

6332

USASRDL Technical Report 2273

1752

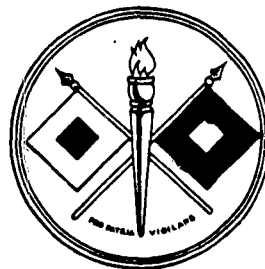
CATALOGED BY ASTIA
AS AD NO. _____

401 705

401705

**DIELECTRIC CONSTANT AND LOSS TANGENT OF MICROWAVE FERRITES
AT ELEVATED TEMPERATURES**

T. Collins
I. Body



April 1962



U. S. ARMY SIGNAL RESEARCH AND DEVELOPMENT LABORATORY
FORT MONMOUTH, NEW JERSEY

U. S. ARMY SIGNAL RESEARCH AND DEVELOPMENT LABORATORY
FORT MONMOUTH, NEW JERSEY

August 1962

USASRD L Technical Report 2273 has been prepared under the supervision of the Electronic Components Department, and is published for the information and guidance of all concerned. Suggestions or criticisms relative to the form, contents, purpose, or use of this publication should be referred to the U. S. Army Signal Research and Development Laboratory, Fort Monmouth, New Jersey, Attn: Chief, Microwave and Induction Devices Branch, Electronic Parts and Materials Division.

J. M. KIMBROUGH, JR.
Colonel, Signal Corps
Commanding

OFFICIAL:
HOWARD W. KILLAM
Major, SigC
Adjutant

DISTRIBUTION:
Special

Qualified requesters may obtain copies of this report from ASTIA.

This report has been released to the Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C., for sale to the general public.

**DIELECTRIC CONSTANT AND LOSS TANGENT OF MICROWAVE FERRITES
AT ELEVATED TEMPERATURES**

Thomas Collins

Isidore Bady

DA TASK NR 3A99-15-001-01

Abstract

Measurements were made of the real part of the dielectric constant and loss tangent of 32 commercial ferrites at x-band at temperatures from 25 C to 250 C, but not exceeding the curie temperature. A modified perturbation technique was used for these measurements. The principal modification included a correction based on the diameter and real part of the dielectric constant. For a sample diameter of 35 mils, the correction ranged from 4 to 10% for dielectric constants of 7 to 16, respectively. Expressions were also derived for the correction due to the contribution of the irises and metal losses to the cavity Q, since the resonant frequency of the cavity changed when a sample was introduced.

The accuracy in the measurement of the real part of the dielectric constant is $\pm 3\%$, where 1% is attributed to the taper and ellipticity of the samples and 2% to the electrical measurement. The accuracy in the measurement of the loss tangent is ± 0.0005 .

**U. S. ARMY SIGNAL RESEARCH AND DEVELOPMENT LABORATORY
FORT MONMOUTH, NEW JERSEY**

CONTENTS

	<i>Page</i>
ABSTRACT	
INTRODUCTION	1
GENERAL TEST METHOD	1
TEST RESULTS	1
DISCUSSION OF TEST METHOD	2
Formulas Based on Perturbation Theory	2
Modifications in Perturbation Theory	2
ACCURACY	7
REFERENCES	7

TABLES

I. K' as a Function of Temperature	8
$\tan \delta$ as a Function of Temperature	9

FIGURES

1. Block Diagram of Test Equipment	10
2. Correction for Calculation of $K' - 1$	11
3. Ferrite Sample in a Coaxial Line: Cross-section View	12
4. Iris Plate and Equivalent Circuits	13

DIELECTRIC CONSTANT AND LOSS TANGENT OF MICROWAVE FERRITES AT ELEVATED TEMPERATURES

INTRODUCTION

The dielectric properties of ferrites play an important role in the behavior of ferrites in microwave devices. Since the dielectric properties of ferrites are affected by temperature, a study was undertaken to determine the variation of the dielectric constant of a large number of commercial ferrites. The temperature range covered was from room temperature to 250°C, but not exceeding the curie temperature. The samples tested were commercially available at the time they were obtained from several commercial suppliers.

The dielectric constant of ferrites is a complex quantity, as shown in Eq. (1).

$$\left(K = K' - jK'' \right) \quad (1)$$

K' is the real part of the dielectric constant, and K'' the imaginary, or dissipative part. The dielectric loss tangent is defined in Eq. (2).

$$\left(\tan \delta = K''/K' \right) \quad (2)$$

The dielectric loss tangent is also called the dissipation factor.

GENERAL TEST METHOD

Measurements were made using a resonant cavity and the perturbation theory, as described by Artman and Tannenwald.¹ This method is also the basis of the "Proposed Method of Test for Complex Dielectric Constant of Nonmetallic Magnetic Materials at Microwave Frequencies," now being prepared by a task group of the American Society for Testing Materials (ASTM). A block diagram of the equipment used is shown in Fig. 1.

The test frequency was approximately 9.4 gigacycles. The samples were in the shape of rods approximately 0.035 inch in diameter and 1¼ inches long. All frequency measurements were made using a frequency counter that measured a known subharmonic of the actual frequency.

TEST RESULTS

Test results for the real part of the dielectric constant, K' , are shown in Table I. At 25°C the actual value of K' is given. At other temperatures, the ratio of K' at that temperature to K' at 25°C is given.

Table I shows that the real part of the dielectric constant generally increased with temperature. The increase, however, was quite small. Sample 1 showed the maximum increase; at 250°C this amounted to 6.2%, which corresponds to a temperature coefficient of approximately 300 parts per million per degree centigrade.

Test results for $\tan \delta$ are shown in Table II. For most samples, $\tan \delta$ increased with increasing temperature. Several cases of $\tan \delta$ decreasing with temperature were noted. These decreases are fairly small and may be due to measurement error.

The composition of the samples and the values of saturation magnetization ($4\pi M_s$) were obtained from the manufacturer's data. The composition gives only the principal elements and may not include small amounts of additives. It will be noted that in some cases there are two samples that behave quite differently, but each has the same indicated composition and very similar saturation magnetization. This could be due to differences in processing techniques and use of additives as practiced by different manufacturers.

