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Monthly Progress Report

P-B1981-8

**DEVELOPMENT OF BROAD-BAND
ELECTROMAGNETIC ABSORBERS FOR ELECTROEXPLOSIVE DEVICES**

by

Paul F. Mohrbach
Robert F. Wood

February 1, 1963 to February 28, 1963

Prepared for

U. S. NAVAL WEAPONS LABORATORY
Dahlgren, Virginia
Code WHR

N178-8087

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ABSTRACT

One of the more critical criteria for acceptability of an attenuator using a ferrite as the absorbing medium is the effect of temperature on both resistance and attenuation. A graph is presented which shows this relationship with temperature varied from -50°C to 225°C .

Attenuation data are presented on FIL attenuator, Model 1, and a schematic drawing illustrates its construction.

In the synthesis of a ferrite material for good attenuation of RF energy at low frequencies, it has been shown that the volume-resistivity plays an important part. It is therefore expedient that a method be devised that measures this parameter with acceptable accuracy. A discussion of several methods is presented with their correlation given in tabular form.

One system is for measuring volume resistivity without making contact with the toroid sample. For samples having resistance of ten ohms or less this system functions properly. For values above ten ohms, the effect of flux leakage prevents obtaining a true reading.

Tantalum oxide doped with manganese oxide shows promise as a lossy dielectric for our ferrite sample. This material when used in tantalum solid electrolytic capacitors has a loss tangent of 0.665 at 20 Kc. Results of our evaluation of commercial tantalum capacitors confirms this lossiness.

A new furnace which permits firing the ferrite bodies at higher temperature was used during this period. When the material is fired at 1450°C for two hours, the final density is independent of molding pressure.

Rapid cooling of the fired ferrite is necessary to obtain high conductivity and loss. This consideration over-shadows the effects of varying the firing atmospheres. The problem of brittle samples continues, aggravated by the rapid cooling.

A high percentage of broken samples allowed only a few loss measurements to be made, and these are not yet complete. We have, nevertheless, presented the available data.

A 0.015 inch layer of 73% barium, 27% strontium titanate was fired in air on a platinum substrate with a maximum firing temperature of 1450°C , held for two hours. A dielectric constant of 2100 was obtained at 1000 cps.

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An attempt to sinter a layer of barium titanate₂ simultaneously with the green ferrite body failed, due to diffusion of the two materials at the firing temperature.

An acryloid slip with 94.5% barium titanate solids was developed for coating of ferrites. A dielectric constant of $K = 40$ was obtained at 1000 cps before sintering.

The calculation of worst-case attenuation from input impedance measurements is only useful for attenuations up to about 20 db. The limitation is imposed by the inherent error and lack of resolution of the measuring equipment.

Theoretically, the worst-case attenuation of a number of cascaded networks should never be less than the sum of the individual worst-case attenuations of the cascaded networks. Experimental results are presented to verify this hypothesis.

A definition of Z_{wc} for symmetrical networks is presented that is quite similar to that of the characteristic impedance. This definition is used to simplify the expressions of the worst-case attenuation of the networks.

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1. INTRODUCTION

The Franklin Institute, under contract to the Naval Weapons Laboratory and Picatinny Arsenal, has during the past several years been active in the search for materials which attenuate RF energy. A significant development has been the carbonyl iron attenuating material which provides, in a one centimeter length, adequate protection for frequencies above 100 megacycles. For frequencies in the range of 1 to 10 megacycles, very little attenuation is afforded in a one centimeter length. Since we do not foresee any radical improvement in the carbonyl iron's attenuating ability at low frequencies, we have discontinued its development on this contract. It has therefore become necessary to seek other materials to obtain the desired attenuation at low frequencies.

An ideal material would have the absorption characteristics shown by curve 1 in Figure 1-1. The probability of there being a single material having a step function of this type is remote. Curve 2 would more reasonably represent the actual characteristics; curve 1 is the goal toward which we work.

At the outset, our research indicated that the class of materials known as ferrites show promise, and particularly so if the dielectric and magnetic properties of these materials can be selected for optimum results. Two basic approaches to the problem are being pursued; one is the development of an ideal model that could be used by a ferrite manufacturer to make a specific ferrite; the second approach is the development of ferrites in our own laboratory. We would point out, however, that other types of materials (such as organic compounds) will also be considered.

Concurrently, we are developing techniques and processes to use ferrites in practical applications. This includes the application of a high-K dielectric to the material or to the conductor to improve its dc

resistance and voltage breakdown properties. Molding of ferrites into such things as plugs for EED's presents a problem because of the high temperatures involved in sintering the ferrites. Methods of molding plugs around wire conductors without the necessity of heat is being investigated.

A supporting instrumentation development program is being conducted concurrently with the materials study. Instrumentation developed to measure attenuation at the frequencies of concern (10 Mc and below) will, in itself be advancing the state of the art. We are interested in true dissipative attenuation; not insertion loss. Since most of our samples are low impedance, this makes matching difficult, and matching has been used in most of our attenuation measuring systems up to now. We have developed two other systems that do not require matching for measuring true attenuation below 10 Mc. These systems are now in the process of being evaluated.

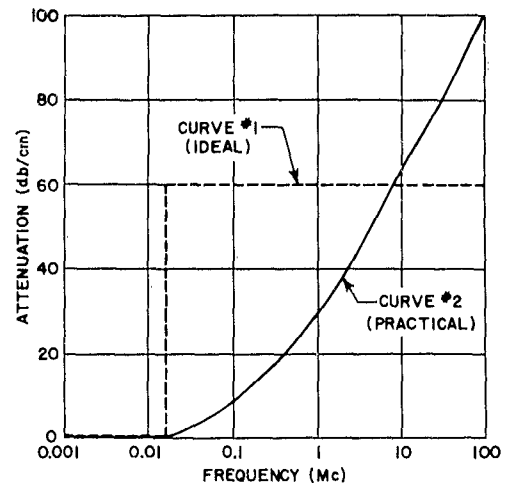


FIG.1-1. IDEAL ATTENUATION CURVE

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2. MATERIAL STUDY

2.1 Material Evaluation - Ferrites

Contributer: Daniel J. Mullen, Jr.

