C. N. O'LOUGHLIN B.Sc* and R. HEPPINSTALL B.Sc, Ph. D*

AN IMPROVED RANGE OF 10kW KLYSTRONS AND ASSOCIATED CIRCUITRY

INTRODUCTION

The past decade has seen rapid technical advances in television broadcasting. Colour has been widely introduced and an ever increasing number of authorities have started transmitting in the u.h.f band. The propagation characteristics at u.h.f are such that a large number of transmitters and transposers are required and, inevitably, many of these tend to be located in remote areas. The current planning of many broadcast authorities is based on the concept of regional mobile maintenance teams servicing a large number of unattended sites. To meet this requirement the transmitter must be designed either for automatic or remote control operation. All maintenance, whether routine or emergency, must be at infrequent intervals and be such as can be carried out as rapidly as possible. Transmitters capable of meeting such stringent requirements have been made possible by advances in solid-state techniques and by the development of highly reliable klystron amplifiers.

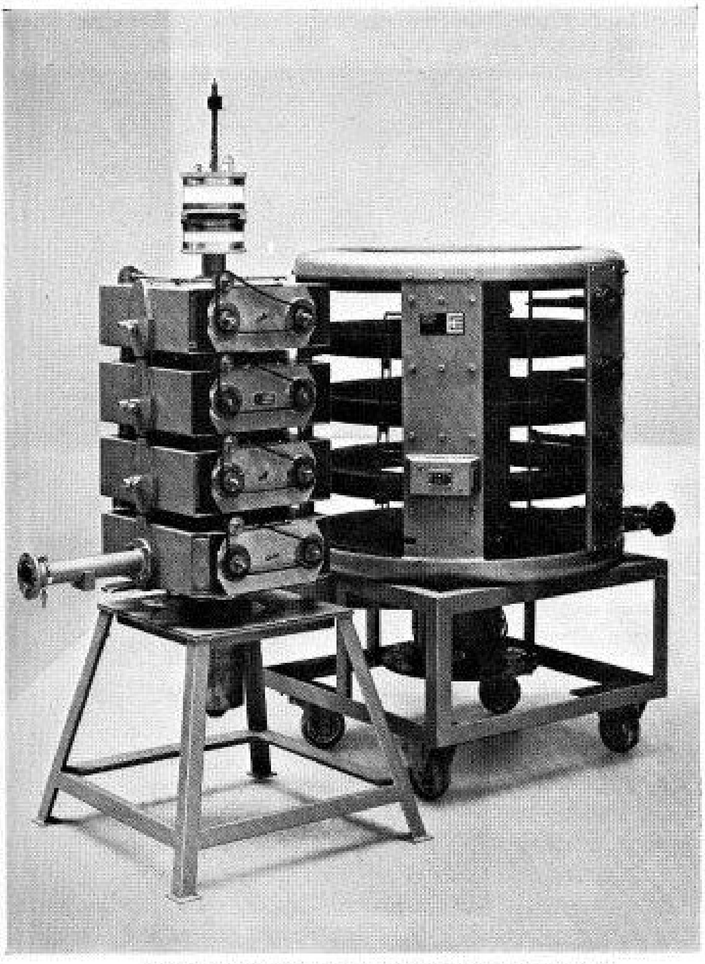

Fig.1 K370A klystron and K4145 circuit assembly

The existing K370 range of 10kW klystrons first went into service five years ago and, since then, over one million hours of operational life have been recorded. The experience gained with these tubes has on the whole been very good, but as the authorities moved in the direction of unattended operation, two factors emerged as being of particular importance – long-term stability and ease of maintenance. With these in mind, the klystrons and their associated circuit assemblies were re-engineered to produce an improved range of 10kW klystrons particularly suited for use in unattended transmitters (Fig.1). The underlying philosophy behind the new design is simplicity. It was considered essential that the klystron replacement operation on site should be reduced as nearly as possible to a purely mechanical operation, involving a minimum of klystron tuning. Improvements fall into two categories – those of a mechanical nature related to improved ease of installation, and secondly, those related to stability. After first explaining the underlying reasoning this article goes on to describe these improvements and finally some experimental results are given.