DISCUSSION OF TEST METHOD

Formulas Based on Perturbation Theory

In measuring the dielectric constant of the ferrite, the resonant frequency and loss tangent of the empty cavity, and of the cavity with the sample, are determined. By using subscript 1 to denote measurements made on the empty cavity and subscript 2 to denote measurements made on the cavity with the sample, we obtain

$$\frac{F_1 - F_2}{F_1} = 2(K' - 1) \frac{V_s}{V_c} \quad (3)$$

$$(\tan \epsilon_L)_2 - (\tan \epsilon_L)_1 = 4K'' \frac{V_s}{V_c} \quad (4)$$

where V_s and V_c are the volume of the sample and cavity, respectively, and $\tan \epsilon_L$ is the (loaded) loss tangent of the cavity. K' and K'' can be readily determined from the above.

The loaded loss tangent of a cavity is measured by determining the two frequencies, F_h and F_l , on either side of the resonant frequency, F_r , at which the output of the cavity drops by α db. Thus

$$\tan \epsilon_L = \frac{F_h - F_l}{F_r \sqrt{10^{\alpha/10} - 1}} \quad (5)$$

Modifications in Perturbation Theory

1. *Effect of Sample Diameter.*

For the perturbation theory to be accurate, the sample diameter must be sufficiently small. The criteria as to when a diameter is sufficiently small will be discussed below. In practice, sample diameters in the range of 0.03 to 0.05 inch have been used by different laboratories at a test frequency in the range of 9 to 10 gigacycles. The test method for dielectric constant now being proposed by the ASTM calls for a sample diameter of 0.04 inch. As noted above, samples used in connection with this USASRD study had diameters of approximately 0.035 inch. This value was chosen before the ASTM diameter was established.

The equivalent circuit of a dielectric post in a rectangular waveguide is given by Marcuvitz.² For a sample with a diameter of 0.035 inch at a frequency of 9.4 gigacycles, the sample behaves like a shunt capacitive reactance whose normalized magnitude is given in Eq. (6) below.

$$\begin{aligned}
X' &= 0.257 \left[\frac{2 \left(\frac{\lambda}{\pi d} \right)^2}{K' - 1} - 1.84 \right] \\
&= 0.257 \left[\frac{261}{K' - 1} - 1.84 \right].
\end{aligned} \tag{6}$$

If the equation for shunt reactance had been derived on the basis of perturbation theory, the result would be as shown in Eq. (7).

$$X' = \frac{67.1}{K' - 1}. \tag{7}$$

Equation (6) is more accurate.

It can be shown that the error in calculating K' using Eq. (3) is substantially the same as in calculating X' using Eq. (7). A first-order correction to the perturbation theory can, therefore, be obtained from Eq. (6) and (7). Manipulation of these equations yields

$$\frac{(K' - 1)_T}{(K' - 1)_A} = \frac{1}{(1 + .00705 (K' - 1)_A)} \tag{8}$$

$(K' - 1)_T$ is the true value of $(K' - 1)$. $(K' - 1)_A$ is the apparent value of $(K' - 1)$ that would be obtained by using Eq. (3).

Equation (8) applies only for a diameter of 0.035 inch. A correction graph to cover the range of diameters actually encountered is shown in Fig. 2.

2. Consideration of Denominator in Equation Used in Perturbation Theory

Equation (3) shows F_1 in the denominator on the left-hand side, and this is the way the formula is generally used. However, it will now be shown that it is more accurate to use F_2 . For the purpose of simplicity, this will be demonstrated on a coaxial line, as illustrated in Fig. 3. Similar results can be obtained with a rectangular waveguide.

The resonance condition is given by

$$\frac{1}{\sqrt{K'} \tan \sqrt{K'} \beta \Delta \ell} = \tan \beta(\ell - \Delta \ell) \tag{9}$$

where β is the phase constant in the air region. Let $\beta = \beta_0 - \Delta \beta$, where β_0 is the phase constant in the empty cavity at resonance.

$$\frac{1}{\sqrt{K'} \tan \sqrt{K'} \beta \Delta l} = \tan \left[\beta_0 l - l \Delta \beta - \beta_0 \Delta l + \Delta \beta \Delta l \right] \quad (10)$$

$$= \frac{1}{\tan (l \Delta \beta + \beta_0 \Delta l - \Delta \beta \Delta l)}.$$

For small electrical angles, we can write as an approximation,

$$K' \beta \Delta l = l \Delta \beta + \beta_0 \Delta l - \Delta \beta \Delta l \quad (11)$$

$$\frac{\Delta \beta}{\beta} \left(K' - \frac{\beta_0}{\beta} \right) \cdot \frac{\Delta l}{l} \cdot \frac{1}{1 - \frac{\Delta l}{l}} \approx (K' - 1) \frac{\Delta l}{l}. \quad (12)$$

Thus, we obtain

$$\frac{F_1 - F_2}{F_2} \approx (K' - 1) \frac{\Delta l}{l} = (K' - 1) \frac{V_s}{V_c}. \quad (13)$$

It should be noted that the presence of the factor of 2 in Eq. (3) and its lack in Eq. (13) is due to the differences in the field distribution in the rectangular waveguide and in the coaxial line.

3. Effect of Cavity Iris on Measurement of $\tan \delta$

According to Marcuvitz,³ the equivalent circuit of a small iris centered in a thin, transverse, metallic plate in a rectangular waveguide is a small shunt inductor, whose normalized reactance is given by

$$X' = \frac{X}{R_0} = \frac{2\pi d^3}{3ab\lambda_g} = \frac{2\pi d^3 F_c}{3abV} \left[\left(\frac{F}{F_c} \right)^2 - 1 \right]^{1/2}. \quad (14)$$

The meaning of a , b , d , is shown in Fig. 4A. V is the velocity of electromagnetic radiation in free space. The other terms are assumed to be known.

