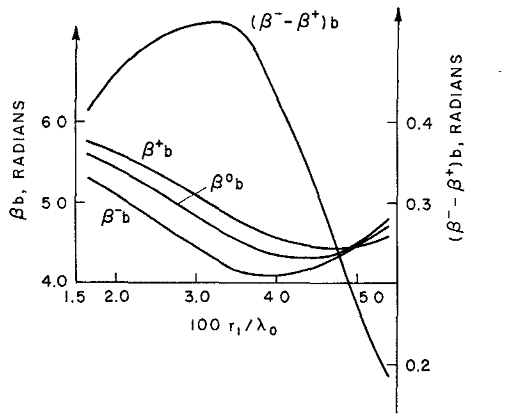

Fig. 4. Normalized propagation factors and differential phase shift versus normalized position of inner toroid.

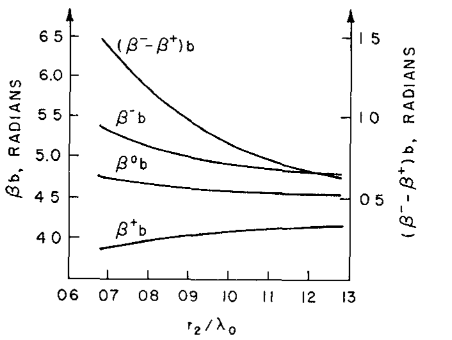

Fig. 5. Normalized propagation factors and differential phase shift versus position of outer toroid.

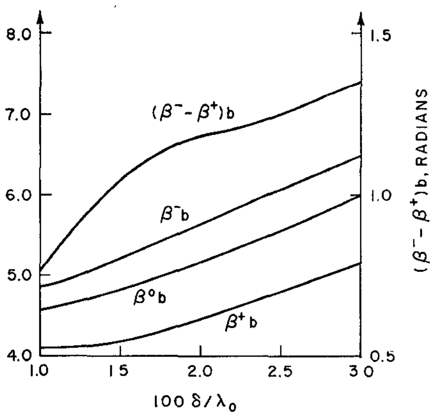

Fig. 6. Normalized propagation factors and differential phase shift versus normalized toroid thickness.

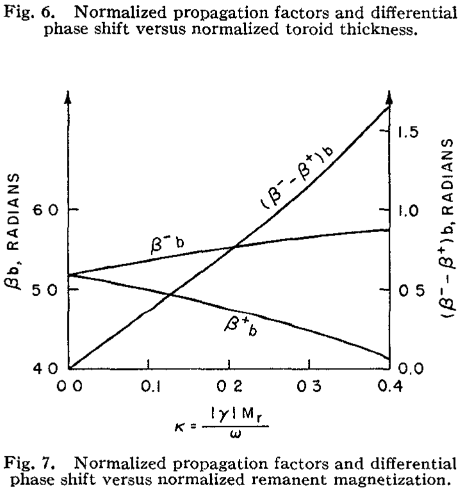

Fig. 7. Normalized propagation factors and differential phase shift versus normalized remanent magnetization.

are not appreciably distorted from those for the isotropic case, these cannot be expected to increase above the loss introduced by the ferrite toroids.

Although all these computations have been performed for particular values and limited ranges of the different parameters involved, it is clear that the form of the variation of the differential phase shift with these parameters will not depend on the particular values chosen. In particular, the almost linear dependence with respect to remanent magnetization and outer toroid location can be used to scale any given value of the differential phase shift for any other values of these parameters. The location of the inner toroid is more critical, but this can be predicted quite accurately by obtaining the lesser of the two loci where the magnetic field is circularly polarized.

Conclusions

For ferrite loaded devices such nonreciprocal parameters as differential phase shift may well prove maximal for the twin-ferrite-toroid loaded waveguide operating in the TE_{01} mode where the toroids can be magnetized at remanence in opposite direction by means of a single axial wire. The differential phase shift is maximized when the inner toroid is positioned near that point where the magnetic field intensity for the unloaded guide is circularly polarized, but this does not hold for the outer toroid. Also the differential phase shift increases almost linearly with increasing normalized remanent magnetization.