UNDERLYING REASONING

The basic klystron

The essential components of a klystron are shown in figure 2. These are:

i. An electron beam
ii. A drift tube with gaps
iii. Two or more cavities

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*English Electric Valve Company Limited

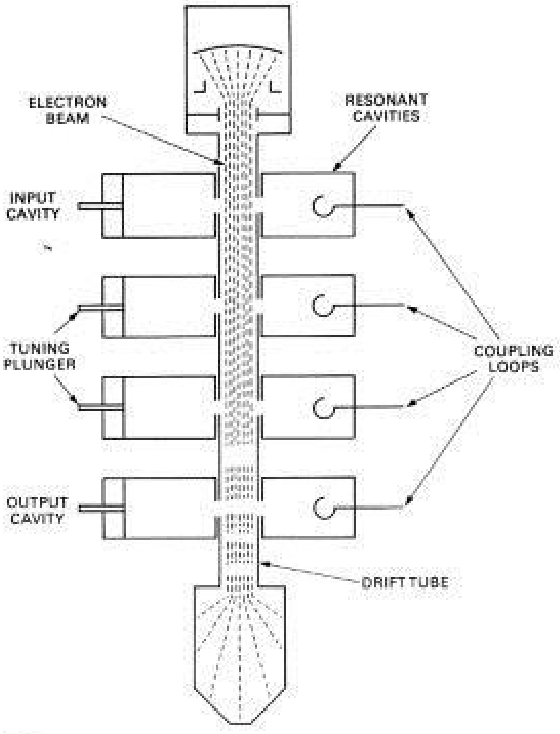


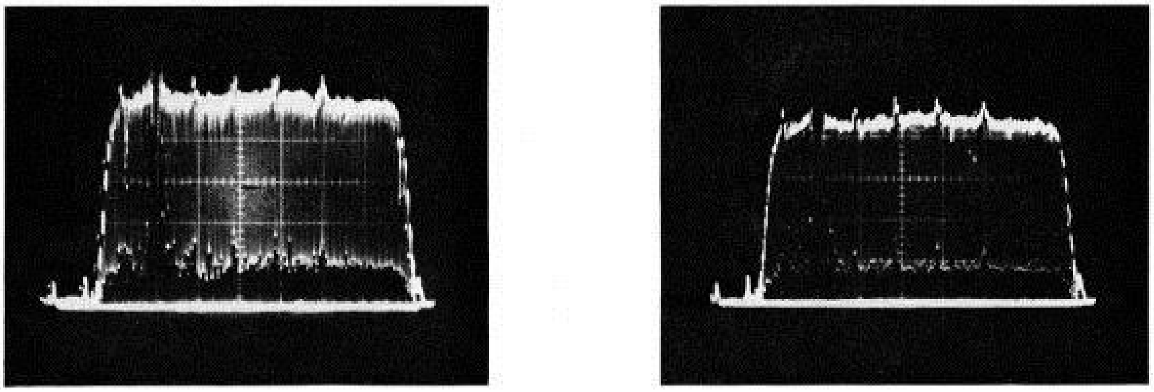
Fig.2 Schematic diagram of a multi-cavity klystron

The first two are inseparable because the electron beam must be contained within a vacuum envelope which also serves as a drift tube. The klystron depicted is typical of the multi-cavity klystrons used in television transmitter service and consists of four stagger-tuned cavities cascaded along a common drift tube and coupled by a common beam.