Materials are being sought which are effective in absorbing RF energy at low frequencies. The present study is concerned with evaluating commercially available ferrites of various types. On the basis of our evaluation, we expect to determine which type show the most promise. This knowledge will be used to aid in the synthesis of a material as nearly ideal as possible. From this material, we will attempt to design RF attenuating devices that will truly be broad-band.

2.1.1 Temperature Effects on Resistance and Attenuation Properties of Ferrite

One of the many effects which might mitigate against the use of ferrites in the design of attenuators is temperature. Accordingly, we have conducted a series of tests of a C-27 ferrite in our standard holder. The frequency was held constant at 5 Mc and the temperature of the assembly was varied through the range of -50°C to 255°C . A plot of the attenuation and resistance versus temperature is shown in Figure 2-1 which shows that a increase in attenuation occurs with an increase in temperature while the resistance versus temperature is reversed. This inverse relationship of the attenuation and resistance is not surprising since we know that the ferrites depend a great deal on conductivity.

The maximum temperature that we could use was 225°C (437°F) which is just over the Curie Point (224°C). This was not a limitation of the heating unit but the maximum temperature that the Teflon spacers in the coaxial test fixture could stand. When we exceeded this temperature, the Teflon distorted and changed the impedance of the system.

After the sample was evaluated through the temperature range, it was allowed to return to room temperature. Both its resistance and attenuation returned to the values obtained before the test.

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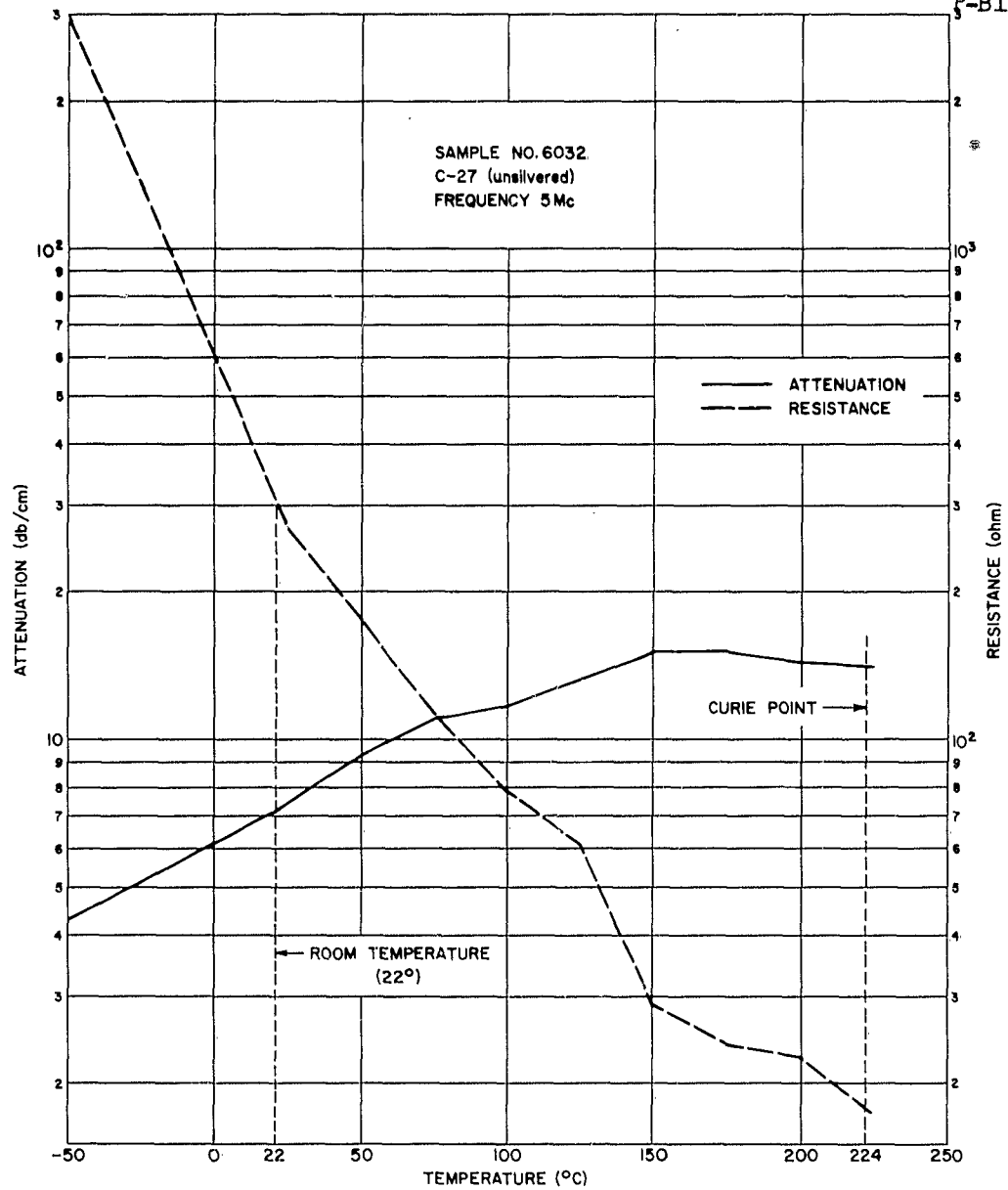


FIG. 2-1. ATTENUATION AND RESISTANCE VERSUS TEMPERATURE

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We do not plan to make any future temperature test on individual ferrites; however, we will probably make similar tests on our packaged ferrite attenuators. These tests will be conducted on contract N178-8102.