The equivalent circuit of a transmission line containing a cavity is shown in Fig. 4B. R_u is the resistance due to the finite resistivity of the cavity walls. Figure 4C shows the equivalent circuit of the cavity at resonance. R_s is the resistance reflected into the cavity by one of the irises. Its value is given by

$$\frac{R_s}{R_0} = R'_s = \frac{1}{R_0} \operatorname{Re} \left[\frac{jXR_0}{R_0 + jX} \right] \approx (X')^2 \quad (15)$$

$$= \left(\frac{2\pi d^3}{3abV} F_c \right)^2 \left[\left(\frac{F}{F_c} \right)^2 - 1 \right].$$

The current in the resonant cavity is given by

$$I_o = \frac{E \frac{X}{R_o}}{R_u + 2R_s} \quad (16)$$

The voltage across the output iris is, therefore, given by

$$E_o = XI_o = \frac{E(X^2/R_o)}{R_u + 2R_s} = \frac{ER_s}{R_u + 2R_s} \quad (17)$$

This is also the output across the transmission line load. Since in the absence of the cavity the output voltage would have been $E/2$, the transmission loss T , due to the cavity, is

$$T = \frac{2R_s + R_u}{2R_s} \quad (18)$$

Equation (18) will be used later.

Equation (15) shows that R_s is a function of frequency. Since in the process of measuring the dielectric properties of ferrites the resonant frequency of the empty cavity is different from that of the cavity with the sample in it, consideration must be given to the effect of the change in R_s on the measurement of loss tangent.

The loss tangent of a circuit element is given by the well-known equation

$$\text{Loss Tangent} = \frac{\text{energy lost per second}}{2\pi F \text{ energy stored in circuit}} \quad (19)$$

Using the above relation, and taking into account the fact that the energy lost per second due to R_s is proportional to the square of the magnetic field at the iris, we get

$$\tan \delta_{2R_s} = C \frac{(F^2 - F_c^2)^{3/2}}{F^2} \quad (20)$$

where $\tan \delta_{2R_s}$ is the contribution to the loss tangent of the cavity due to the iris only and C is a constant independent of frequency.

Let us define $\Delta(\tan \delta_{2R_s})$ as the difference between the value of $\tan \delta_{2R_s}$ at F_1 and its value at F_2 . To a good approximation, $\Delta(\tan \delta_{2R_s})$ can be obtained by taking the differential of $\tan \delta_{2R_s}$ with respect to frequency. We then have

$$\Delta(\tan \delta_{2R_s}) = \frac{\Delta F}{F} (\tan \delta_{2R_s}) \frac{(F/F_c)^2 + 2}{(F/F_c)^2 - 1} \quad (21)$$

We want to express $\tan \delta_{2R_s}$ in terms of the loaded loss tangent of the cavity, $\tan \delta_L$. It is readily shown that

$$T = \frac{\tan \delta_L}{\tan \delta_{2R_s}}. \quad (22)$$

Using Eqs. (21) and (22), we obtain

$$\Delta(\tan \delta_{2R_s}) = \frac{\Delta F}{F} \frac{(\tan \delta_L)}{T} \cdot \frac{(F/F_c)^2 + 2}{(F/F_c)^2 - 1}. \quad (23)$$

Using Eqs. (3), (4), and (23) and making the approximation $K' \approx K' - 1$, it is readily shown that the error in the $\tan \delta$ due to the irises is given by

$$(\text{Error in } \tan \delta)_{2R_s} = \frac{(\tan \delta_L)}{2T} \cdot \frac{(F/F_c)^2 + 2}{(F/F_c)^2 - 1}. \quad (24)$$

For $F = 9.4$ gigacycles and $F_c = 6.6$ gigacycles, the above equation reduces to

$$(\text{Error in } \tan \delta)_{2R_s} = \frac{2}{T} \tan \delta_L. \quad (25)$$

For the cavity used in these tests, approximate values for $\tan \delta_L$ and T were 3×10^{-4} and 3, respectively. Thus the measured loss tangents of the samples are too high by approximately 2×10^{-4} due to the effect of the cavity irises.

4. Effect of Resistivity of Cavity Walls on Measurement of $\tan \delta$

The frequency dependence of $\tan \delta_u$, the unloaded loss tangent of the empty cavity of the type used in these tests, is shown in Eq. (26).

$$\tan \delta_u = \frac{A(F^2 + B)}{F^{5/2}}. \quad (26)$$

A and B are functions of the waveguide dimensions and the intrinsic resistivity of the cavity metal. There is no need to know the value of A for the purpose of this report. The value of B for the particular cavity used in most of these tests is given later.

In these tests the resonant frequency of the cavity changed due to the insertion of the test sample; the cavity dimensions were not changed. A good approximation to the variation of $\tan \delta_u$ as a function of frequency under this condition can be obtained by taking the derivative of $\tan \delta_u$ with respect to frequency. Manipulation of Eq. (26) yields

$$\frac{\Delta(\tan \delta_u)}{\tan \delta_u} = -\frac{1}{2} \cdot \frac{\Delta F}{F} \frac{1 + 5B/F^2}{1 + B/F^2} \quad (27)$$

At a test frequency of 9.4 gigacycles, and with the cavity used in most of our tests (TE₁₀₁), B/F^2 was less than 0.01. We can, therefore, write

$$\frac{\Delta(\tan \delta_u)}{\tan \delta_u} = -\frac{1}{2} \frac{\Delta F}{F} \quad (28)$$

The above equation can be rewritten as

$$\Delta(\tan \delta_L) = -\frac{1}{2} \frac{\Delta F}{F} \tan \delta_L \left(\frac{T-1}{T} \right) \quad (29)$$

For $\tan \delta_L = 3 \times 10^{-4}$ and $T = 3$, the error caused by the resistivity of the cavity walls is to make the measured loss tangent of the sample too low by approximately 0.5×10^{-4} .

In the actual calculation of the loss tangent of the samples, no corrections were made for the effects of the irises and for the effect of the resistivity of the cavity walls, since their net effect was very small.

ACCURACY

1. *Real Part of Dielectric Constant.* Measurements of the rod diameter were made with a supermicrometer. All samples had some taper along the length and some ellipticity about the cross section. It is estimated that the effective diameter was measured with an accuracy of 1/2%. This would contribute an error of 1% in the measurement of K' .

The resonant frequency was determined by taking the average of the two frequencies at which the output was a given fraction below the resonant output. A frequency counter was used to make all frequency measurements. A maximum error of 2% was attributed to the electrical measurement on the basis of spread in results using different cavities. The maximum overall error in measuring K' was thus 3%.