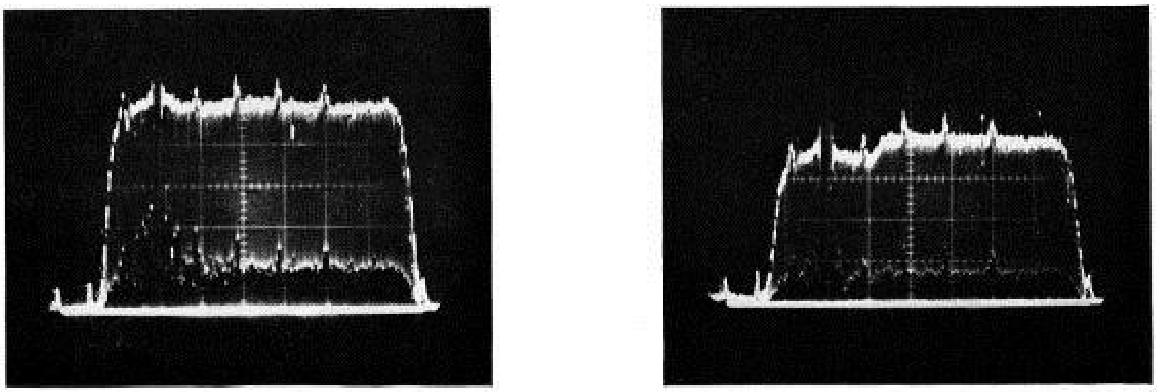
Klystron tuning

The tuning pattern of a multi-cavity klystron is largely determined by the output cavity. The output cavity is tuned to the carrier frequency and the loading is adjusted in order to maximize the operating efficiency. This determines the Q of the output cavity and, for a perveance-two klystron operating at 12kW output, the value of Q is typically 50. The earlier cavities are then tuned to give a flat overall output response. Each cavity is tuned in frequency by means of the tuning plunger and its Q value is adjusted by varying the external loading using the coupling loop. Normally the input cavity is tuned slightly higher than band centre and has a Q in the order of 90. The intermediate cavities are stagger-tuned to frequencies on either side of the centre frequency and have Q values of 200 or more.

When klystron amplifiers are operated in u.h.f television transmitters a step can sometimes be seen in the frequency response prior to correction (Fig. 3). On examination it can be seen that the step extends symmetrically around the vision carrier. The edge of the step occurs at a frequency which marks the change-over from double to single side-band frequencies and which is determined by the v.s.b filter. An explanation for the occurrence of this step has been given by Edgcombe and O'Loughlin.[1] The amplitude of the step depends on the linearity of the amplifier and as such on the picture amplitude



12% AVERAGE PICTURE LEVEL (APL) INPUT 55% APL



12% APL OUTPUT 55% APL

Fig.3 Klystron frequency responses showing the occurrence of a step

(Fig. 3). The amplitude is also influenced by the group delay characteristics of the filter because this determines the relative amplitude and phase of the two side bands.

If the best overall frequency response is to be achieved it becomes necessary to adjust the klystron cavity loading to match the characteristics of the transmitter drive. This associates the tuned klystron with a specific drive unit.

Klystron replacement

If the klystron had an infinite life the transmitter could be tuned as described and would not require further adjustment. However, as cathode emission deteriorates with time, the klystron has a limited life and has eventually to be changed. Looking again at figure 2 it can be seen that, with the single exception of the electron beam, all other elements are passive. Logically, therefore, only the electron beam need be changed. If the new beam is an exact replacement then the cavity tuning and loading remain correct as they are already matched to the driver, and no retuning is required. Beam replacement alone is impossible but a practical solution lies in a vacuum tube the envelope of which comprises the drift tubes spaced by ceramic insulators (Fig.4). The resultant gaps contained within the vacuum envelope can be accurately controlled during manufacture, thus ensuring consistent beam coupling. The interaction gap forms part of the resonant circuit and so the gap capacitance must be held within close tolerances if the frequency response is to remain unchanged when a tube is replaced. It will be recognized that figure 4 is merely a schematic diagram of a standard external-cavity klystron.

The re-engineered design

The underlying philosophy is that of a replaceable electron stick. The cavities are associated with the transmitter and, when the electron stick is replaced, the loop loading settings are correct and only a small frequency tuning adjustment is required.