2.1.2 Experimental Attenuator

Our first package attenuator was completed and evaluated this month. It is a coaxial device having BNC connectors. A coaxial input, rather than twin-lead, was picked for the initial unit since the coaxial ferrites were immediately available. A schematic drawing showing the arrangement is shown in Figure 2-2. The resistance of this unit is 8 ohms. A graph of the attenuation measurements is shown in Figure 2-3.

A new configuration of the coaxial type is now being designed in which no heating due to soldering wires is required. A group of these will be fabricated and completely evaluated both for attenuating properties, environmental requirements, and any other pertinent test which will aid in establishing a performance profile of the attenuator.

2.1.3 Measurement of Volume Resistivity

One of the criteria that has been established for high attenuation of RF energy through a ferrite medium is low volume resistivity. It is of particular importance to be able to determine the volume resistivity by some means of measuring techniques so that claims for any special sample can be corroborated. Several methods are being investigated. The first of these is strictly a rule of thumb method which consists of baking two electrodes on the periphery of a toroid, as shown in Figure 2-4, and using the probes of a Simpson microammeter #269 to get a measurement of resistance. To obtain the volume resistivity, we take $1/4$ of this reading. Another method, giving values quite close to the first method, is demonstrated as follows:

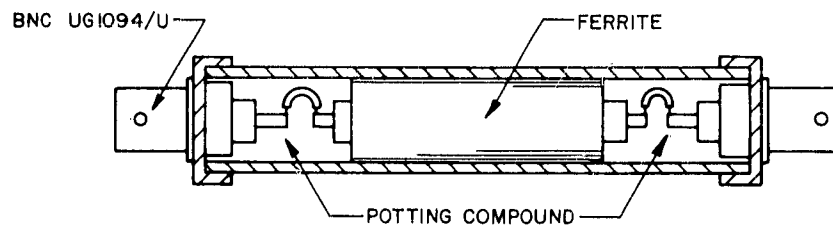


FIG. 2-2. FIL ATTENUATOR

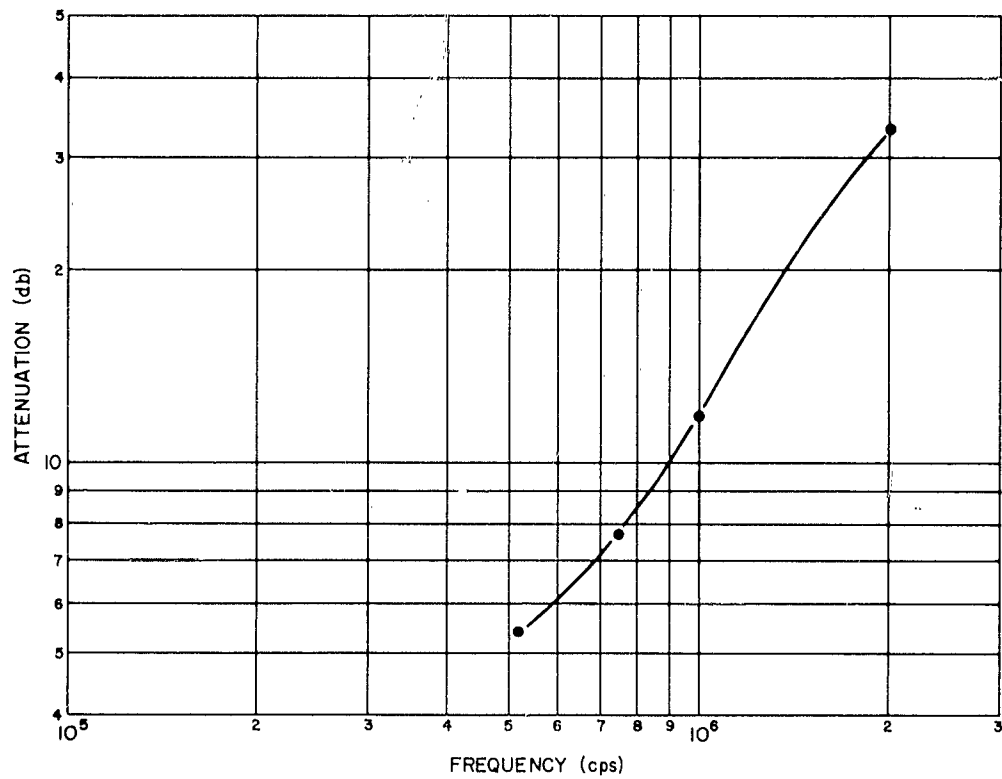


FIG. 2-3. ATTENUATION VERSUS FREQUENCY FIL ATTENUATOR

Resistance = 8 ohms

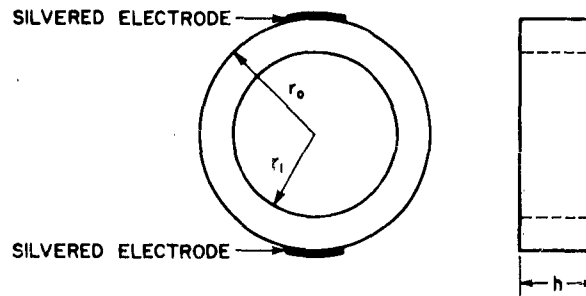


FIG. 2-4. TOROID WITH ELECTRODES

Imagine the ferrite to be distorted into the following configuration:

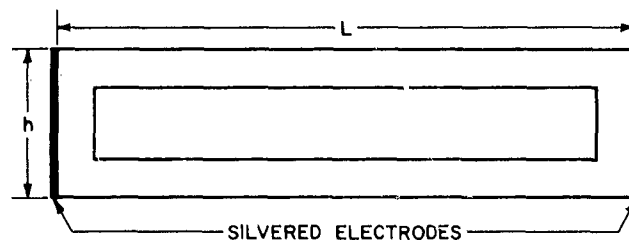


FIG. 2-5. APPROXIMATION OF TOROID AS A CONDUCTOR

With this configuration, we can use the relation

$$R = \rho \frac{L}{A} \quad (2-1)$$

where $L = \frac{(r_i + r_o)}{(2)} \frac{2\pi}{2} = \pi \frac{(r_i + r_o)}{(2)} \text{ (CM)}$

$$A = 2(r_o - r_i) h \text{ (CM}^2\text{)}$$

R = resistance (ohms)

ρ = resistivity (ohm-cm)

The third method entails grinding the inner and outer diametral surfaces, silvering these surfaces, and then mounting the sample in our

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standard coaxial holder. The holder is then inserted in our constant current resistance tester and the resistance read. It can be shown that the volume-resistivity can be expressed as follows.

$$(\text{ohm-cm}) = \frac{2\pi Rh}{\ln \frac{(b)}{(a)}} \quad (2-3)$$

where R = resistance of sample in holder
h = length of toroid in centimeters
b = outside diameter of toroid
a = inside diameter of toroid

Table 2-1 shows a comparison of the first two methods. Data in the third method are not given because of difficulties with silver application.

Table 2-1

COMPARISON OF METHODS FOR MEASURING VOLUME RESISTIVITY

<u>Sample No.</u>	<u>Resistivity (ohm-cm)</u>	
	<u>Method I</u>	<u>Method II</u>
6529	2.25	2.6
6528	1.75	1.4
6962	4.5	4.2

We are at present investigating different silver paints and electrodepositing methods of coating the toroids. We also plan to try evaporation methods of coating the toroids.

2.1.4 Measurement of Volume Resistivity Without Contacting the Specimen

Personnel of the Naval Weapons Laboratory have suggested a method whereby the volume resistivity of a toroid could be obtained without making contact with the specimen. The value of this technique is that the surface contact problem discussed in Section 2.1.3 would be eliminated. A diagram of the system used to prove the proposed method is shown in Figure 2-6.

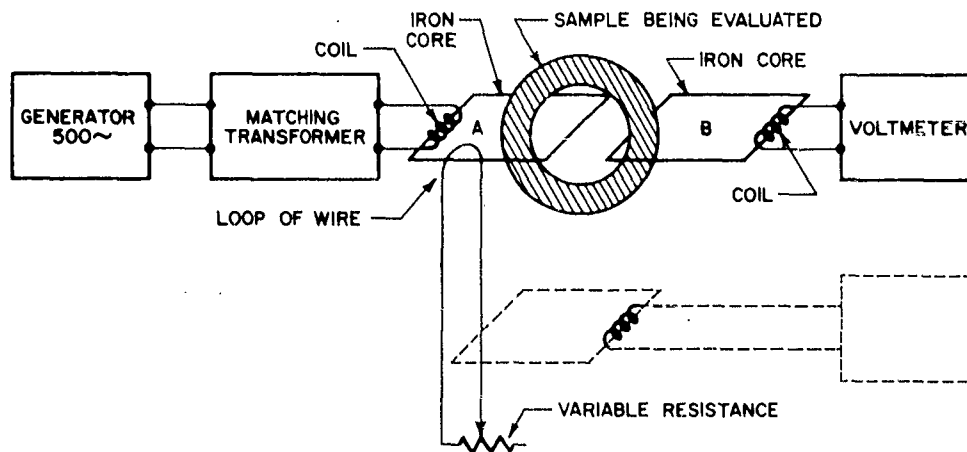


FIG. 2-6. SYSTEM FOR MEASURING VOLUME RESISTIVITY

2.1.4.1 Basic Circuit

The theory behind the method is as follows. Current in Core A induces a current in the specimen being evaluated which in turn induces a current in Core B that is measured by voltmeter. Output of the generator is adjusted until some convenient reading on the voltmeter is obtained. Core B is then moved from the test specimen and placed around a loop of wire that goes through the field of Core A. The variable resistor is adjusted until the voltmeter reading is the same value as

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obtained when Core B was placed around the test specimen. When this occurs, the value of resistance inserted is the resistance of the sample, measured circumferentially. Resistivity (ρ) is then calculated using equation 2-4

$$\rho = R \frac{h \ln \left[\frac{r_o}{r_i} \right]}{2\pi} \quad (2-4)$$

where H = specimen length
 r_o = outside diameter
 r_i = inside diameter
 R = measure value of variable resistor

2.1.4.2 Test Results

As a method of checking out the system we replaced the toroid sample with a loop of copper wire that contained a one-ohm resistor. The variable resistor was adjusted until the second reading of the voltmeter agreed with the initial setting. A measurement of one ohm was obtained. This technique was repeated using two ohms and ten ohms. Both values were accurately measured.

When values greater than ten ohms were inserted in the loop, the indicated resistance became approximately 0.5 ohms. The reason for this is that high resistance cuts down the current in the loop which in turn reduces the flux that links the voltmeter coil to the test specimen. The leakage flux between the two iron cores now becomes a dominating factor, so that the variable resistor determines the current due to stray flux linkage rather than that induced by Core A.

