TEMPERATURE CONTROL in the Design of Stable Oscillators

The ideas presented herein may well apply to various types of self-excited u.h.f. and v.h.f. oscillators for frequency stabilization.

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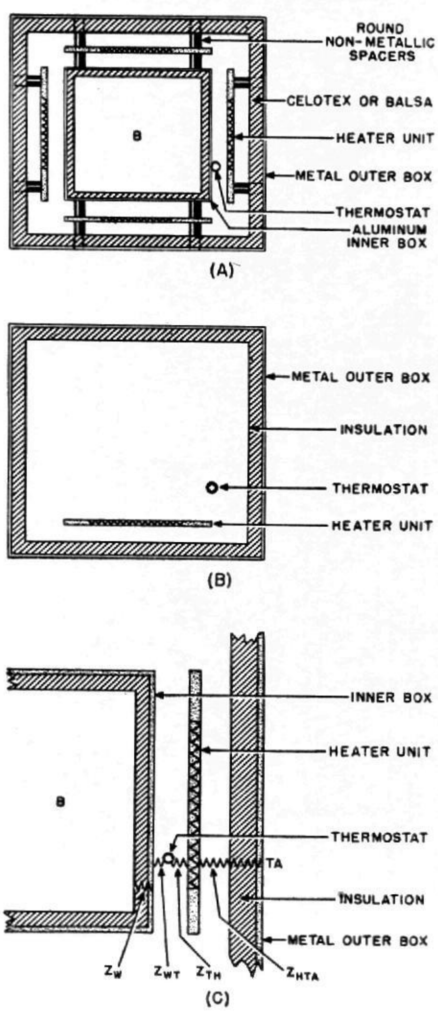
ONE of the requirements in the design of a stable oscillator is close control of the temperature of the frequency determining elements of the circuit, whether that is a quartz plate or the LC tank of a variable frequency oscillator. In order to attain a close control of temperature, considerable attention should be given the design of the controlled compartment.

Fig. 1. The construction of temperature control enclosure. (A) Sectional rear view showing suggested type of construction and placement of components. Front and rear heater units not shown. (B) Type of arrangement which would give poor control. (C) Illustrating how spaces between components may be shown as thermal impedences.



Let us take, for example, a metal box lined with celotex or balsa wood within which is a heater and thermostat as in Fig. 1B. The thermostat is set to operate at a given temperature. The ambient temperature outside the box is somewhat lower. Now, if the ambient temperature is increased, the temperature inside the box will increase, not necessarily the same amount, even though the box is heat insulated and the thermostat is assumed to control the temperature. The temperature of various spaces within the box will probably not be uniform. Added insulation will not correct the fault, but only slow up the rate of change of temperature with a change of ambient temperature. The reason for the performance of this type oven is that the thermostat will control only the temperature immediately surrounding the controlling element of the thermostat. However, as will be explained later, the temperature of the controlling element can be adjusted to give the desired control provided the heater is correctly arranged and other design problems are properly considered.

If these components are rearranged, the heater and thermostat placed outside the box to be controlled, the heater distributed evenly on all sides of the box, and then all surrounded by an outer box as in Fig. 1A, a much greater amount of control can be attained for the reason that all sides of the box will be close to the same temperature as the controlling element of the thermostat. We can consider the box walls, the space between the box and the thermostat, the space between the thermostat and heater, and the space between the heater and ambient temperature as thermal impedances, Fig. 1C. By correct adjustment of these various thermal impedances, the temperature at B can be maintained very close to a constant value, even though the ambient temperature, T_A and the power in the heater varies within limits.

Fig. 1C illustrates how these impedances are arranged. The impedance Z_W should be high enough to smooth out the heat cycles from the heater, which will cause the temperature at B to be maintained without fluctuations due to on and off periods of the heater.