The re-engineered system takes full advantage of the loading loop adjustment facilities inherent in the external cavity design. It has, however, the added advantage that, once the loops have been adjusted for optimum, they can then be fixed and will remain so when a klystron is changed. This has been achieved by associating the loop with one half of the cavity box, thus enabling the cavity to be split (essential when replacing a klystron) without effecting the loop setting. The mechanical arrangement can be seen in figure 1.

On the earlier design it was necessary to detune the cavities to the high-frequency end in order to remove the klystron from the focus mount. This cumbersone procedure has now been eliminated, the new arrangement enabling the cavities to be removed from the electron stick without altering either the tuning or the loading loop settings.

Results obtained

The results obtained on a swept frequency response, before and after replacement of the electron stick, are shown in figure 5. Figure 5a shows the overall response of a klystron immediately before replacement and figure 5b the response immediately after replacement of the electron stick in the tuned circuits. It should be stressed that this response was achieved without any retuning or loading loop adjustment. Reference was made earlier to the fact that the interaction gap capacitance would affect the frequency response. In the case of figures 5a and 5b the gap capacitance was very similar on both klystrons involved. However, if the change is made on klystrons where the gap dimensions are at either end of the manufacturing tolerance, a significant change in the swept frequency response will occur as shown in figures 5c and 5d. Even here it is clear that a picture would be transmitted and only a minor trimming adjustment is necessary in order to achieve the desired response.

The simplification of the necessary tuning procedures to trimming adjustments alone goes a long way towards meeting the first objective – improved ease of installation. During re-engineering a great deal of attention has been paid to the mechanical handling aspects. The improvements made are best indicated by the time required for a klystron change. The total time taken from switching off a transmitter to re-transmitting a picture is less than 45 minutes. An important economic consequence of this is that it is no longer necessary to hold a dressed spare klystron in its focus mount on site.

Klystron performance stability

Unattended transmitter operation demands reliable long-term stability from the transmitter components. Two distinct aspects have to be considered when klystron stability is being assessed. Firstly, how is klystron performance affected by changes in the various supplies – h.t, focus current, etc.? Second-

