STABILIZATION OF REFLEX KLYSTRONS
BY HIGH-Q EXTERNAL CAVITIES

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Introduction

The frequency stability of the local oscillator is often the most important factor in determining the IF bandwidth of superheterodyne receivers. The inherent frequency stability of the local oscillator, which in the case of millimeter reflex klystrons is quite poor, can be improved by electronic means with the use of some forms of microwave discriminator.[1] An alternate method is to increase the effective Q of the oscillator, since the frequency stability of a free-running oscillator is proportional to the Q of the resonant circuit.[2] The latter method has the advantages of simplicity and of ease of alignment and tuning. The frequency stability which results, while not as great as can be obtained electronically, is sufficient for some purposes.

Theory of Operation

The effective Q of the klystron oscillator can be raised if a high-Q external cavity is coupled to the klystron in a suitable manner; for stabilization to result, the energy stored in the high-Q external cavity must be effective in determining the frequency of the oscillator. The stabilization of magnetrons by means of external cavities has been dealt with thoroughly elsewhere.[3] Although magnetron and klystron oscillators operate on fundamentally different principles, they have identical external characteristics; that is, the ideal Rieke diagrams of magnetrons and klystrons differ quantitatively only and therefore the analysis of magnetron stabilization applies to the klystron as well. The analysis will not be repeated here. Instead, the operation of the stabilized klystron oscillator will be made plausible from a study of the Rieke diagram of an ideal klystron and from the frequency behavior of a resonant cavity.

Figure 1(a) is an ideal Rieke diagram of a klystron referred to the detuned short position of the output line. The diagram is drawn on the Swith admittance chart. Figure 1(b) is the admittance vs. frequency of a critically coupled resonant cavity again referred to the detuned short in the coupling line. Stabilization is made possible by the fact that an inductive load causes the klystron to oscillate at a frequency higher than that of its own resonant cavity. However, the resonant circuit appears capacitive at frequencies above resonance. Therefore, if the two detuned shorts are superimposed, any change in frequency, up or down, which would normally result from a change in internal conditions in the klystron will be reduced due to the rapid variation of load admittance with frequency. This reduction, called the stabilization factor, will hold for all internal klystron parameters which affect frequency. In particular, the effect of reflector voltage on frequency is reduced so that the frequency is stabilized with respect to supply voltage fluctuations. The stabilization factor is given by Eq. (1).

$$s = 1 + \frac{Q_S}{Q_T} \qquad (1)$$

where:

Q_S = the loaded Q of the stabilization cavity
Q_T = the operating Q of the tube

The methods of measuring these parameters are well known.

The physical superposition of the detuned short positions of the tube and of the stabilization cavity is not possible since all commercial klystrons of the internal cavity type have comparatively long output coupling lines. However, the operation is no different if the separation of the detuned short positions is a multiple of a half-wavelength. The physical separation of the klystron cavity and the stabilization cavity does introduce a difficulty of a different nature. Refer to Fig. 2. If the klystron cavity and stabilization cavity are both tuned to the same frequency, f_o, and separated by a line of length 1/2 n , then the klystron can oscillate at f_o. For this mode of oscillation, the energy stored in each resonant cavity is large while, assuming that the stabilization cavity is nearly critically coupled on the input side, the energy stored in the coupling line is small. For some frequency greater than f_o, say $f_o + \delta_1$, the situation will be as shown in Fig. 2(b). Both cavities will appear capacitive, and they will be separated by a line of electrical length slightly greater than 1/2 n This combination can also resonate, and therefore there is a second mode of oscillation possible at the frequency $f_o + \delta_1$. For this mode, the energy stored in the resonant cavities is small compared to the energy stored in the coupling line. Similarly, there is a third possible mode of oscillation, at a lower frequency $f_o - \delta_2$. These last two modes are undesirable since their mode shape and frequency stabilization are poor. However, the speed of starting of these modes is greater than that of the desired mode if the stabilization factor is greater than 3.[3] Therefore, some provision must be made to suppress these modes. This can be done by placing a small amount of dissipative loss in the coupling line. The effect on the desirable mode will be negligible, since for this mode the field intensity in the coupling will be small, but for the two undesired modes, the dissipative loss will be great since these modes are characterized by large field intensities in the coupling line. Stabilization cavities were built for a 2K33 and a

QK290 klystron. The mode suppressor loss was on the order of 0.2 db, which is negligible compared to the loss due to the finite Q_7 of the stabilization cavity.