2. *Tan δ .* As noted previously, the loss tangent of the cavity was determined by using Eq. (5). The measurement was made twice using a different value of α each time. If the two different determinations disagreed by more than 3%, additional measurements were made. A frequency counter was used in making the measurements. The maximum overall error in the loss tangent was taken as 0.0005.

REFERENCES

1. J. O. Artman and P. E. Tannenwald, "Microwave Susceptibility Measurements in Ferrites," Technical Report No. 70, MIT Lincoln Laboratory (1954).
2. N. Marcuvitz, "Wave Guide Handbook," Vol. 10, Radiation Laboratory Series, McGraw Hill (1951), p. 266.
3. Ibid, p. 238.

TABLE I
K' AS A FUNCTION OF TEMPERATURE

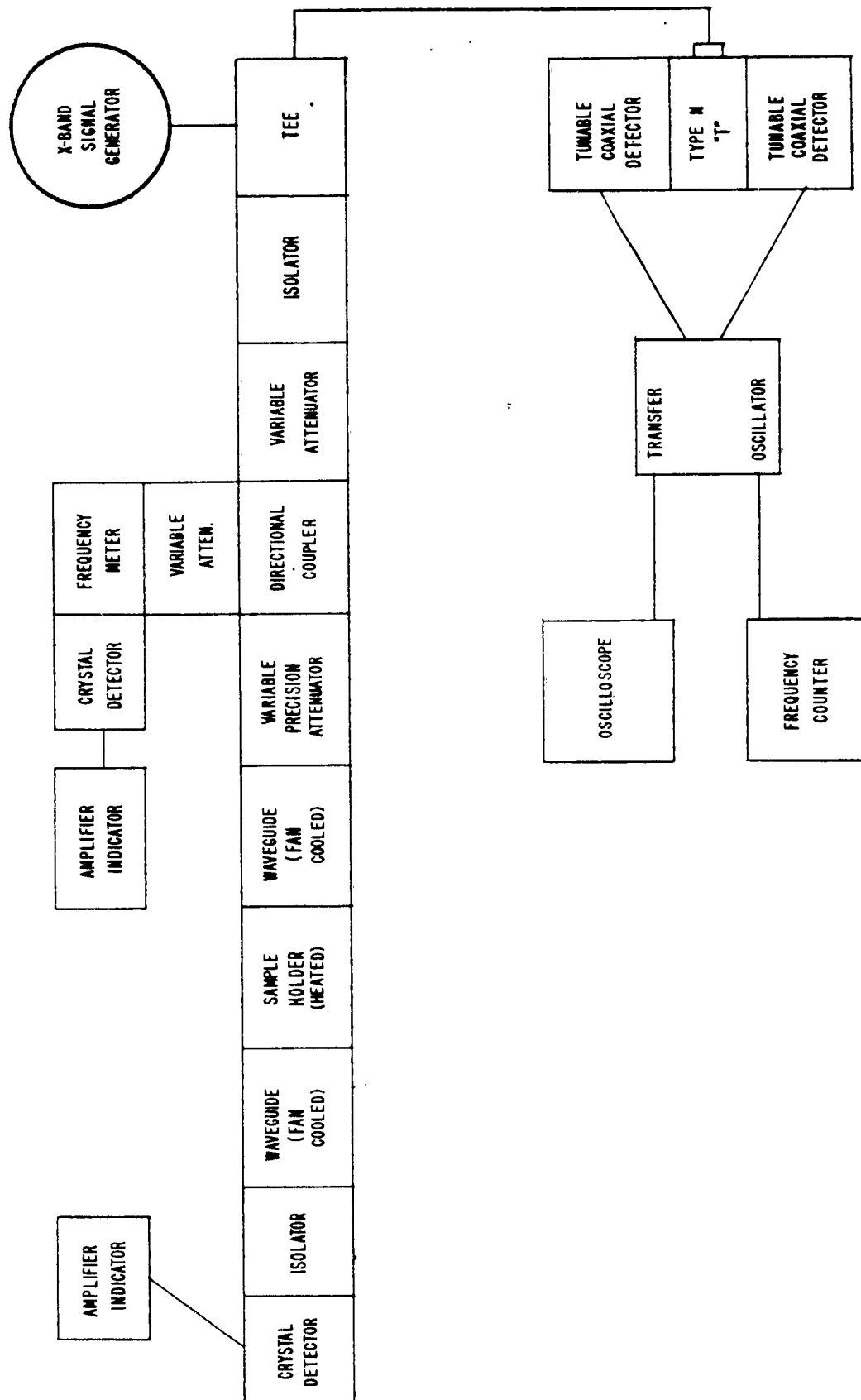
Sample	Composition	$4\pi M_s^*$	25°C K'	100°C Ratio	150°C Ratio	200°C Ratio	250°C Ratio
1	Ni	3300	12.5	1.013	1.027	1.036	1.062
2	NiCo	3150	12.4	1.008	1.019	1.021	1.031
3	NiCo	3000	12.5	1.004	1.003	1.021	1.027
4	NiCo	2400	12.4	.998	1.012	1.024	1.032
5	Ni	2390	8.72	.994	1.009	1.016	1.023
6	MgMn	2300	12.3	1.009	1.018	1.016	---
7	MgMn	2300	12.7	1.007	1.017	1.013	1.034
8	MgMn	2000	12.2	1.006	1.019	1.021	1.037
9	MgMn	1900	12.5	1.007	1.019	1.022	1.032
10	Yig	1880	14.7	1.009	1.015	1.034	1.030
11	MgMn	1800	11.9	1.009	1.015	1.021	1.041
12	MgMn	1800	11.8	1.010	1.023	1.020	1.051
13	NiCoAl	1670	10.9	1.003	1.016	1.019	1.031
14	Ni	1500	8.46	1.005	.986	.981	1.029
15	MgMnAl	1500	11.7	1.000	1.014	1.026	---
16	NiCoAl	1400	12.0	.998	1.009	1.025	1.027
17	NiAl	1300	11.0	1.002	1.017	1.031	1.051
18	MgMnAl	1250	11.2	.994	1.013	---	---
19	MgMnAl	1200	11.3	1.000	1.000	1.025	---
20	MgMnAl	1200	10.7	.988	1.011	---	---
21	MgMnAl	1100	10.4	1.000	1.018	---	---
22	MgMnAl	1030	11.2	.989	1.012	---	---
23	MgMnAl	950	9.26	1.002	1.010	---	---
24	MgMnAl	950	11.2	1.002	1.014	---	---
25	MgMnAl	800	10.8	1.000	1.016	---	---
26	NiAl	750	10.1	.999	1.014	1.030	1.049
27	MgMnAl	700	9.60	1.006	---	---	---
28	Hybrid Garnet	670	14.1	1.005	1.003	---	---
29	MgMnAl	600	11.2	1.006	---	---	---
30	MgMnAl	500	10.8	.997	---	---	---
31	NiAl	440	8.06	1.000	1.020	---	---
32	NiAl	350	8.20	1.007	1.006	---	---