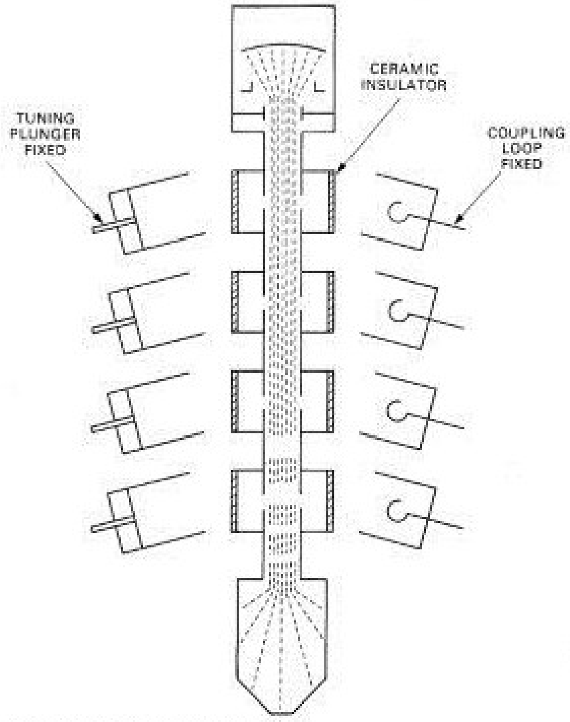
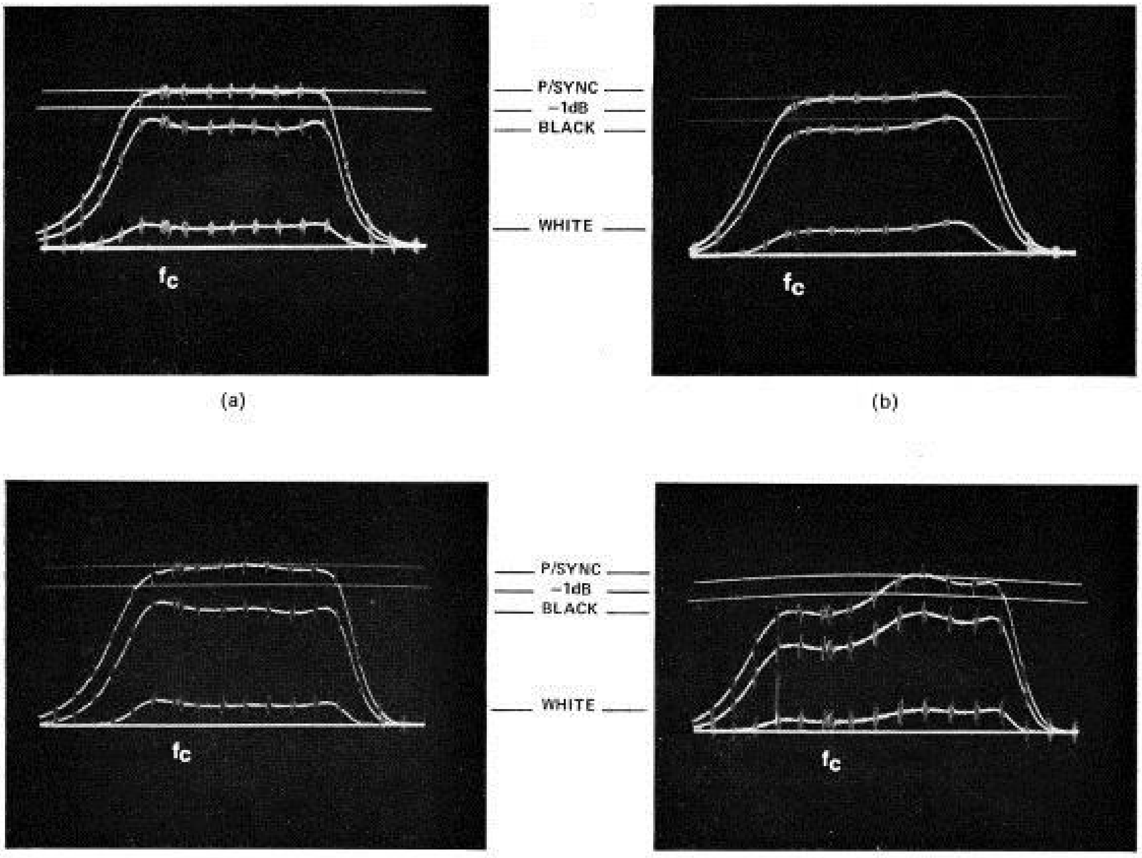


Fig.4 The replaceable element



(a) (b)

(c) (d)

Fig.5 Klystron swept frequency responses at peak sync, black and white levels. Frequency markers at 1MHz intervals and a vision carrier marker are shown

ly, what is the inherent stability of the klystron, assuming that the supplies, input etc. remain constant?

FOCUS CURRENT

First generation equipments were fitted with focus current stabilization. Early experience, however, indicated that the first order klystron performance was not very sensitive to changes in magnetic field and, consequently, a number of transmitter manufacturers dispensed with stabilization on later designs. The increased emphasis on performance stability has necessitated a reassessment of the situation. Recent operating experience has shown that changes in magnetic field produce the major second order effects of which a.m noise is perhaps the most important. Experimental investigations have shown that the amount of random or periodic noise generated within the klystron can be minimized by adjustment of the focus current. Generally, over the focus current range in which the klystrons may be operated, there are a number of sub-ranges in which noise is present, and other sub-ranges or clear windows in which the noise level is less than −60dB, measured as a peak-to-peak voltage referred to the rectified level of the peak sync signal. It has, therefore, been specified that the focus current should be adjusted within the permitted range to an optimum value where noise is at a minimum and then stabilized at that value.

