximations stated, the lines of constant power in the Rieke diagram are lines of g_L constant, intersected by the lines of constant frequency at an angle:

$$-\tan\psi = \frac{2}{b'} g_L \tag{5}$$

For the Philips YJ 1441 2.5 Kw magnetron, $Q_e = 200$, $a = 0.00857$ and $A^0 = 330$ V give results for the power that differ from the manufacturer's data sheet by less than 5%. The effect of b' is neglected.

RESULTS

We consider two identical single tuned oscillators except for one parameter at a time, as follows:

a) $Q_{e1} \neq Q_{e2}$ $(w_{01} = w_{02},\ \bar{g}_1 = \bar{g}_2)$

The oscillators are locked for:

$$P_c \geq |\bar{g}_1(A_{10}) - 1|^2 \frac{Q_{e2}}{4Q_{e1}} \tag{6}$$

For a magnetron this can also be written:

$$P_c \geq \frac{1}{4}\left(\frac{aA^0\varepsilon}{4}\right)^2, \text{ with } \varepsilon = \frac{|Q_{e1} - Q_{e2}|}{Q_{e2}} \leq 0.2 \tag{7}$$

which shows that the tubes will lock with very weak coupling. For the YJ 1441:

$$P_c \geq 0.125\,\varepsilon^2 \tag{8}$$

For example, for $\varepsilon = 10\%$, $P_c \geq 0.125\%$

b) $\bar{g}_1 \neq \bar{g}_2$ $(w_{01} = w_{02},\ Q_{e1} = Q_{e2})$. That is, the uncoupled oscillators run with different amplitudes $A_1^0 = A_2^0$.

In this case the locked operation amplitudes are identical independently of the coupling. Locking will take place for the same condition (6), which for a magnetron can now be put in the form:

$$P_c \geq \left(\frac{aA_{10}}{4}\right)^2 \left(\frac{\Delta A_1}{A_{10}}\right)^2, \quad (\Delta A_1 = A_{10} - A_1^0 \leq 0.1 A_{10}) \tag{9}$$

and in particular, for the YJ 1441:

$$P_c \gtrsim 0.5 \left(\frac{\Delta A_1}{A_{10}}\right)^2 \qquad (10)$$

that shows that the magnetrons lock again with very weak coupling.

c) $w_{01} = w_{02}$ $(Q_{e1} = Q_{e2},\ \bar{g}_1 = \bar{g}_2)$

This is the most interesting case. A closed form solution for k_m is not possible now even for linear or quadratic behaviour of $\bar{g}(A)$. Results computed for the magnetron YJ 1441 are shown in figures 4, 5 and 6.

Preliminary experiments performed on a 0.8x0.9x1.0 m^3 cavity fed from two guides radiating with the same polarization from the top show that, with small loads (less than 0.5 l of water), values of P_c higher than 25% may be easily attained. This result and fig. 6 show that, under the stated conditions, the chances of locking can be very high.

Nôte also that, for values close to k_m, small variations of the coupling produce large variations on the frequency and amplitudes of the oscillations. Operation under this condition will be very erratic.

REFERENCES

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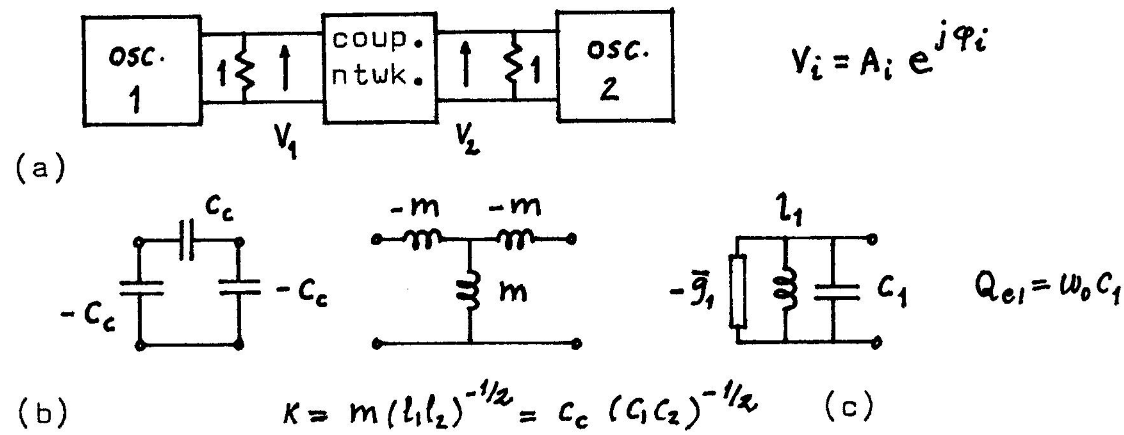

Fig. 1. (a) Coupled oscillators. (b) Simple "canonical" coupling networks. (c) Single tuned model of oscillator used in this work.

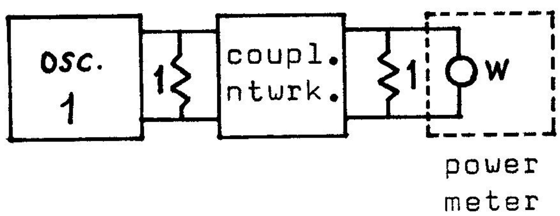

Fig. 2. Definition of the coupled power P_c with the use of a matched power meter.