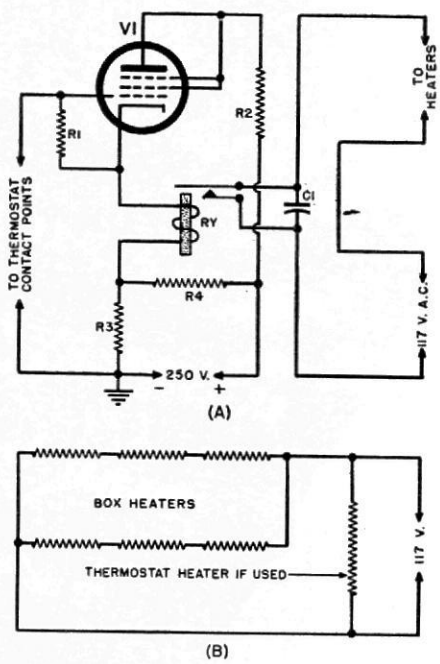


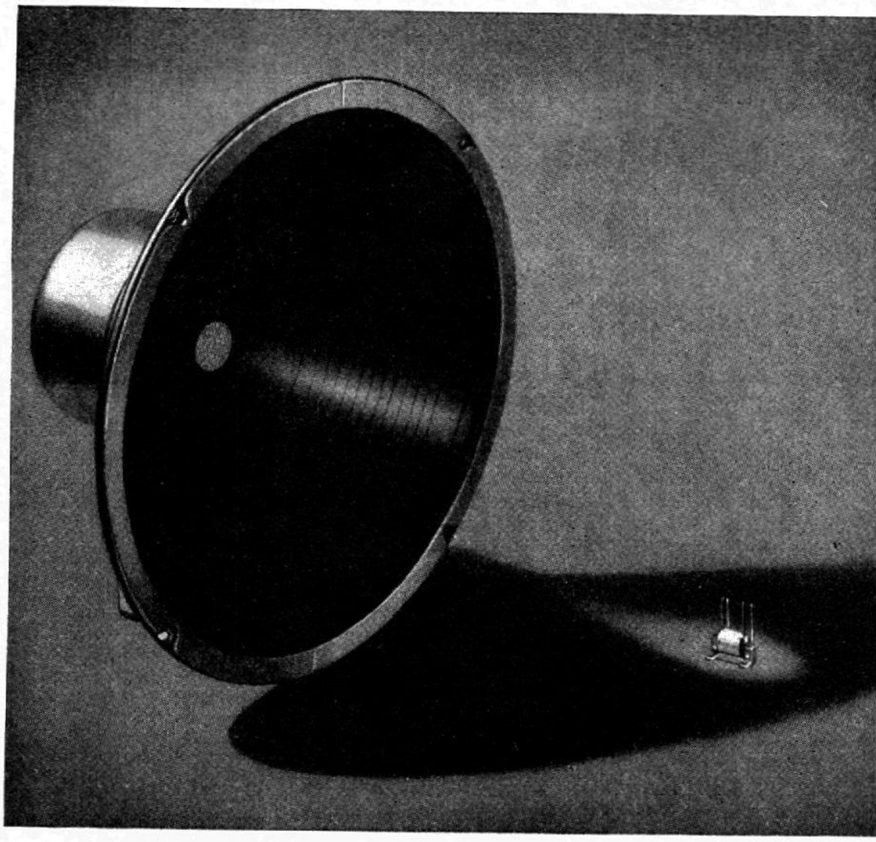
Fig. 2. (A) Relay circuit diagram for use with mercury thermostat. (B) Heater connections used in example described in text.

The impedance Z_{WT} should be as low as possible, that is so the wall of the box will be maintained at the temperature of the thermostat, which will be approximately equal to the temperature inside the box. The type thermostat used determines how this is accomplished. This will be treated in more detail later.

The impedance Z_{TH} should also be as low as possible in order that the thermostat on-off cycles will be short.

The impedance Z_{HTA} should be as high as possible for economical reasons, that is, the better the insulation in the walls of the outer box, the shorter the "on" time of the heater will be, as less heat will be dissipated through the walls of the outer box.

In the design of an oven of this type, the first thing to consider is the size and material of the inner box, B. It should be made just large enough to conveniently hold the components to be temperature controlled. An aluminum box lined with balsa wood or celotex will provide an effective shield electrically. Aluminum, being a good thermal conductor, will equalize the temperature inside the box, while the



balsa or celotex will provide the necessary thermal filter. Necessary wire leads from the components should be brought out at a convenient place through as small an opening as possible.

The temperature at which the components are to be maintained is next considered. The highest ambient temperature at which the equipment will operate is determined. The temperature rise within the box caused by heat dissipation of the components mounted within is determined. This can be found by experiment as follows:

The inner box, *B*, is constructed and all component parts are mounted within it. The box is then subjected to a temperature equal to the highest ambient temperature, T_A, at which the equipment will operate. The components are then operated normally. After approximately one hour, measure the temperature within the box, *B*. Call this T_B. The temperature rise, T_R, will be T_B-T_A and the operating temperature, $T_O = T_R + T_A + 2$. If crystals only are to be temperature controlled and one crystal is to be operated at a time, T_R can be assumed to be 5 degrees centigrade. If all component parts of a variable frequency oscillator (except the tube) are to be controlled within the box then T_R should be 10 degrees centigrade. The operating temperature of the box, T_O, is then $T_R + T_A$. All temperatures are expressed in degrees centigrade. Note that the factor 2 is used only if T_R is determined experimentally. If T_R is assumed 5° C. or 10° C. in the specific cases as above, this factor is already considered.

Having determined the operating temperature of the box, the next step is to select the thermostat. The thermostat selected should have a small operating temperature differential. The mercury type is usually the best for this application, although it is usually more expensive than other types. It is fragile and must be handled with care. One type mercury thermostat has the thermometer scale engraved on the stem which, of course, would save the price of a separate thermometer. Other types of thermostats include the bimetallic and the snap-disc. These, as a general rule, will not operate on as small a temperature differential as the mercury type, but can be made to operate satisfactorily with special treatment, as will be explained later.