Since the samples that we are measuring will be about 50 ohms, this system will not work without greater refinements. Higher μ cores and proper shielding would probably make this technique feasible. We do not plan, however, to pursue this technique any further at this time.

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2.2 Material Evaluation - Tantalum Oxide

In our search for new attenuating or insulating materials our attention has been directed to tantalum oxide, as a lossy insulating material rather than an attenuating material. In particular, we are interested in tantalum oxide doped with manganese dioxide (MnO_2). These are the principal ingredients in tantalum solid electrolytic capacitors.

Data obtained on attenuating versus frequency for a feed-through tantalum capacitor indicates that they are extremely lossy⁽¹⁾. McLean⁽²⁾ has shown that high losses are to be expected in a tantalum solid electrolytic capacitor. Table 2-2 is extracted from his article.

Table 2-2
TAN δ VERSUS FREQUENCY⁽³⁾

<u>Test No.</u>	<u>Frequency (Kc)</u>	<u>Tan δ</u>
1	0.05	0.0215
2	0.1	0.0224
3	1.0	0.0564
4	5.0	0.196
5	10.0	0.394
6	20.0	0.664

(1) These data were obtained on Contract NL78-8102 and are reported in Report P-B1980-8.

(2) D. A. McLean, "The A-C Properties of Tantalum Solid Electrolytic Capacitors," Journal of the Electrochemical Society; Volume 108, No. 1 (January 1961), p. 48.

(3) For 50 μf capacitor.

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Of special interest to us is that the loss tangent ($\tan \delta$) rises to 0.664 at 30 Kc. This suggests the use of this material as a lossy dielectric for insulating our ferrite samples. We are now looking into the feasibility for such a use.

2.3 Fabrication of Ferrites

Contributor: Joseph F. Heffron

A new furnace was constructed to produce higher firing temperatures and more reproducible firing conditions. The initial run with this furnace was designed to demonstrate the effect of molding pressure on final density when high firing temperatures were employed. The effect of rapid versus slow cooling of the samples was studied at the same time.

2.3.1 Molding Pressure versus Fired Density

Seven samples of manganese zinc ferrite ($\text{Mn}_{0.67} \text{Zn}_{0.33} \text{Fe}_2\text{O}_4$) were prepared at various pressures and fired in an argon atmosphere. After two hours at 1450°C, they were cooled to 1200°C. At this point, half the samples were removed from the furnace and cooled quickly in a stream of argon; the remaining samples were allowed to cool overnight (approximately 18 hours) in the furnace. An argon atmosphere was maintained during cooling. Results of these tests are shown in Table 2-3.

The data indicates that no increase in density is realized by the use of molding pressures higher than 40,000 psi, with the firing just described, and with either cooling rate. A subsequent test showed no difference in the density of samples pressed at 25,000 psi and 50,000 psi and subjected to a similar firing cycle.

Table 2-3

EFFECT OF MOLDING PRESSURE ON FIRED DENSITY
(Manganese Zinc Ferrites)

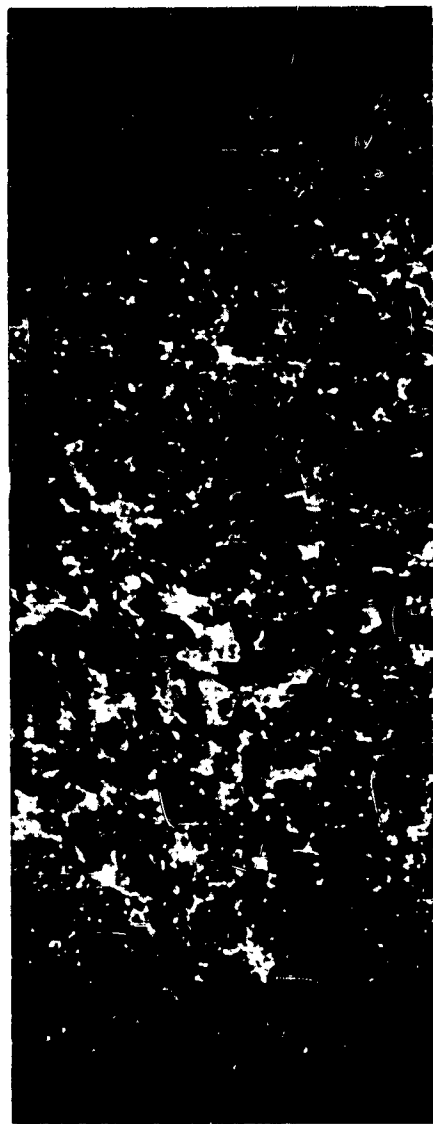
<u>Sample No.</u>	<u>Molding Pressure PSI</u>	<u>Density gm/cm³</u>	<u>Cooling Rate</u>
6955	85,000	4.27	18 hours
6956	40,000	4.20	18 hours
6957	60,000	4.35	18 hours
6958	50,000	4.30	18 hours
6959	40,000	4.24	0.5 hour
6960	50,000	4.22	0.5 hour
6961	60,000	4.28	0.5 hour

2.3.2 Effect of Cooling Rate on Ferrites

All samples, regardless of the rate of cooling, were covered with a coat of shale which was essentially non-conductive. When the samples were ground to size, 0.010 to 0.020 inch of material was removed from the inner and outer surfaces of the sample. For the sample that had been cooled quickly, a large change in resistance was noted after grinding. Samples which measured megohms before grinding measured a few hundred ohms afterwards. Silvering the sample reduced resistance still further.

Samples which were cooled slowly did not exhibit such large resistance changes. Resistances after grinding varied widely, 30,000 ohms being typical value. It was found, however, that these samples were not homogeneous, and that material of lower resistance existed in the center of the sample. The shale, in this case, is not a distinct layer but rather diminishes as the distance from the surface increases.