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A Reference Noise Standard for Millimeter Waves

W. C. DAYWITT

***Abstract*—The WR15 thermal noise standard that is used as the national reference standard of noise power in the frequency range from 56 to 64 GHz is described in this short paper. The source forms a basis for both the noise-power comparison service and noise-figure service offered by the National Bureau of Standards in this frequency range.**

Introduction

The Electromagnetics Division of the Institute for Basic Standards of the National Bureau of Standards (NBS) offers calibration services of effective noise power emerging from a noise generator.

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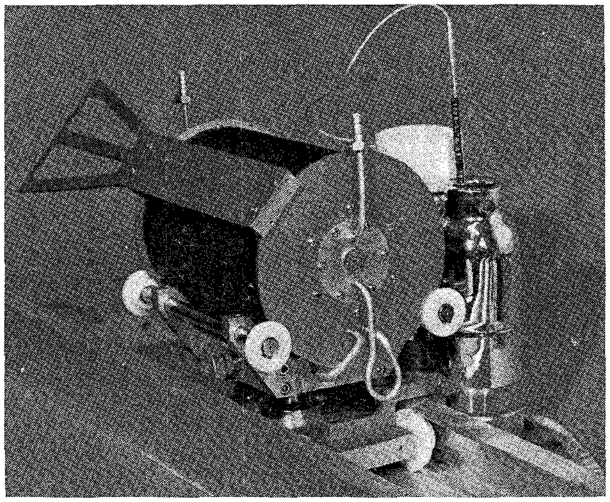

Fig. 1. Close-up view of the WR15 noise standard.

These services are in both coaxial and rectangular waveguides, in frequency bands, and at spot frequencies ranging from 3 MHz to 18 GHz, as detailed in [1]. Addition of the 56- to 64-GHz frequency range (WR15) to these traditional services is now being completed [2]. Along with this extension, a calibration service for the effective input noise temperature of amplifiers operating in this frequency range is also being initiated in WR15 [2]. This new type of service is being prepared in recognition of the fact that a large proportion of the noise generators being calibrated are used in noise-figure measurements, and in response to the expressed needs of "ultimate users." This service, like its more traditional counterpart, is solidly based on accurate primary-reference noise standards like the one described in this short paper.

The new standard features a small oven enclosure providing a rapid warm-up time which allows the standard to be used within 2 h after being turned on. This obviates the time-consuming practice of calibrating secondary gas-discharge standards as is done in the other waveguide bands, and allows a customer's device to be compared directly against the national standard. The output noise temperature of the standard is variable, but is usually operated in the neighborhood of 1210 K and is known to an accuracy of better than ± 2.4 K.

The Ouput Noise Temperature

The noise temperature T at the output flange of the standard is calculated from the following new and more exact formula [3] once the temperature distribution and electrical resistivity along the waveguide are known:

$$T = T_m + \Delta T$$

where ΔT is the correction temperature added to the average termination temperature T_m. The formula for the correction temperature is

$$\Delta T = (T_0 - T_m)(1 - \alpha_0) + \int_0^l T_x'(1 - \alpha_x)\, dx$$

where T_0 is the waveguide temperature at the position of the termination, T_x' is the temperature gradient at position x measured from the termination towards the flange at position l, and α_x is the ratio of the available power at $x = l$ to the given available power at x. The quantity α_x is given by the following formula:

$$\alpha_x = \frac{(1 - |\Gamma_x|^2) e^{-2\int_x^l a_y\, dy}}{1 - |\Gamma_l|^2}$$

where α_x is α_0 when $x = 0$, in which case Γ_0 is the reflection coefficient of the terminating element. Γ_x is the reflection coefficient looking towards the termination from point x in the waveguide. Γ_l is the reflection coefficient looking into the flange towards the termination. Both Γ_x and Γ_l vanish if the load is matched to the characteristic impedance of the waveguide. The factor a_y is the real part of the propagation constant of the waveguide at position y along its length and is a function of the electrical resistivity at that position. This formula does not suffer from the restriction that the termination must be matched to the waveguide, as is the case in previous formulas [4], [5]. Its derivation [3] is based on the use of the available power loss ratio, which is more in keeping with the concept of noise temperature than the attenuation loss that is usually used in the noise-output equation of a thermal noise standard [4], [5]. For the WR15 standard, T_m and ΔT are approximately 1236 K and -26 K, respectively.