* Commercial Values

Ratio = $\frac{K' \text{ at given temperature}}{K' \text{ at } 25^\circ\text{C}}$

TABLE II
Tan δ AS A FUNCTION OF TEMPERATURE

Sample	Composition	$4\pi M_s^*$	25°C	100°C	150°C	200°C	250°C
1	Ni	3300	.0137	.0205	.0318	.0447	.0715
2	NiCo	3150	.0011	.0006	.0008	.0007	.0009
3	NiCo	3000	.0013	.0008	.0006	.0007	.0075
4	NiCo	2400	.0001	.0004	.0006	.0012	.0022
5	Ni	2390	.0009	.0006	.0005	.0009	.0020
6	MgMn	2300	.0002	.0001	.0003	.0006	---
7	MgMn	2300	.0001	.0001	.0004	.0012	.0020
8	MgMn	2000	.0004	.0002	.0007	.0011	.0032
9	MgMn	1900	.0001	.0001	.0002	.0002	.0011
10	Yig	1880	.0007	.0006	.0006	.0006	.0006
11	MgMn	1800	.0004	.0013	.0025	.0034	.0096
12	MgMn	1800	.0029	.0076	.0149	.0194	.0393
13	NiCoAl	1670	.0007	.0004	.0002	.0001	.0001
14	Ni	1500	.0014	.0018	.0011	.0017	.0021
15	MgMnAl	1500	.0001	.0003	.0007	.0017	---
16	NiCoAl	1400	.0005	.0005	.0006	.0007	.0011
17	NiAl	1300	.0043	.0071	.0106	.0165	.0244
18	MgMnAl	1250	.0001	.0002	.0005	---	---
19	MgMnAl	1200	.0009	.0003	.0006	.0011	---
20	MgMnAl	1200	.0008	.0016	.0027	---	---
21	MgMnAl	1100	.0009	.0008	.0013	---	---
22	MgMnAl	1030	.0001	.0002	.0005	---	---
23	MgMnAl	950	.0002	.0003	.0005	---	---
24	MgMnAl	950	.0002	.0001	.0002	---	---
25	MgMnAl	800	.0001	.0002	.0004	---	---
26	NiAl	750	.0002	.0003	.0008	.0006	.0002
27	MgMnAl	700	.0004	.0003	---	---	---
28	Hybrid Garnet	670	.0014	.0011	.0009	---	---
29	MgMnAl	600	.0001	.0001	---	---	---
30	MgMnAl	500	.0003	.0005	---	---	---
31	NiAl	440	.0004	.0007	.0013	---	---
32	NiAl	350	.0003	.0007	.0004	---	---
*Commercial Values							