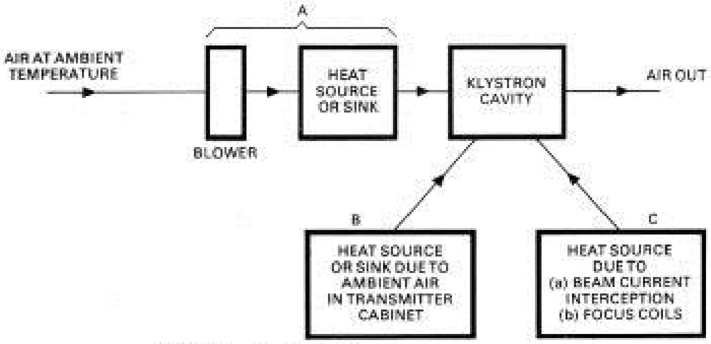


Fig.6 Cavity heat balance system

KLYSTRON INHERENT PERFORMANCE STABILITY

The klystron's inherent performance stability is basically determined by temperature expansion effects. Cavity and gap dimensions change as the temperatures of the resonator and drift tube rise from ambient to their steady operating values. These dimensional changes alter the tuning pattern and thus affect the gain of the tube. An estimate of the magnitude of the effect for a rectangular cavity box alone can be readily made. The fractional change in tuned frequency for such a box, due to a temperature rise of T°C, is given by

$$\frac{\delta f}{f} = -T.\epsilon$$

where f is the frequency to which the box is initially tuned and $\in$ is the coefficent of linear expansion of the material of the box. For brass $\in \simeq 20 \times 10^{-6}$ cm/cm/°C and, so for a brass cavity initially tuned to 800MHz, a frequency change of 0·5MHz is produced by a temperature rise of about 30°C. Experiments indicate that when the contribution due to drift gap changes are also included, then a frequency shift of the order of 27kHz/°C is typical.

The steady operating temperatures of klystron cavities depend upon a number of factors. The heat balance for an air-cooled cavity would be as shown in figure 6. Air from an ambient temperature source is blown on the cavity via a heat chamber (source or sink), which is used to ensure that the air entering the cavity remains at a constant temperature independent of ambient. It should be noted that the air entering the heat chamber will be at a higher temperature than ambient by an amount ΔT°C due to the power, W, watts imparted to it by the blower. In fact,

$$\Delta T = \frac{W \times 1{\cdot}783}{F}$$

where F is the volume of air flow in cubic feet per minute. The heat source or sink, B, is a variable depending upon the ambient temperature within the transmitter cabinet, whereas heat source, C, can be considered as a constant for a particular klystron operated at a particular focus current.

It is apparent that the lower the steady cavity operating temperature the more rapidly will effective stabilization occur after switch-on. It is, therefore, desirable to optimize the klystron design to give a low beam-current interception, but even then the inevitable remaining interception, together with the heat supplied via radiation and convection from the focus coils, leads to a stabilization temperature significantly above ambient. A sufficient volume of air at a predetermined temperature blown into the cavity will exercise a controlling influence over its temperature. Assuming that this technique is adopted, it is then necessary to determine the optimum air temperature. The most obvious answer is to blow at the same temperature as that at which the cavity would stabilize in the absence of any air blowing. This procedure will not affect the value of the steady operating cavity temperature but does result in two important advantages. Firstly, the time taken after switch-on to achieve stable operation is decreased. Secondly, once this condition has been reached the system will be relatively immune to extraneous heating caused, for example, by changes in the focus coil temperature.