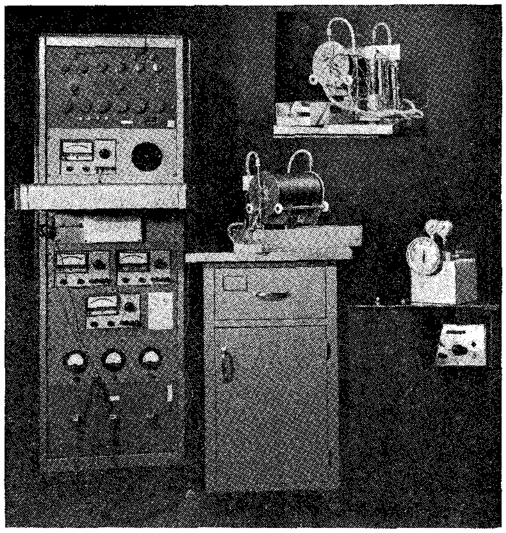

Fig. 2. View of the WR15 noise standard with its heating control and cooling apparatus.

The Noise Standard and Auxiliary Equipment

The standard and its auxiliary heating and cooling apparatus are shown in Figs. 1 and 2. The cylindrical oven heats the termination and waveguide, the small output flange of which is seen in the center of the face at the end of the cylinder. Both the flange and the outer casing of the oven are cooled to room temperature by distilled water from the recirculating water bath, shown at the right in Fig. 2. The output-flange temperature is maintained at 24°C$\pm$0.1°C. The upper right-hand portion of Fig. 2 shows a rear view of the oven with the control and temperature-monitoring thermocouples protruding from the rear plate of the cylinder. The vacuum bottles are the thermocouple reference junction ice baths. The cylindrical oven and bottles sit in a carriage that allows them to be positioned anywhere along a rail like the one shown. The oven contains three servocontrolled heating coils that maintain an appropriate temperature distribution along the waveguide and maintain the waveguide termination at a uniform temperature. The rack on the left in Fig. 2 contains four microvoltmeters, three of which control the heating coils in the oven,