Figure 2-7 shows the ferrite samples in cross-section. The porosity of the slowly cooled sample (a) decreases as the center is



(a) Slow Cooled



(b) Quick Cooled

FIG. 2-7. CROSS SECTION OF A FIL FERRITE

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approached. This indicates a reaction with some component of the atmosphere which penetrated progressively into the material. However, as the atmosphere was supposedly inert, we must consider the possibility that the reaction is internal, or that nearby refractory material releases sufficient reactive gases at the temperatures involved.

We did not pursue this matter, but confined subsequent tests to rapidly cooled samples. A cross section of typical quickly-cooled sample is shown in Figure 2-7 (b) for purposes of comparison.

A second group of ($\text{Mn}_{0.67} \text{Zn}_{0.33} \text{Fe}_2\text{O}_4$) samples were prepared. After two hours at 1450°C in argon, half the samples were removed from the furnace and cooled quickly in a stream of argon.

The remaining items were allowed to cool to 1200°C in the furnace at which time they too were withdrawn and cooled quickly in argon.

Little difference between these groups was noted. Densities were similar and resistances were uniformly low. (Average 160 ohms measured with probes). All samples were extremely brittle; only one survived the grinding operations.

2.3.3 Effect of Various Firing Atmospheres

Initial efforts employing argon firing atmospheres raised some doubt as to the relative benefits to inert environments. We decided, therefore, to fire in a different gas; nitrogen: and also in air, as a control. The ferrites were fired for two hours in the desired atmosphere at 1450°C , allowed to cool to 1200°C in the furnace, withdrawn, and cooled rapidly in a stream of argon.

The items fired in nitrogen were comparable in density and resistance to those fired in argon but not as brittle.

Samples fired in air differed little in density but showed an increased resistance. (Average 1000 ohms measured with probes). These ferrites were also very brittle. It is felt that the brittleness of the samples produced during this period is due partly to the rapid cooling.

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Perhaps a system which provides controlled and even cooling will be necessary.

2.3.4 Attenuation

Few samples survived the grinding operations necessary for attenuation measurements. Others broke when removed from the measuring holder before tests were complete, and some are being tested at present. For these reasons we do not consider our data complete and shall merely list the results available (Table 2-4) without drawing conclusions.

2.3.5 Conclusions

It appears that lossy ferrites can be produced by cooling the fired bodies rapidly. The firing atmosphere seems relatively unimportant compared to the cooling rate. One drawback to this system is the extreme brittleness of the bodies produced. A system which provides controlled and uniform cooling appears to be necessary.

Within the range tested; 25,000 psi to 85,000 psi, molding pressure has no noticeable effect on fired density. It may be profitable to explore this further, establishing the lowest limit of molding pressure which yields suitable densities, in hope of improving the samples mechanically.

Attenuation data are not complete and measurements are continuing on the samples produced. Generally, resistance is a good indication of attenuation, low-resistance sample having high attenuation. On this basis nearly all quickly cooled samples, most of which broke before testing, would have been comparable to those tested, as their resistances were similar.

Table 2-4

ATTENUATION OF FERRITES ($Mn_{0.67}Zn_{0.33}Fe_2O_4$)

Sample No.	Density gm/cm^3	Resistance Silvered	db/cm	Firing Cycle All samples 2 hours at 1450°C in atmosphere noted.
6957	3.99-4.35 ¹	27 kilohms	5.65 @ 65 mc	Argon. Slow cooling (18 hours)
6959	4.24	11 ohms	177 @ 200 mc	Argon. Quick cooling from 1200°C
6960	4.22	29 ohms	106 @ 200 mc	Argon. Quick cooling from 1200°C
6961	4.28	7 ohms	141 @ 65 mc	Argon. Quick cooling from 1200°C
7073	4.32	11 ohms	120 @ 50 mc	Argon. Quick cooling from 1200°C
7078	4.35	1.1 ohms ²	160 @ 50 mc	Nitrogen. Quick cooling from 1200°C

(1) Density was 3.99 before grinding; 4.35 after. This was sample with porous outer layer.
Low initial density was not typical of group.

(2) This sample was silvered by electroplating. Low resistance has been typical of electroplated samples.

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3. APPLIED STUDIES

3.1 Dielectric Insulators

Contributor: James D. Dunfee

High dielectric constant insulation, applied to conductors, is being studied as a means of increasing the voltage breakdown and insulation resistance of the attenuating assembly. Tests were conducted using tubular capacitor bodies having a dielectric constant of 115 or greater, with a wall thickness of 0.017 inch or less. The tubes were cemented inside high resistance carbonyl iron toroids and test results indicated no loss in attenuation compared to uninsulated assemblies. More recently a mixture of barium titanate powder (85% by weight) in an acryloid binder with an approximate dielectric constant of 30 was applied to conductors and molded on a high resistance carbonyl iron sample. For a 2 to 3 mil coating of this insulation, the voltage breakdown was 500-600 volts, with a loss in attenuation of 20-25% compared with the uninsulated assembly.

Data obtained using this insulation applied to ferrite attenuators indicates that high dielectric constant insulators are far less effective in preventing attenuation losses. Consequently, we have been attempting to sinter barium and other titanates in position on the conductors and the ferrite body itself.

3.1.1 Preparation of High Dielectric Coatings

Last month a 0.006 inch thick coating of BaSrTiO_3 was fired on a platinum substrate at a maximum temperature of 1230°C. A dielectric constant of 1450 at 1000 cps was obtained. This month a 0.015 coating of BaSrTiO_3 (73% Ba-27% Sr) was fired on platinum at 1400°C using a Glo-Bar furnace. The dielectric constant was 2100 at 1000 cps. Both of these coatings were fired in air.

