IV. Resolution

Equation (6) shows that, for high resolution in the system, ω should be small and R_y/R_x large. However, from (8) it appears that it is C_xR_y that is to be made large and the frequency is arbitrary. Choosing all R's to be of the same order (10^4 Ω, say) $C_x = 10^{-7}$ F, $A = 4 \times 10^{-4}$ square m and with $k = 10^{-9}$ units, the output can be as large as 1 mV per 10^{-12} mm for a supply of 1 V.

It is imperative that all the resistors and capacitors are to be of the low-tolerance type with the capacitors having negligible leakage.

The resolution is limited by noise in such a sensitive system. In the proposed scheme, the electrical noise is largely determined by the operational amplifier (OA) and the supply voltage. OA's are, therefore, to be chosen to have very low-noise figures. Selection of matched systems would also ensure low drift. If there exists a nominal initial displacement of x_i, the supply voltage is V_i and the noise figure is N_A, the noise equivalent displacement (NED) is given by

$$d_n = \frac{x_i}{V_i} N_A. \tag{9a}$$

The usual value of N_A is about 2 μV [6] such that larger V_i and a smaller x_i would make NED negligible. However, a more practical way of NED calculation follows from the relation

$$d_n = \frac{d}{V_i}\sqrt{4KTf_nR_n} \tag{9b}$$

where f_n is the noise bandwidth and R_n is the equivalent resistor for noise calculation. Data indicate a noise bandwidth of not more than 1 Hz [6] and, for a $d = 0.5$ mm and a supply of 1 V, $d_n = 5 \times 10^{-11}$ mm. This, therefore, becomes the limit of the resolution.

V. Results and Discussion

The circuit was tested for linearity with simulated displacement. Special OA blocks were used for the purpose of matching. The resistances (all of the order of 10^4 Ω having 1-percent tolerance and R_1, R_3, and R_7) were trimmed for constraints (2) and (5b). Initially, R_x and r_2 were kept for verification, with R_y providing the trim. The input frequency was kept at 1 kHz. Then, for frequency independence, R_x and r_2 were replaced by capacitors of low leakage and a nominal value of 0.1 μF having 2-percent tolerance. Initial balancing was performed with a pair of identical high-quality capacitors connected like the probe and a switching arrangement was provided to bring in this pair or the probe. Linearity results were extremely satisfactory in the first instance. In the latter case, the test showed a deviation from the ideal response which increased with decreasing frequency. However, increasing the values of C_x and C_r, some improvement was observed.

The deviation arises because of the leakage in the capacitors C_x and C_r. If the leakage resistances of C_x and C_r are R_x and r_2, respectively, one can easily show that, in view of the constraints (5a) and (7), the transfer function is readily written as

$$\frac{V_o(s)}{V_i(s)} = \frac{2R_y}{skAR_x}(1 + sC_xR_x)\frac{(R_1 + R_2)}{R_1^2}x. \tag{10}$$

From (8) and (10) the ratio of nonideal V_o to ideal V_o can be easily obtained as

$$\rho(s) = 1 + 1/(sC_xR_x) \tag{11}$$

showing its nature of variation with frequency. Also the deviation has a 90° phase shift and increases with decreasing frequency. The percentage deviations are plotted in Fig. 2 against ω/ω_o, where $1/\omega_o = C_xR_x$.

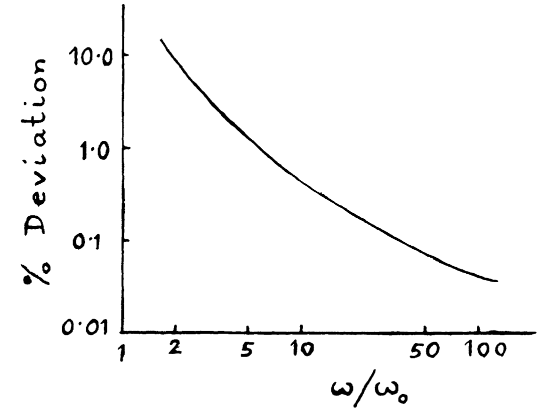

Fig. 2. Plot of percentage deviation versus ω/ω_o.

The magnitude analysis of (11) shows that for $\omega/\omega_o > 100$, the deviation is less than 0.05 percent. Fig. 2 corroborates this. Fortunately R_x is very large such that a reasonable value of C_x would keep the lower limit of the frequency sufficiently low.