The operating point of the thermostat should be equal to or above the operating temperature of the box. If a mercury thermostat is used, a relay will have to be used to handle the heater current, as the contacts of this type thermostat will not handle any appreciable current. A suggested circuit for the relay is shown in Fig. 2A. The relay, *RY*, should have d.c. resistance of approximately 5000 ohms and operate on a current of from 2 to 4 ma. The contacts should be capable of handling the full heater current without arcing. Any bimetallic or snap-disc type thermostat used will handle the heater current without the aid of a relay. However, more attention will have to be given this type to keep the operating temperature differential at a minimum. This can be done with the use of a separate thermostat heater adjusted so the on and off periods will be short, and the temperature of the wall of the box B will remain as nearly constant as possible through the thermostat cycle. This will especially be necessary if the operating temperature of the thermostat is higher than the desired operating temperature of the box.

It should be noted that while Fig. 1A shows the correct *effective* placement of the thermostat with respect to the heaters and the box, it may be *physically* placed at any convenient location within the outer box provided the thermostat heater is adjusted so as to cause the thermostat to maintain the correct temperature at the wall of the box B.

All heaters used, including the thermostat heater, should be the open type with as little thermal storage capacity as possible. This is important if a non-fluctuating constant temperature is to be maintained. Heaters for the box should be the open "grill" or "card" type placed so that each unit will be parallel to and approximately one inch from its respective side. The heater unit area should be at least ¾ the area of the box side. The thermostat heater may be wound so as to surround or be adjacent to the controlling element. The size and power of the thermostat heater will have to be determined by experiment.

The total heating power of the box heaters should be considered next. The power used will depend partly on the amount of insulation used in the outer box. The heater power should be adjusted high enough to maintain the correct operating temperature of the box when operated at the lowest ambient temperature to be encountered, and low enough so "over-shooting" of operating temperature will not occur when operated at the highest ambient temperature. It will be found that the actual heating power is not critical if the thermostat heater is correctly adjusted. As a matter of fact, the heater power can vary or the ambient temperature can vary within reasonable limits and the correct operating temperature of the box can be maintained if the thermostat heater is correct.

Correct adjustment of the heater power and thermostat will be indicated by short "on" and "off" periods of the thermostat (complete thermostat cycle), no "over-shooting" of operating temperature during the warm-up period, and no "over-shooting" when the heater power or ambient temperature is increased within limits. With an increase in ambient temperature, the "off" time should remain constant and the "on" time should decrease. If the "off" time increases appreciably with an increase in ambient temperature, an effort should be made to reduce the thermal impedance between the thermostat heater and the thermostat controlling element. The shorter the thermostat cycle, the smaller the thermal smoothing impedance Z_w can be, that is, the insulation thickness of the inner box. For thermostat cycles of 1 minute or less, insulation may not be necessary in the inner box B, to maintain a non-fluctuating temperature within the box.

As an example of the performance that may be expected, we will assume an inner box, B, to be 5 inches outside dimension all sides, made of 1/16 inch aluminum, and lined with ¼ inch thick celotex. This box will contain one crystal. The outer box of metal will be 9 inches inside dimension, all sides lined with ½ inch thick celotex. See Fig. 1A for suggested type of construction. The inner box operating temperature is assumed to be 55°C. Six heater units of the open "grill" or "card" type will be used, each having a rating of approximately 50 watts. These will be connected series-parallel (Fig. 2B). Each unit will then dissipate approximately 5½ watts, making a total heater power of 6x5½ or approximately 33 watts.

A mercury thermostat which will make contact at 55°C. will be used. The mercury bulb is placed between the heater and the inner box wall as close to the wall as possible. If the thermostat is not also a thermometer, the thermometer bulb should be placed in the same effective location. At an ambient temperature of 25°C., the initial warm-up period when the thermostat will start operating will be approximately one to one and one-half hours and the temperature within the box will stabilize after four hours. The temperature at the thermostat bulb should not vary more than .2°C. over a complete thermostat cycle, approximately 1½ minutes, and the temperature within the box should remain constant through an ambient temperature range of from 10°C. to 50°C. A twenty per-cent line voltage change should not affect the inner box temperature, if the ambient is constant.

Due to the wide variety of applications, operating conditions, and requirements of an oven of this type, no rules or formulas can be set forth for use in its design and, therefore, a certain amount of "cut and try" will have to be used in each individual case. The methods and results as outlined herein are based on fundamental principles and actual experience of the author.

It should be noted that if any control shafts are used for components within the inner box, those shafts should be of non-metallic material such as bakelite or fiber. Any parts used that will be in contact with both the inner and outer box should be non-metallic, the reason being obvious in that a metallic part would furnish a low thermal impedance path between the inner box and the ambient temperature.

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