BLOCK DIAGRAM OF TEST EQUIPMENT

FIG. 1

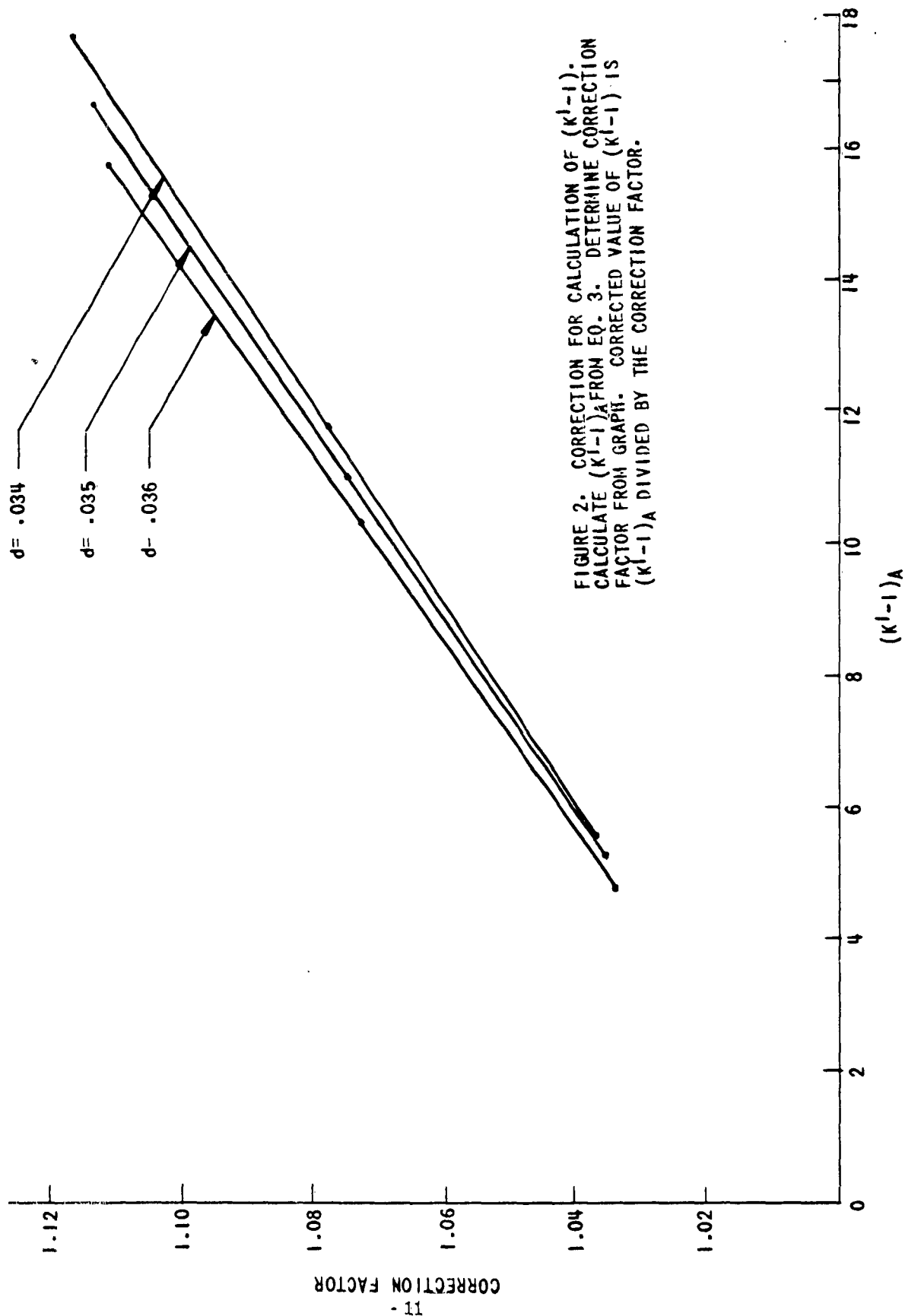


FIGURE 2. CORRECTION FOR CALCULATION OF $(K'-1)$.
 CALCULATE $(K'-1)_A$ FROM EQ. 3. DETERMINE CORRECTION
 FACTOR FROM GRAPH. CORRECTED VALUE OF $(K'-1)$ IS
 $(K'-1)_A$ DIVIDED BY THE CORRECTION FACTOR.

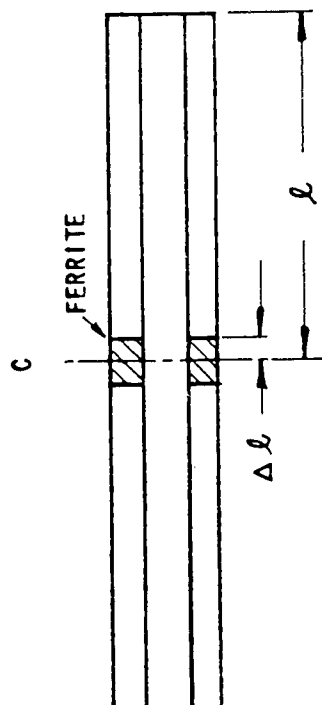


FIGURE 3 FERRITE SAMPLE IN COAXIAL LINE

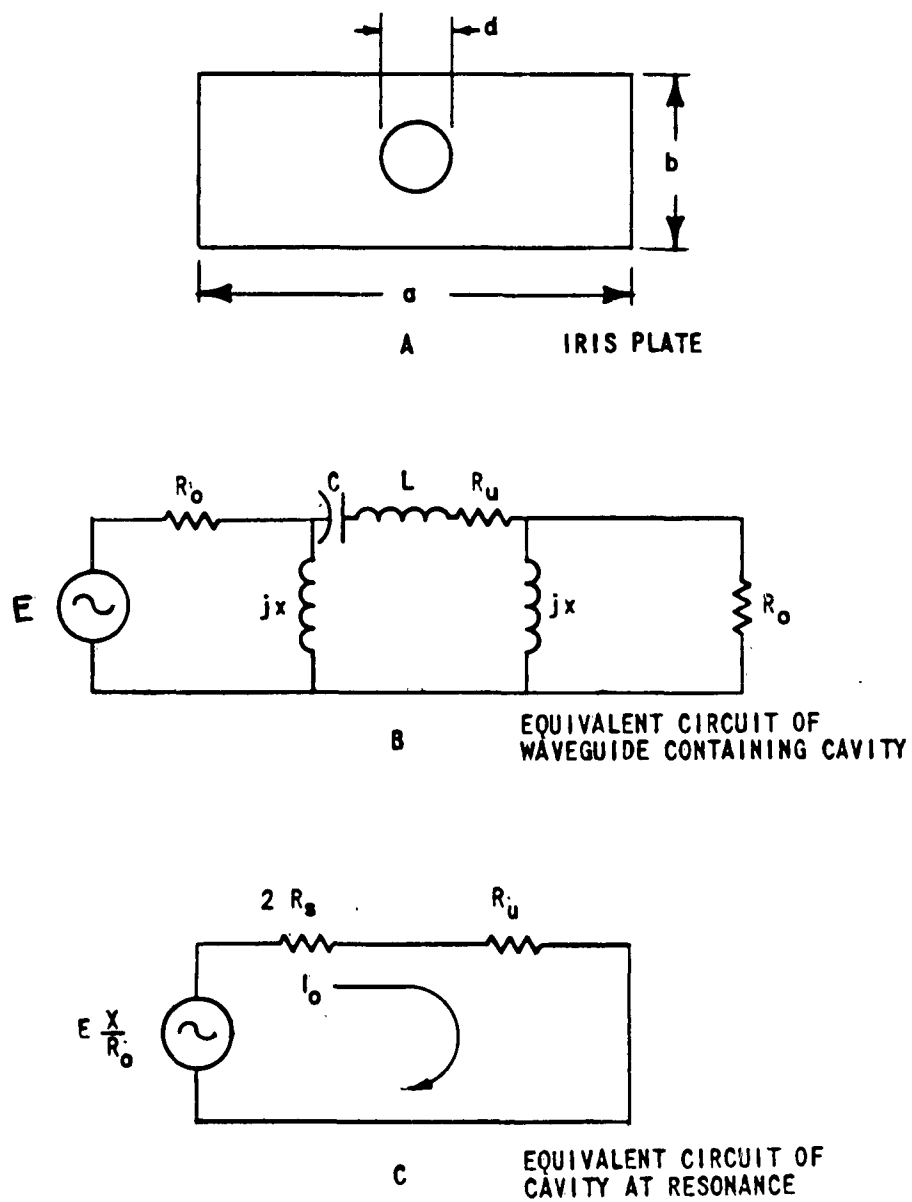


FIGURE 4 IRIS PLATE AND EQUIVALENT CIRCUITS

IDENTIFICATION OF SAMPLES

Sample Nr.	Company	Number
1	Raytheon	R-161
2	Motorola	MO-52
3	Raytheon	R-191
4	Trans-Tech	TT2-100
5	Motorola	MO-42
6	Raytheon	R-151
7	Motorola	MO-22
8	Kearfott	MGM
9	Trans-Tech	TT-390
10	Motorola	MO-12
11	General Ceramics	R-1
12	General Ceramics	R-4
13	Trans-Tech	TT2-118
14	Kearfott	N40
15	Trans-Tech	TT1-105
16	Trans-Tech	TT2-115
17	Kearfott	AN-20
18	Motorola	MO-112
19	General Electric	36 L
20	General Electric	42 H
21	General Ceramics	R-5
22	Motorola	MO-92
23	General Electric	36 H
24	General Electric	42 L
25	Motorola	MO 32
26	Kearfott	AN 25
27	General Ceramics	R-6
28	Motorola	MO-62
29	Trans-Tech	TT-414
30	Trans-Tech	TT1-103
31	Trans-Tech	TT2-113
32	Kearfott	AN 50