A coating of BaTiO_3 was fired at 1100°C on some sections of prefired ferrites, without visible combining of the two materials.

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We attempted to fire a layer of BaSrTiO_3 on a "green" ferrite compact, thus sintering both materials simultaneously. The test was conducted in air with a maximum temperature of 1400°C . The titanate appears to have diffused into the ferrite and to have migrated across the face of the ferrite toroid, destroying the usual properties of both materials.

Work on cold curing of barium titanate powder in melted carnauba wax was continued during this report period. We have duplicated closely the process as described by the Naval Research Laboratory⁽⁴⁾, but high dielectric constants have not been obtained.

Further experimentation with barium titanate in acryloid binder was resulted in a coating of about $K = 40$, as cured on stainless steel wire. The percentage of binder in this mixture is 5.5%, showing an increase of close to 10% of barium titanate. The coating is lower in physical strength but more suited for applications where the titanate is to be sintered in position since less binder has to be burned away during the heating process.

Silica-insulated carbonyl iron powder was evaluated during early work with iron compacts. Since such a powder exhibited medium resistivity and very high voltage breakdown, the properties of an acryloid binder filled with such particles are being studied as a possible high dielectric insulating coating. Stainless conductors coated with such a mixture have exhibited low resistance and voltage breakdown. The silica mixture used to coat the particles appears to have deteriorated in storage, causing the silica concentration to change in value.

(4) "Cold-Cured Piezoelectric Ceramics" NRL Problems M05-01, Project NR514-000 Task NR514-001.

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4. INSTRUMENTATION

4.1 Measurement of Attenuation

Contributor: Ramie H. Thompson

Previous reports have described the worst-case attenuation measurement system. This system is now in use and a limitation has become apparent. It was found that the upper limit of worst-case attenuation which the system can determine is around 20 db. The actual upper limit depends upon the relationship of the impedances measured and the resolving power of the impedance bridge used to make the measurements. The fact that an upper limit could be expected was mentioned in last month's report; such an expectation can be reached by a purely physical argument. The input parameters to our calculation of worst-case attenuation are the input impedances of one port of our two-port device, when the other port is terminated in two distinct load impedances. Now dissipative attenuation can be regarded as a kind of isolation between input and output ports; if this isolation becomes very great the input impedance will not be affected by the load impedance, and we can therefore state that large values of attenuation correspond to very small changes in input impedance for large changes in load impedance.

A system upper limit will therefore be found when the impedance measuring equipment can no longer resolve the difference between the two measured values of input impedance.

4.1.1 Worst-Case Attenuation or Cascaded Samples

Since the worst-case attenuation of a device is the least possible attenuation that can be exhibited by the device under any circumstances, the worst-case attenuation of a number of cascaded networks should never be less than the sum of the worst-case attenuations of the component networks. As a convenient check of this property, two ferrite samples were mounted in roughly symmetrical holders.

The worst-case attenuation of each sample was determined for each direction of propagation at six frequencies. The samples were then cascaded and the measurements repeated. Table 4-1 shows the results. In no case was the cascaded attenuation less than the sum of the individual attenuations.

4.1.2 A Property of Z_{wc}

In general network theory the characteristic impedance of a symmetrical network may be defined as that impedance which, when used as the termination of the network, causes the input impedance of the network to equal the termination impedance. It has been found that for symmetrical networks Z_{wc} is that impedance which, when used as the termination of the network, causes the input impedance of the network to equal the complex conjugate of the termination impedance. This description of Z_{wc} makes apparent that Z_{wc} and Z_o are the same impedance if either is a pure real number.

An indirect demonstration of the above description of Z_{wc} can be had from Figure 4-1.

If Z_{in} equals Z_L^* (* is read as conjugate), then by inspection,

$$Z_{in} = Z_L^* = Z_L + \frac{Z_2 Z_L + Z_L}{Z_1 + Z_2 + Z_L} \quad (4-1)$$

Simplifying we obtain

$$Z_1 (Z_1 + 2Z_2) = |Z_L|^2 - 2j (Z_1 + Z_2) \text{Im} \{Z_L\} \quad (4-2)$$

if we let

$$Z_1 = X + jY, Z_2 = G + jH, Z_L = K + jL$$

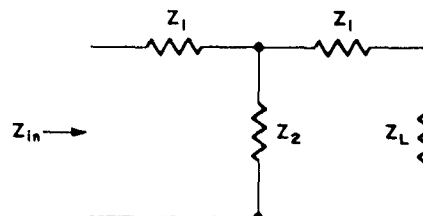


FIG. 4-1. SYMMETRICAL NETWORK WITH LOAD

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and substitute these in Equation 4-2, we can then equate real and imaginary parts to obtain

$$Y = \frac{G(H + 2L) + H(G + 2K)}{-2(G + K)} \quad (4-3)$$

and

$$X^2 + Y^2 + 2Y(H + L) = G(G + 2K) - H(H + 2L) \quad (4-4)$$

then, of 4-3 is substituted in 4-4

$$X = \frac{1}{G + K} \sqrt{G(G + 2K) [(G + K)^2 + L^2]}$$

If Equations 4-3 and 4-5 are expanded and checked against Equation 4-9, of Report P-B1981-3 of this project, we see that the impedance defined by Equations 4-3 and 4-5 is exactly Z_{wc} .