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Complex Permittivity of Beryllium Oxide Between 100 and 300 K at 9.3 GHz

WILLIAM C. DAYWITT

***Abstract*—9.3 GHz measurement results of the relative permittivity and loss tangent of beryllium oxide at 99, 145, 223, and 300 K are reported.**

***Keywords*—Beryllium oxide, loss tangent, and relative permittivity.**

I. Introduction

Water condensation on the center conductor of the output connector, and temperature gradients across the cooled termination, both a result of heat conduction along the center conductor, make it difficult to construct an accurate, cryogenic, coaxial noise standard. Both problems are eliminated by using beryllium-oxide beads to support the center conductor [1]. Because of the high thermal conductivity of BeO (shown in

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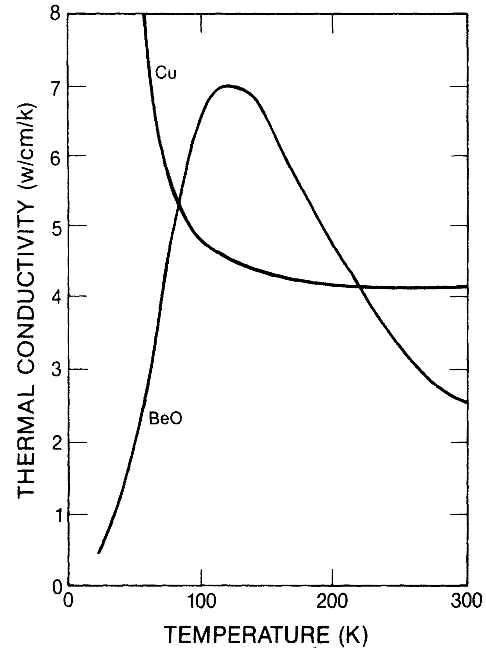

Fig. 1. The thermal conductivity of copper and beryllium oxide versus temperature.

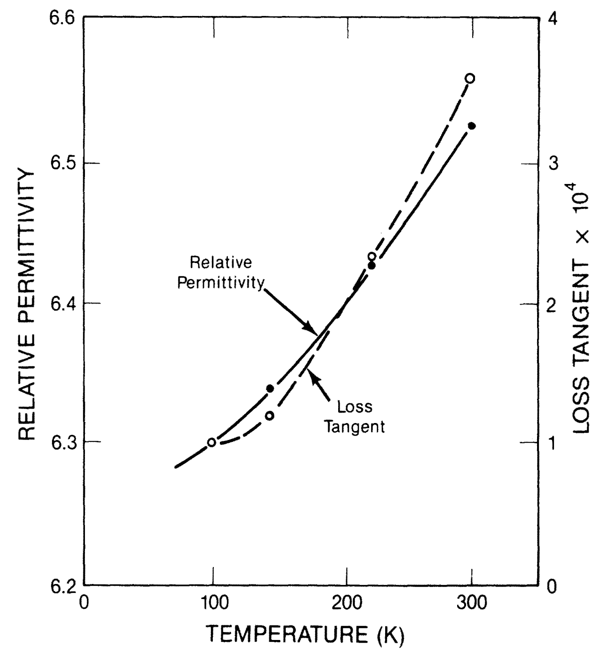

Fig. 2. The relative permittivity and loss tangent of cold-pressed (2.85 g/cm^3) beryllim oxide versus temperature at 9.3 GHz.

TABLE I
THE RELATIVE PERMITTIVITY AND LOSS TANGENT OF COLD-PRESSED (2.85 g/cm^3) BERYLLIUM OXIDE VERSUS TEMPERATURE AT 9.3 GHz

Temperature (kelvin)	Relative permittivity	Loss tangent x 10^4
99	6.298	0.99
145	6.337	1.19
223	6.425	2.33
300	6.525	3.58

Fig. 1 compared to copper [2]), the bead supports act as thermal short circuits, locking the center conductor (gold plated, stainless steel) temperature to the temperature of the outer conductor, which is close to room temperature at the output connector and close to the cryogen temperature at the termination. This construction eliminates the problems just mentioned.

The complex permittivity must be accurately known at the average frequency for which the noise standard is designed, the relative permittivity for calculating bead impedance, and the loss tangent for estimating excess noise generated by the beads. Thus, as both the permittivity and loss tangent are sensitive to the material density and temperature, they should be measured for the material and temperatures being used. Previously published data [3] refers to BeO prepared by hot pressing to 2.94 g/cm^3, and agrees very well at room temperature with the present measurements on the cold-pressed, 2.85-g/cm^3 sample when allowance is made for the different densities.

II. MEASUREMENT RESULTS

A standard TE_{011}-mode cavity-resonator technique [4], [5] was used to measure the relative permittivity and loss tangent of a commercially available sample of cold-pressed, 99.5 percent pure BeO with a density of 2.85 g/cm^3. The cylindrical rod sample used in the cavity Q measurements was 6.4 cm in length with a diameter of 0.64 cm, and to reduce losses and increase measurement accuracy, a variable temperature, pure-silver, tunable TE_{01n}-mode resonator was used. The assumed errors [4] in the relative permittivity and loss tangent were 1 and 5 percent, respectively. An extensive analysis [4] correcting for perturbations to the ideal solution for a rod in a resonant cavity and previously coded into a computer program was used to reduce the raw measurement data [5]. The results from the computer output are summarized in Table I from which the graph of Fig. 2 was constructed.

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Improved Temperature-to-Frequency Converters

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***Abstract*—Three alternative feedback networks that can be used in an astable multivibrator for temperature-to-frequency conversion are proposed. Compared to those recently proposed, all of these have fewer components, two have similar performance, whereas the third has im-**

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