Design Considerations

The design of the stabilizing cavity and the coupling network can take a variety of forms. Fig. 3 shows the essential elements which must be present. The phase shifter makes possible the superposition of the detuned short positions of the tube and stabilization cavity at any frequency in the klystron band. The IRC cord suppresses the undesired modes. The cavity is an electroformed copper cavity operated in the TE 012 mode. The input and output coupled Q's of the stabilization cavity can be chosen to satisfy either of two criteria:

a) Maximum stabilization consistent with a reasonable insertion loss.
b) Minimum insertion loss consistent with a reasonable stabilization factor.

The transmission through a cavity is given by[4]

$$T = \frac{4\ \beta_1\ \beta_2}{(1 + \beta_1 + \beta_2)^2} \tag{2}$$

where:

$$\beta_1 = \frac{Q_o}{Q_{c1}}$$

$$\beta_2 = \frac{Q_o}{Q_{c2}}$$

Q_{c1}, Q_{c2} = input and output coupled Q's.

Q_o = unloaded Q of the cavity.

In addition, the input coupled Q must be very near critical in order to keep the SWR (and hence the field intensity in the coupling line) small for the stabilized mode of oscillation. This condition was assumed in discussing the action of the mode suppressor. Typical design values are given for both cases.

Maximum Stabilization

The Q which is effective in stabilizing the klystron is the loaded Q of the stabilization cavity.

$$Q_L = \frac{Q_o}{(1 + \beta_1 + \beta_2)} \tag{3}$$

If the maximum stabilization factor is to be obtained, β_1 and β_2 must be small. A second condition which must be met is that the input SWR be near unity; that is, $\beta_1 = 1$. Therefore, even if the output loading is small, the maximum realizable stabilization cavity Q is $Q_r = 1/2\ Q_o$. If β_2 is chosen as 0.2 then:

$\beta_1 = 1$ $\quad\quad\beta_2 = 0.2$
$Q_L = 0.9\ Q_r$
$T = 0.1655 = -7.8$ db
Input SWR = 1.2

Minimum Insertion Loss

For this case, the most efficient use of the cavity results if $\beta_1 = \beta_2 = \beta$. A small insertion loss requires that β be large. For large β, equal input and output coupling results in a nearly matched input. A reasonable choice for this case is $\beta = 2$; then:

$\beta_1 = \beta_2 = 2$
$Q_L = 0.4\ Q_r$
$T = 0.64 = -2$ db
Input SWR = 1.5

Experimental Results

Stabilization cavities were built for operation with a K-band (1.25 cm) 2K33 klystron and a K_a-band (9 mm) QK290 klystron. Two K-band cavities were built, one designed for maximum stabilization and one for minimum insertion loss. One K_a-band cavity, designed for minimum insertion loss was built. Table I summarizes the characteristics of the resultant stabilized klystrons. Figs. 4-7 show typical stabilized klystron modes. The modes of Fig. 4 are the undesired modes which have not been suppressed. Due to tube hysterisis, the stabilized mode is not present at all. In Figs. 5-7 the widening of the reaction wavemeter pip, which is due to the reduced modulation sensitivity, is a direct measure of the stabilization ratio.

Acknowledgement

The author wishes to thank Mr. O. C. Lundstrom of Hughes Aircraft Corporation for introducing him to the technique of cavity stabilization of klystrons.

TABLE I

Characteristics of K-band and K_a-band Cavity Stabilized Klystrons

	K-band (Fig. 5)	K-band (Fig. 6)	K_a-band (Fig. 7)
Insertion Loss, db	8.0	1.6	2.7
β_1	0.85	2.5	1.4
β_2	0.20	2.5	1.4
Q_o	20,000	18,000	15,000
Q_L	10,000	3,000	4,000
S	10	3	5
Long term stability	1 part in 10^5	1 part in 10^5	1 part in 10^5

References

1. R. V. Pound, "Frequency stabilization of microwave oscillators," Proc. IRE, vol. 35, pp. 1405-1415; 1937.

2. W. A. Edson, "Vacuum Tube Oscillators," John Wiley and Sons, New York, pp. 83-85; 1953.

3. G. B. Collins et al, "Microwave Magnetrons," MIT Rad. Lab. Series, vol. 6, Ch. 16; 1948.

4. C. G. Montgomery et al, "Principles of Microwave Circuits," MIT Rad. Lab. Series, vol. 8, p. 238; 1948.

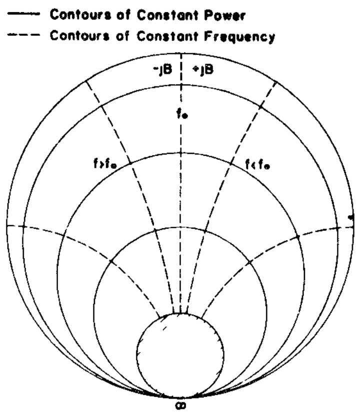


Fig. 1(a) - Ideal Reike diagram referred to the detuned short of the output coupling line.

