A NEW ABSOLUTE NOISE THERMOMETER AT LOW TEMPERATURES[1]

H. J. FINK[2]

ABSTRACT

If three resistors, which are kept at different temperatures, are arranged in form of a π network and if two of the thermal noise voltages appearing across the π network are multiplied together and averaged with respect to time, then under certain conditions the correlation between those voltages can be made zero. This condition is used to calculate the temperature of one noise source provided all the resistance values and the other temperatures are known. A noise thermometer of this kind was constructed which is capable of measuring temperatures below approximately 140° K. The boiling points of liquid oxygen and liquid nitrogen were determined absolutely within 0.2%. Between 1.3° K and 4.2° K the thermometer had to be calibrated due to errors arising in the equipment and the measured temperatures were then accurate within ±1%.

I. INTRODUCTION

This paper deals with the construction of a thermometer which makes use of the thermal fluctuations of voltage across an impedance to measure absolutely temperatures below approximately 140° K. Preliminary investigations were carried out for such a device to measure accurately temperatures in the liquid helium region.

According to Nyquist's (1928) law the mean-square voltage fluctuations arising from the thermal agitation of the electrons across an impedance, Z, are given by:

$$\overline{v^2} = 4kT\,\mathrm{Re}[Z]\,p(f, T)\,df, \tag{1}$$

where k is Boltzmann's constant, T the absolute temperature, Re[Z] is the real part of the complex impedance, Z, $p(f, T)$ the Planck factor, and df the frequency interval in which the measurements are performed. The above formula can be derived from the equipartition law and the second law of thermodynamics and the available noise power is a universal function of the frequency and the absolute temperature (see also Van der Ziel 1954). Equation (1) has also been proved for models which describe the random motion of the electrons in a conductor (Bernamont 1937; Bakker and Heller 1939; Spenke 1939). Nyquist's theorem can also be proved for the one-dimensional form of black-body radiation (Burgess 1941) which is received by an antenna kept in a sphere at uniform temperature. The thermodynamic method has the merit that it is independent of the mechanism causing the noise.

A number of papers have been published (Lawson and Long 1946; Brown and MacDonald 1946; Gerjuoy and Forrester 1947; Cook, Greenspan, and Wussler 1948) which suggests the possibility of using thermal fluctuations of

[1]Manuscript received July 15, 1959.
Contribution from the Department of Physics, University of British Columbia, Vancouver, British Columbia.
[2]Present address: The Clarendon Laboratory, Oxford, England.

voltage across an impedance to measure low temperatures but they do not propose any practical scheme for a thermometer of this kind and no serious attempt has been reported which indicates that such an experiment has been performed at low temperature.

In 1946 Dicke *et al.* reported a radiometer which measures thermal radiation at microwave frequencies. This method is essentially a commutation comparison technique which compares the unknown noise with that of a standard source. The radiometer has been used for observations of microwave radiation from the sun and the moon and for the measurement of atmospheric absorption at several microwave frequencies. Garrison and Lawson (1949) developed an absolute noise thermometer of the Dicke type to measure high temperatures. A chopper at the input of the amplifier is used to connect alternately the thermometer resistor and a resistor at ambient temperature (standard noise source). The principal limitation of such a switching device for comparison of noise voltages is the variation in contact potential of the chopper. Also the ultimate sensitivity of such a thermometer depends upon the noise-signal-to-amplifier-noise ratio. Aumont and Romand (1954) attempted an improvement of Garrison's and Lawson's thermometer, but the final results have not yet been reported. The National Physical Laboratory (1957) reports also an improved noise thermometer for high temperatures ($\sim$1100° C) based on the switching technique which is capable of comparing noise voltages to 0.05%. Cade (1958) uses an electronic switch instead of a chopper.

To avoid any switching device at the inputs of the amplifier and to make noise measurements virtually independent of the amplifier noise, one can arrange three resistors, which are kept at different temperatures, in form of a π network; and if now two of the thermal noise voltages appearing across the network are multiplied together and averaged with respect to time, then under certain conditions the correlation between those voltages can be made zero. From this condition one can calculate the temperature of one noise source,

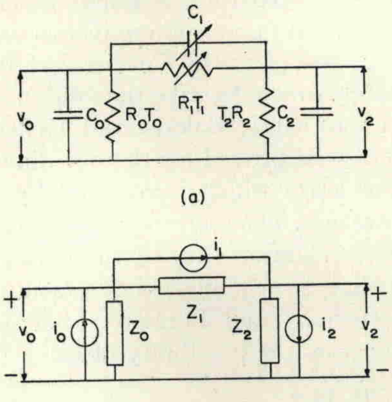

FIG. 1. (*a*) The π network as used to correlate noise between R_0 and R_2 via R_1.
(*b*) The block diagram and the equivalent noise current sources of the π network.