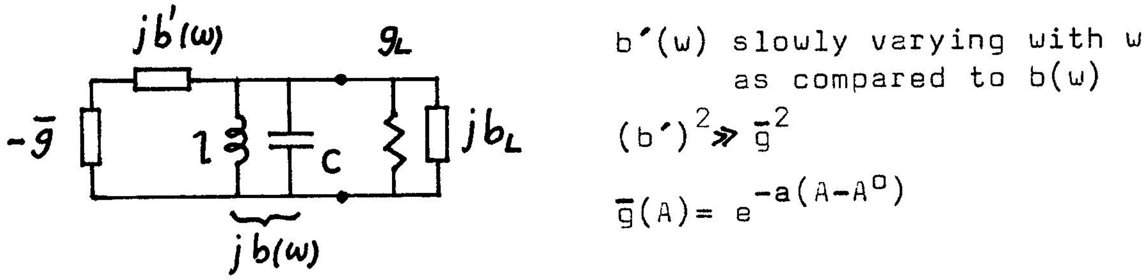

Fig. 3. Simple equivalent circuit for a magnetron with moderate VSWR loads.

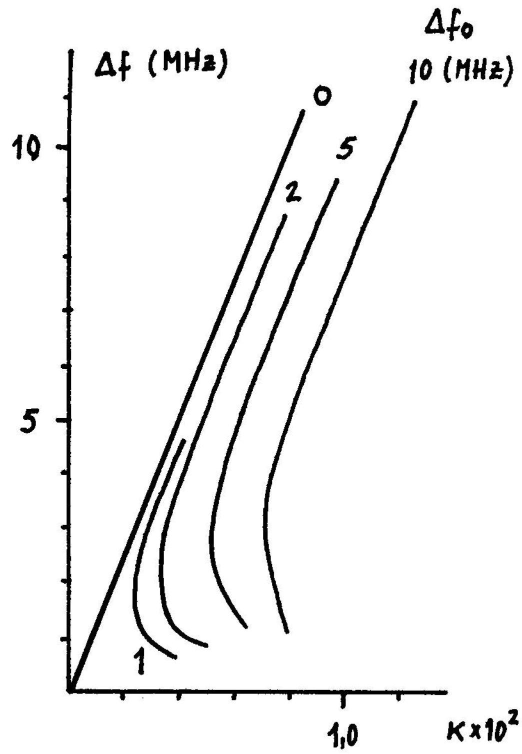

Fig. 4. Frequency shift of the oscillations vs. coupling k, with the uncoupled oscillators freq. deviation as a parameter, for the YJ 1441.

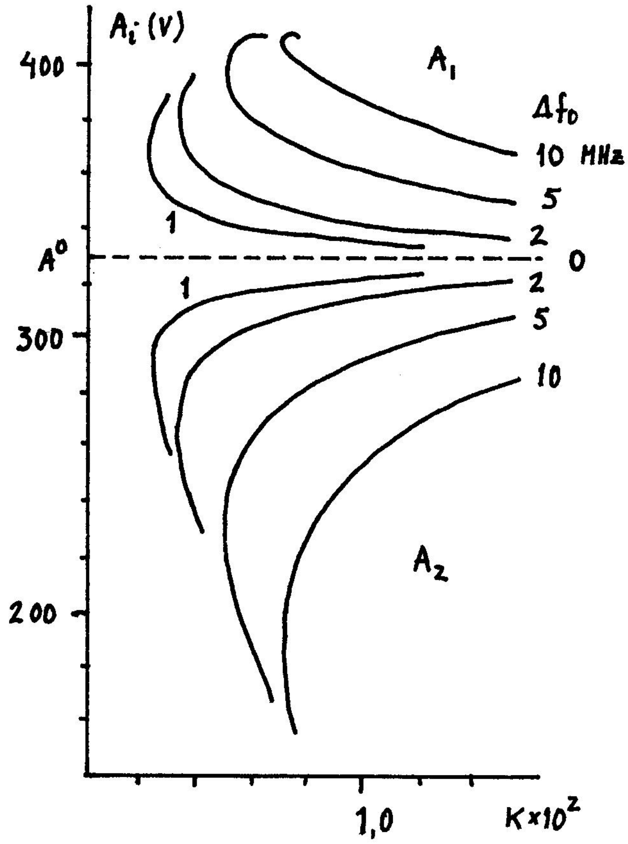

Fig. 5. Amplitudes of the oscillations at each load vs. coupling k, with the uncoupled osc. freq. deviation as a parameter, for the YJ 1441.

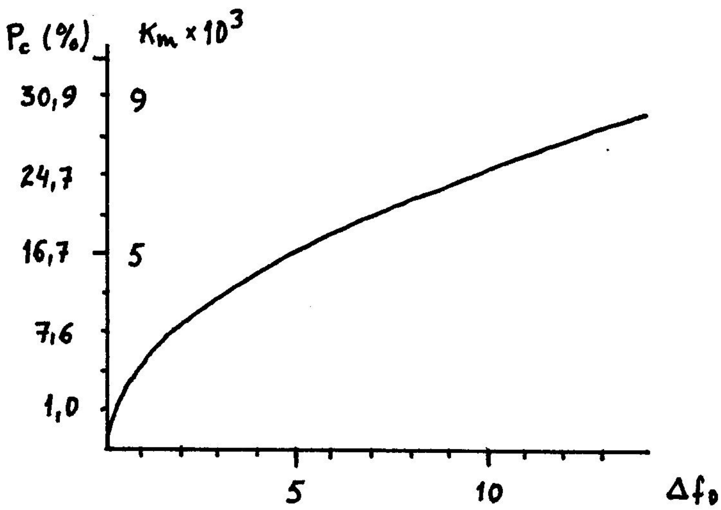

Fig. 6. Minimum coupling for locking, k_m, and corresponding coupled power P_c (%), vs. the uncoupled oscillators frequency deviation for the YJ 1441.