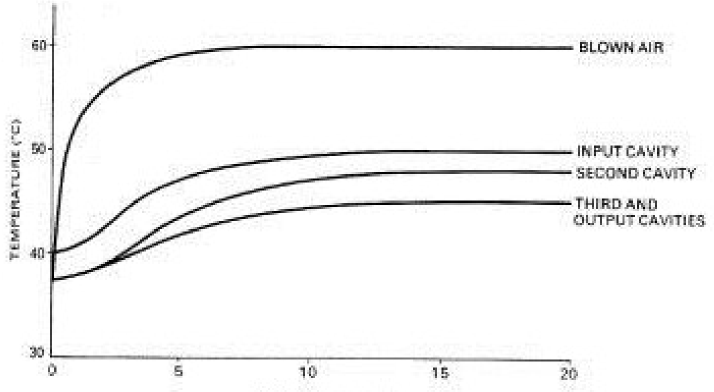


Fig.7 Cavity temperature variation with air temperature

RE-ENGINEERED CAVITY COOLING SYSTEM

It should be remembered that the whole of the argument presented has been made with reference to a single cavity. The K370A series klystrons are four-cavity tubes and, in general, the cavities do not operate at the same temperature. It is inconvenient to provide a separate air supply to each cavity. Consequently, arrangements have been made whereby the air stream from a single inlet is channelled equally to each of the four cavities.

Experimental results

A series of experiments have shown that for this system a total air flow of 100 c.f.m or more is sufficient to exercise a satisfactory degree of control over cavity temperatures. Figure 7 presents results demonstrating this control. It shows the effect of raising the blown air temperature from 38°C (at which the klystron had been stabilized) to 60°C. The cavity temperatures responded quickly to this change to restabilize in 15 minutes. The rapidity of the response clearly demonstrates that the air is exercising a controlling influence upon cavity temperatures.

Careful comparison has been made of klystron gain stability for two different air blowing systems, defined as follows:

1. The 're-engineered' system just described in which all four cavities and the output drift tube are blown by a total of 100 c.f.m.
2. The 'original' system, employed to date (K370 series in K4105 mount), in which only the output cavity and output drift tube are blown by a total of about 25 c.f.m.

Figure 8 shows the relative variation in black level amplitude with a constant input for the two systems as a function of time after switch-on. It is seen that, when using the re-engineered system, the tube stabilizes more quickly. Furthermore, the system results in a much reduced overall variation of level.

With the original cooling system each of the cavities reached thermal equilibrium at some temperature dependent on its own heat balance. Since there was no single over-riding control, each of the cavities drifted in frequency independent of the others. As this drifting was occurring over a long period of time the result was a changing shape of frequency response during the warm-up time. A big advantage of the new system is the fact that the cooling air acts as the over-riding control for all four cavities. This means that all four cavities follow the air temperature (Fig.7), and consequently change in frequency in unison. The effect of this is that the shape of the response stays the same but the whole response shifts in frequency. As the klystron is in general tuned to be wider bandwidth than the television signal, the shape of the video-frequency response remains unaltered.

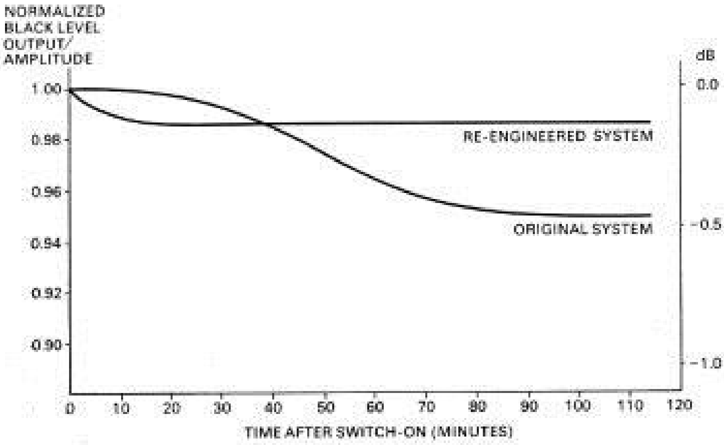


Fig.8 Black level output variation

CONCLUSIONS

A new range of 10 kW klystrons and circuit assemblies have evolved as a result of experience and the designs have taken account of the various features required for operation in the modern conception of a u.h.f transmitter. Pretuned cavities and coupling loops make for easier installation and optimum performance at all channels, and the air-cooling system has been designed to provide the thermal stability required for long periods of unattended operation. External cavities have been adopted to make the main frequency sensitive element a permanent part of the transmitter and not a part requiring change on valve replacement.

ACKNOWLEDGEMENTS

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REFERENCE

1 Edgcombe and O'Loughlin, 1971. Accepted for publication by the I.E.R.E.