A specific use for this definition of Z_{wc} is the simplification of the expression for the power ratio in a symmetrical T network. This ratio can be written as

$$\frac{P_L}{P_{in}} = \frac{|Z_2|^2}{|Z_1 + Z_2 + Z_L|^2} \frac{\text{Re } \{Z_L\}}{\text{Re } \{Z_{in}\}} \quad (4-6)$$

where Z_1 , Z_2 , Z_{in} , Z_L are shown in Figure 4.1 and P_L is load power, P_{in} the input power. We have defined worst-case attenuation as

$$10 \log \frac{P_L}{P_{in}} \bigg|_{Z_1 = Z_{wc}} \text{ db}_{wc} = 10 \log \frac{|Z_2|^2}{|Z_1 + Z_2 + Z_{wc}|^2} \frac{\text{Re } \{Z_{wc}\}}{\text{Re } \{Z_{in}\}} \quad (4-7)$$

Applying our definition that $Z_{in} = Z_{wc}^*$ when $Z_L = Z_{wc}$, we have

$$\text{db}_{wc} = 20 \log \frac{|Z_2|}{|Z_1 + Z_2 + Z_{wc}|}$$

since

$$\text{Re } \{Z_{wc}\} = \text{Re } \{Z_{wc}\}^*$$

Table 4-1

ATTENUATION OF CASCADED SAMPLES

Freq. in Mc	Worst-Case Attenuation in db					
	Sample 6401		Sample 6396		Samples Cascaded	
	Direction 1	Direction 2	Direction 1	Direction 2	Direction 1	Direction 2
1	.07	.07	.23	.23	.45	.34
3	.45	.47	.73	.74	1.41	1.33
5	.77	.75	1.16	1.16	2.27	2.16
7	1.08	1.04	1.40	1.44	3.07	2.99
10	1.57	1.56	1.77	1.76	4.22	4.11
15	2.22	2.23	2.19	2.22	5.85	5.76
19	2.64	2.65	2.5	2.5	6.84	6.85

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5. CONCLUSIONS AND FUTURE PLANS

Ferrites

Conductive Coatings

The two methods of measuring volume resistivity appear to be valid if the silver coating is good. We have used several types of silver paint (air dry and oven baked) without consistent results. During this next month we plan to look into electroplating of silver and gold as a means of overcoming this difficulty.

One interesting point that comes from the data on measuring volume resistivity is that the rule of thumb method used by Krystinel of measuring the resistance of the sample between the two silver electrodes and then dividing by four does give an approximate value of volume resistivity, for the particular geometry involved.

The method of measuring volume resistivity without making contact with the sample worked very well when the sample resistance was below ten ohms. For resistance values greater than this, cores with higher μ are needed to increase the flux density. Also, a μ metal shield should be placed around the input core (A) and another one around the sensing core (B). This would cut down the flux linkage that now occurs between the two circuits. Rather than becoming involved at this time in designing an instrument for measuring volume resistivity, we will concentrate on silvering of the test specimen.

Making Ferrites

With our present system, the rate at which the fired ferrite body is cooled is the greatest factor affecting the conductivity and attenuation of the sample. This same rapid cooling which yields lossy ferrites, however, also results in very brittle ones. More suitable cooling facilities will be required, as well as determination of optimum cooling rates.

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At the firing temperature employed, 1450°C, high molding pressures are not required to obtain satisfactory densities. Perhaps even lower pressures should be attempted in order to improve the mechanical properties of the ferrites.

Only few attenuation measurements have been made and extensive conclusions can not be drawn. The close relationship of measured attenuation to dc resistance remains evident.

FIL Attenuators

Our first group of 10 ferrite attenuators will be assembled as soon as the ferrite plugs are received. These will be coaxial and have BNC connectors. The next units that will be built will have twin lead and Twinax connectors. Final design of this unit cannot be made until the drawings of the modified Twinax connectors are obtained from NWL.

Tantalum Oxide

The possibility of using the basic ingredients of a tantalum solid electrolytic capacitor as a dielectric coating will be investigated. Further study will be made as to why this material attenuates. At the same time we plan to conduct some experiments using pellets from a commercial capacitor as the insulated assembly. We will place ferrite samples over the pellet and measure the attenuation of the composite assembly.

Dielectric Insulators

Barium titanate can easily be fired as a thin film on platinum substrates, after dip or brush coating on the platinum using an acryloid base slip. Obtaining such a film on nickel wire presents a problem in prevention of oxide formation. We have obtained a container of 2% O₂ - 98% Helium to use for a test with a nickel substrate.

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Further test of coating BaTiO_3 on a sintered ferrite will be conducted to determine feasibility. Controlled atmosphere may also be necessary here. It must be kept in mind that such a second heat treatment will fix the properties of the ferrite, although the first sintering can also play an important role.

A request for more detailed information on the cold cured BaTiO_3 process will be forwarded to the Naval Research Laboratories, so that a conclusion on the utility of such a method can be reached.

Research on all types of insulating coatings with medium to high dielectric constants will be intensified to find an insulation suitable for use with ferrite attenuating materials. We shall attempt to determine the relationship between the conductivity parameter in ferrite attenuators and various dielectric constant insulating materials. Development of a high loss insulating film will also be studied.

Instrumentation

The system for determination of worst-case attenuation from impedance measurements is operational and in use. With the present impedance measuring equipment the system has an upper limit of approximately 20 db. The worst-case attenuation of a device has been shown to be the least possible attenuation that the device can exhibit and exactly equal to the attenuation that would be measured with a perfectly lossless matching system.

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During the next report period we intend to investigate the validity of the conventional transmission line equations for perfectly conducting transmission lines filled with high loss material, and as an outgrowth of this work try to predict the propagation constants of two layered coaxial devices. This configuration may be of considerable interest if one of the layers is a non-conducting dielectric which would raise the dc resistance of the composite device.

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