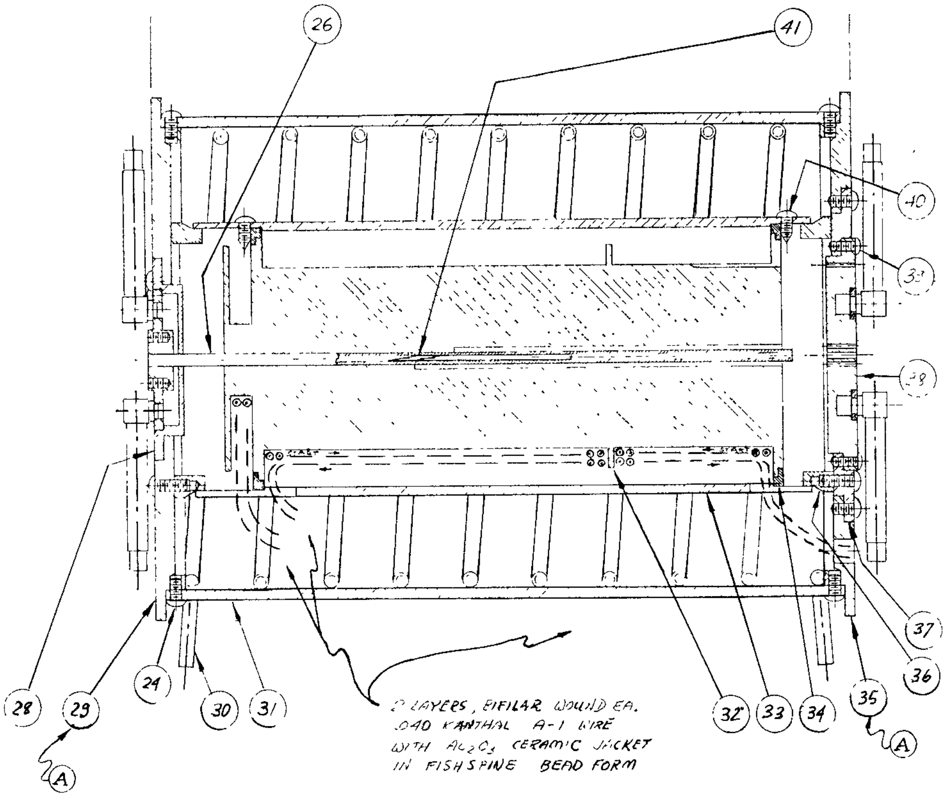

Fig. 3. Assembly drawing of the WR15 noise standard.

the upper one being used as a null detector for the temperature-monitoring potentiometer at the top of the rack.

An assembly drawing of the oven is shown in Fig. 3. The waveguide and termination are items 26 and 41, respectively. The waveguide is manufactured from a platinum 10-percent rhodium alloy to insure a high degree of reliability in predicting its loss characteristics. The termination is a wedge of 40-percent silicon carbide impregnating a beryllium oxide host.

The termination in the waveguide is centered longitudinally in a heat distributor (item 32) to insure a uniform temperature along the termination. The three heating coils (not shown in the drawing) that are wound onto the heat distributor are constructed from a resistive wire stock (5.5 Al, 22 Cr, 0.5 Co, balance Fe) that is considerably more resistant to oxidation than the wire used in previous noise standards [5]. An insulating material (not shown in the drawing) is packed between the heating coils mounted on the heat distributor and the heat distributor sleeve (item 33). The insulating material used is a felt form of zirconium oxide that has an extremely low thermal conductivity. Cooling coils (item 30) are pressed against the inner circumference of the outer casing (item 31) of the oven, and the waveguide flange is cooled by a water jacket (item 28).

Acknowledgment

The author wishes to thank W. F. Foote and E. Campbell, whose design and fabrication efforts were indispensable to the completion of this work.

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Metrological Application of a Stationarity Property in Rectangular Cavities Containing a Dielectric Slab

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***Abstract*—A stationarity property for the resonant frequency of a rectangular cavity as a function of the thickness of a low-loss dielectric slab inserted within is used for the accurate determination of the microwave permittivity of the sample. The accuracy estimated to a few promille in X band has been confirmed by experimentation on a standard material.**

I. Introduction

It is well known that the cavity methods are considered among the best for the accurate measurement of the microwave parameters of dielectric materials. The use of a rectangular cavity containing a dielectric slab has already been reported as a possible structure for such a measurement [1], [2], but until now the most widely recommended configuration remains the cylindrical cavity loaded by an axial-dielectric rod [3], [4]. The use of a stationarity property encountered in the rectangular structure quoted above has given promising results and should revive a new interest in this method.

The basic idea of this stationarity property—which according to us has not yet been considered in the literature—can be explained as follows. A rectangular cavity is considered (Fig. 1), which contains a centrally located dielectric slab (filling the xy section) and which resonates in a TE_{mop} mode; the electric field is thus parallel to the y axis and remains constant along this direction. The sample has a relative permittivity ϵ_r and is assumed to be homogeneous, isotropic, and weakly lossy. For the modes with the third index $p \geq 3$, there is, on each side of the xy median plane, at least one xy plane on which the electric field vanishes. Consequently, if this plane is close to the dielectric interface, the resonant frequency of the cavity will not change at the first order as a function of the sample thickness. It is this stationarity property that will be used below.

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