DISTRIBUTION

To	Copies
Chief Signal Officer ATTN: SIGRD-4a Department of the Army Washington 25, D. C.	1
Office of the Assistant Secretary of Defense (Research and Engineering) ATTN: Technical Library Room 3E1065, The Pentagon Washington 25, D. C.	1
Chief of Research and Development Department of the Army Washington 25, D. C.	2
Chief, United States Army Security Agency ATTN: ACoS, G4 (Technical Library) Arlington Hall Station Arlington 12, Virginia	1
Commanding General U. S. Army Electronic Proving Ground ATTN: Technical Library Fort Huachuca, Arizona	1
Commanding Officer U. S. Army Signal Missile Support Agency ATTN: SIGWS-AJ White Sands Missile Range, New Mexico	1
Commanding Officer U. S. Army Signal Electronic Research Unit P. O. Box 205 Mountain View, California	1
Commanding Officer U. S. Army Signal Materiel Support Agency ATTN: SIGMS-ADJ Fort Monmouth, New Jersey	1
Directorate of Intelligence ATTN: AFOIN-1b1 Headquarters, United States Air Force Washington 25, D. C.	2
Commander Rome Air Development Center ATTN: RAOTL Griffiss Air Force Base, New York	1

DISTRIBUTION (Cont)

To	Copies
Commander Ground Electronics Engineering Installations Agency ATTN: ROZMEL Griffiss Air Force Base, New York	1
Commander Aeronautical Systems Division ATTN: ASAPRL Wright-Patterson Air Force Base, Ohio	1
Commander U. S. Air Force Security Service ATTN: ESD San Antonio, Texas	1
Commander-in-Chief Strategic Air Command ATTN: DOCER Offutt Air Force Base Nebraska	1
Commander Air Proving Ground Center ATTN: PGAPI Eglin Air Force Base, Florida	1
Commander Air Force Cambridge Research Laboratories ATTN: CRXL Laurence G. Hanscom Field Bedford, Massachusetts	2
Air Force Systems Command, USAF ATTN: AFSC STLO NARDAC Johnsville, Pa.	1
Chief of Naval Research ATTN: Code 427 Department of the Navy Washington 25, D. C.	1
Bureau of Ships Technical Library ATTN: Code 312 Main Navy Building, Room 1528 Washington 25, D. C.	1
Chief, Bureau of Ships ATTN: Code 454 Department of the Navy Washington 25, D. C.	1

DISTRIBUTION (Cont)

To	Copies
Chief, Bureau of Ships ATTN: Code 686B Department of the Navy Washington 25, D. C.	1
Director U. S. Naval Research Laboratory ATTN: Code 3027 Washington 25, D. C.	1
Commanding Officer & Director U. S. Navy Electronics Laboratory ATTN: Library San Diego 52, California	1
Commander U. S. Naval Ordnance Laboratory White Oak Silver Spring 19, Maryland	1
Director U. S. Army Engineer Research & Development Laboratories ATTN: Technical Documents Center Fort Belvoir, Virginia	1
Commanding Officer U. S. Army Chemical Warfare Laboratories ATTN: Technical Library, Building 330 Army Chemical Center, Maryland	1
Commander Armed Services Technical Information Agency ATTN: TIPCR Arlington Hall Station Arlington 12, Virginia	10
Commanding Officer Diamond Ordnance Fuze Laboratories ATTN: Library, Building 92, Room 211 Washington 25, D. C.	1
Signal Corps Liaison Officer Ordnance Tank Automotive Command U. S. Army Ordnance Arsenal Detroit, Center Line, Michigan	1
Army Liaison Officer Naval Research Laboratory ATTN: Code 1071 Washington 25, D. C.	1

DISTRIBUTION (Cont)

To	Copies
Signal Corps Liaison Officer Massachusetts Institute of Technology Building 28, Room 131 77 Massachusetts Avenue Cambridge 39, Massachusetts	1
U. S. Army Signal Liaison Office Aeronautical Systems Division ATTN: ASDL-9 Wright-Patterson Air Force Base Ohio	1
Signal Corps Liaison Officer Lincoln Laboratory P. O. Box 73 Lexington, Massachusetts	1
Signal Corps Liaison Officer Rome Air Development Center ATTN: RAOL Griffiss Air Force Base New York	1
Liaison Officer, Los Angeles Area U. S. Army Signal R&D Laboratory 75 South Grand Avenue, Building 18 Pasadena, California	1
USASRDL Liaison Officer Hq, U. S. Continental Army Command Fort Monroe, Virginia	1
USASIMSA Liaison Engineer Signal Section, Eighth U. S. Army A.P.O. 301 San Francisco, California	1
Chief Scientist, SIGRA/SL-CS, Hq, USASRDL	1
USASMSA Liaison Office, SIGRA/SL-LNW, USASRDL	1
Corps of Engineers Liaison Officer, SIGRA/SL-LNE, USASRDL	1
Marine Corps Liaison Officer, SIGRA/SL-LNR, USASRDL	1
U. S. CONARC LIAISON OFFICER, SIGRA/SL-LNF, USASRDL	2
Commanding Officer, U. S. Army Signal Research Activity, Evans Area	1
Chief, Technical Information Division, Hq, USASRDL	6

DISTRIBUTION (Cont)