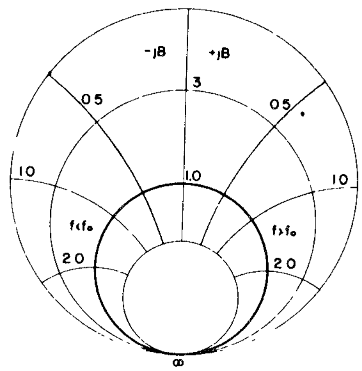


Fig. 1(b) - Admittance vs. frequency of a resonant cavity referred to the detuned short.

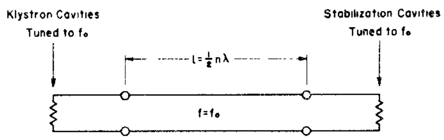


Fig. 2(a) - Equivalent circuit for normal mode of oscillation.

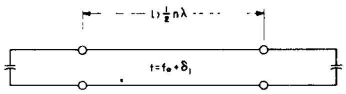


Fig. 2(b) - Equivalent circuit for mode of frequency $f_0 + \delta_1$.

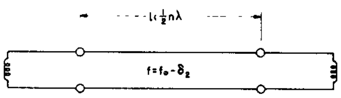


Fig. 2(c) - Equivalent circuit for mode of frequency $f_0 - \delta_2$.

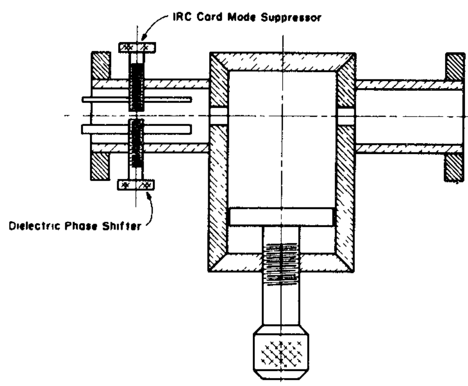
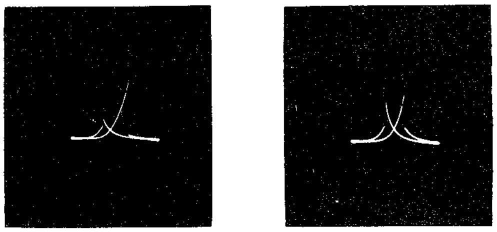
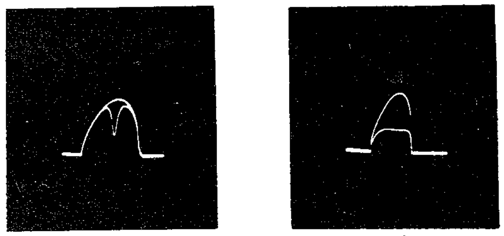


Fig. 3 - Typical design of a stabilization cavity and coupling network.



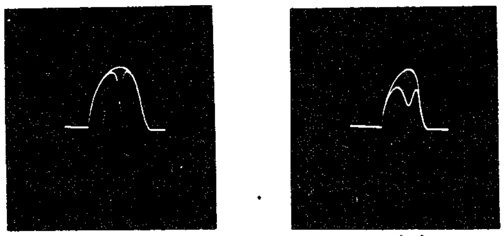
(a) (b)

Fig. 4 - Mode of a stabilized klystron. Spurious modes not suppressed.



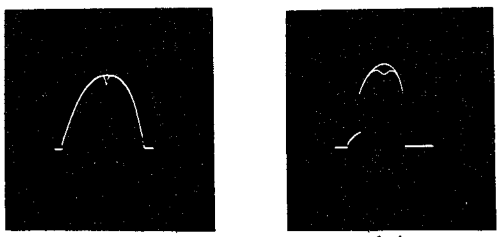
(a) (b)

Fig. 5 - K-band klystron mode showing high-Q wavemeter pip.



(a) (b)

Fig. 6 - K-band klystron mode showing high-Q wavemeter pip.



(a) (b)

Fig. 7 - J-band klystron mode showing high-Q wavemeter pip.