To	Copies
Director, Electronic Parts & Materials Division, Electronic Components Dept., USASRDL	2
Director, Electronic Components Dept., USASRDL	2
USASRDL Technical Documents Center, Evans Area	1
Mail and Record Unit Nr. 1	1
Chief, Microwave and Induction Devices Branch, Electronic Parts and Materials Division	35
Commander, Air Force Electronic Systems Division, ATTN: CCRR & CCSD, Laurence G. Hanscom Field, Bedford, Massachusetts	2
Chief, Technical Staff, Electronic Parts and Materials Division, EC Dept.	1

AD Div.
Army Signal Research and Development Laboratory,
Fort Monmouth, New Jersey
DELECTRIC CONSTANT AND LOSS TANGENT OF
MICROWAVE FERRITES AT ELEVATED TEMPERA
by Thomas Collins, Isidore Bady, April 1962, 13 p.
incl. illus. tables, 3 refs.
(USASRDIL Technical Report 2973)
(DA Task 3499-15-001-01) Unclassified Report

Measurements were made of the real part of the dielectric constant and loss tangent of 32 commercial ferrites at χ -band at temperatures from 250°C to 290°C, but not exceeding the curie temperature. A modified perturbation technique was used for these measurements. The principal modification included a correction based on the glimmer and metal part of the dielectric constant. For a sample diameter of 35 mm, the correction ranged from a 4 to 16% for dielectric constants of 7 to 16 respectively. Expressions were also derived for the correction due to the contribution of the inlets and metal losses to the cavity Q , since the resonant frequency of the cavity changed when a sample was introduced. The accuracy in the measurement of the real part of the dielectric constant is $\pm 3\%$ where 1% is attributed to the taper and ellipticity of the samples and 2% to the electrical measurement. The accuracy in the measurement of the loss tangent is ± 0.0005 .

UNCLASSIFIED

I. Collins, T. Bad, I. Army Signal Research and Development Laboratory, Fort Monmouth, N. J.

II. Dielectric Properties
1. Microwave Ferrites
2. Temperature Effects
3. Perturbation Correction

III. DA Task 3A99-15-001-010

I. Collins, T.
Bady, I.

II. Army Signal Research and Development Laboratory,
Fort Monmouth, N. J.

UNCLASSIFIED

AD Div.
Army Research and Development Laboratory,
Fort Monmouth, New Jersey
DELECTRIC CONSTANT AND LOSS TANGENT OF
MICROWAVE FERRITES AT ELEVATED TEMPERA
by Thomas Collins, Isidore Bady, April 1962, 13 p.
incl. illus. tables, 3 refs.
(USASRL Technical Report 2273)
(DA Task 3499-15-001-01)
Unclassified Report

Measurements were made of the real part of the dielectric constant and loss tangent of 22 commercial ferrires at 5-x-band and temperatures from 250°C to 595°C, but not exceeding the curie temperature. A modified perturbation technique was used for these measurements. The principal modification included the use of the dielectric constant and real part of the dielectric constant. For a sample diameter of 35 mm, the correction ranged from 4 to 10% for dielectric constants of 10 to 16 respectively. Expressions were also derived for the correction due to the contribution of the fringes and metal losses to the cavity Q, since the resonant frequency of the cavity changed when a sample was introduced. The accuracy in the measurement of the real part of the dielectric constant is $\pm 3\%$, where 1% is attributed to the taper and ellipticity of the samples and 2% to the electrical measurement. The accuracy in the measurement of the loss tangent is ± 0.0005 .

UNCLASSIFIED

AD Div.
Army Signal Research and Development Laboratory,
Fort Monmouth, New Jersey
DIELECTRIC CONSTANT AND LOSS TANGENT OF
MICROWAVE FERRITES AT ELEVATED TEMPERA-
ture
by Thomas Collins, Isidore Bady, April 1962, 13 p.
incl. illus. tables, 3 refs.
(USASRD Technical Report 2273)
(DA Task 3499-15-001-01)
Unclassified Report

(USASRD Technical Report 2273) Un
(DA Task 3A99-15-001-01)

Measurements were made of the real part of the dielectric constant and loss tangent of 99.999999999% commercial ferries at x-band at temperatures from 250°C to 250°C, but not exceeding the curie temperature. A modified perturbation technique was used for these measurements. The principal modification included a correction based on the diameter and real part of the dielectric constant. For a sample diameter of 350 mils, the correction ranged from 4 to 10% for dielectric constants of 7 to 10 respectively. Expressions were also derived for the correction due to the contribution of the ferrous and metal losses to the cavity Q , since the resonant frequency of the cavity changed when a sample was introduced. The accuracy in the measurement of the real part of the dielectric constant if $\pm 3\%$ where 1% is attributed to the taper and ellipticity of the samples and 2% to the electrical measurement. The accuracy in the measurement of the loss tangent is ± 0.0005 .

UNCLASSIFIED

AD Div.
Army Signal Research and Development Laboratory,
Fort Monmouth, New Jersey
DIELECTRIC CONSTANT AND LOSS TANGENT OF
MICROWAVE FERTILES AT ELEVATED TEMPERA-
ture by Thomas Collins, Isidore Bady, April 1962, 13 p.
incl. illus. tables, 3 refs.
(USASDAD Technical Report 2278)
(DA Task 5A99-15-001-01) Unclassified Report

incl. illus. tables, 3 refs.
(USASRDL Technical Report 2273)
(DA Task 3A99-15-001-01) Un

measurements were made of the real part of the dielectric constant and loss tangent of 32 commercial ferries at x-band at temperatures from 250°C to 250°C, but not exceeding the curie temperature. A modified perturbation technique was used for these measurements. The principal modification included a correction based on the diameter and real part of the dielectric constant. For a sample diameter of 35 mm, the correction ranged from 4 to 10% for dielectric constants of 7 to 16 respectively. Expressions were also derived for the correction due to the contributions of the irises and metal losses to the cavity Q, since the resonant frequency of the cavity changed when a sample was introduced. The accuracy in the measurement of the real part of the dielectric constant if $\pm 3\%$ where 1% is attributed to the taper and ellipticity of the samples and 2% to the electrical measurement. The accuracy in the measurement of the loss tangent is ± 0.0005 .

UNCLASSIFIED