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E-200-401

PROGRESS REPORT: Proposal No. 11-002-126, Log Serial No. 311, for "Complex Permittivity Measurements of Lunar Samples at Microwave and Millimeter Wavelengths," dated May 22, 1970

MEASUREMENTS TO-DATE

The dielectric constant and loss tangent of Lunar Sample 14163, 164, which is a fine dust, have been measured as a function of both frequency and density. Data have been obtained at 9.375, 24, 35 and 60 GHz. Measurements were made using a modified short-circuit waveguide technique where the rectangular test sample is formed by compressing the powdered material in the shorted waveguide test cell. A block diagram of the 9.375 GHz test equipment is shown in Figure 1. As indicated, the compressed sample rests in the sample holder against the metal plate short-circuit. Extreme care was taken to keep the front surface of the lightly compressed sample parallel with the plane of the short circuit. Careful alignment of the compression mandrel and placement of the slotted section and the sample holder in a vertical plane resulted in more than adequate parallelism.

Sample holders and mandrels were fabricated for each frequency band of interest so that microwave measurements could be made as a function of sample density. The mandrels were machined from high carbon steel to withstand the pressures needed to compress the powdered material to 77 per cent integral density.

RESULTS

The dielectric constant vs. frequency as a function of sample density (Lunar Fine Sample 14163, 164) is tabulated in Table I. These data are plotted in Figures 2, 3, 4, and 5. The straight lines on the density-dielectric curves are the linear least mean squares estimates. At 9.375 GHz it is 0.90, and at 60 GHz it is 0.53. At 9.375 GHz the dielectric constant is 3.59 at a density of 1.71 gm/cm^3 and increases linearly to a value of 4.45 at a density of 2.06 gm/cm^3; the loss tangent remains relatively constant at a value of 0.015.

FUTURE WORK

Complex permittivity measurements will be continued on the Lunar Fine Sample 14163, 164 as a function of both frequency and density. It is also planned to determine the complex permittivity of Lunar Sample 14310 (a solid) at 9.375 GHz. This particular sample, which is rectangular in shape, does not fit into a standard waveguide size, so a special slotted section is being fabricated which will allow permittivity measurements to be made.

In addition to the room temperature measurements, a number of data points will be obtained at 750^{o}F.

TABLE I

Dielectric Constant vs. Frequency as a Function of Density

Density (gm/cm^3)	9.375 GHz	24 GHz	35 GHz	60 GHz
1.587	--	3.01	--	--
1.621	--	3.71	--	--
1.677	--	--	--	3.43
1.697	3.59	--	--	--
1.709	3.54	--	--	--
1.738	3.62	--	--	--
1.762	--	--	--	3.98
1.810	--	--	--	3.87
1.829	--	--	--	4.15
1.831	--	--	--	4.39
1.836	--	--	--	3.74
1.860	--	--	--	4.02
1.880	--	--	--	3.70
1.884	3.96	--	--	--
1.920	4.20	--	4.00	--
1.939	4.17	--	--	--
1.947	--	--	3.99	3.58
2.000	4.31	--	--	--
2.001	--	3.99	--	--
2.001	--	4.11	--	--
2.052	4.38	--	--	--
2.059	4.45	--	--	--
2.084	--	--	4.00	--
2.089	--	--	--	4.57
2.110	--	--	4.15	--
2.153	--	4.22	--	--
2.164	--	4.38	--	--

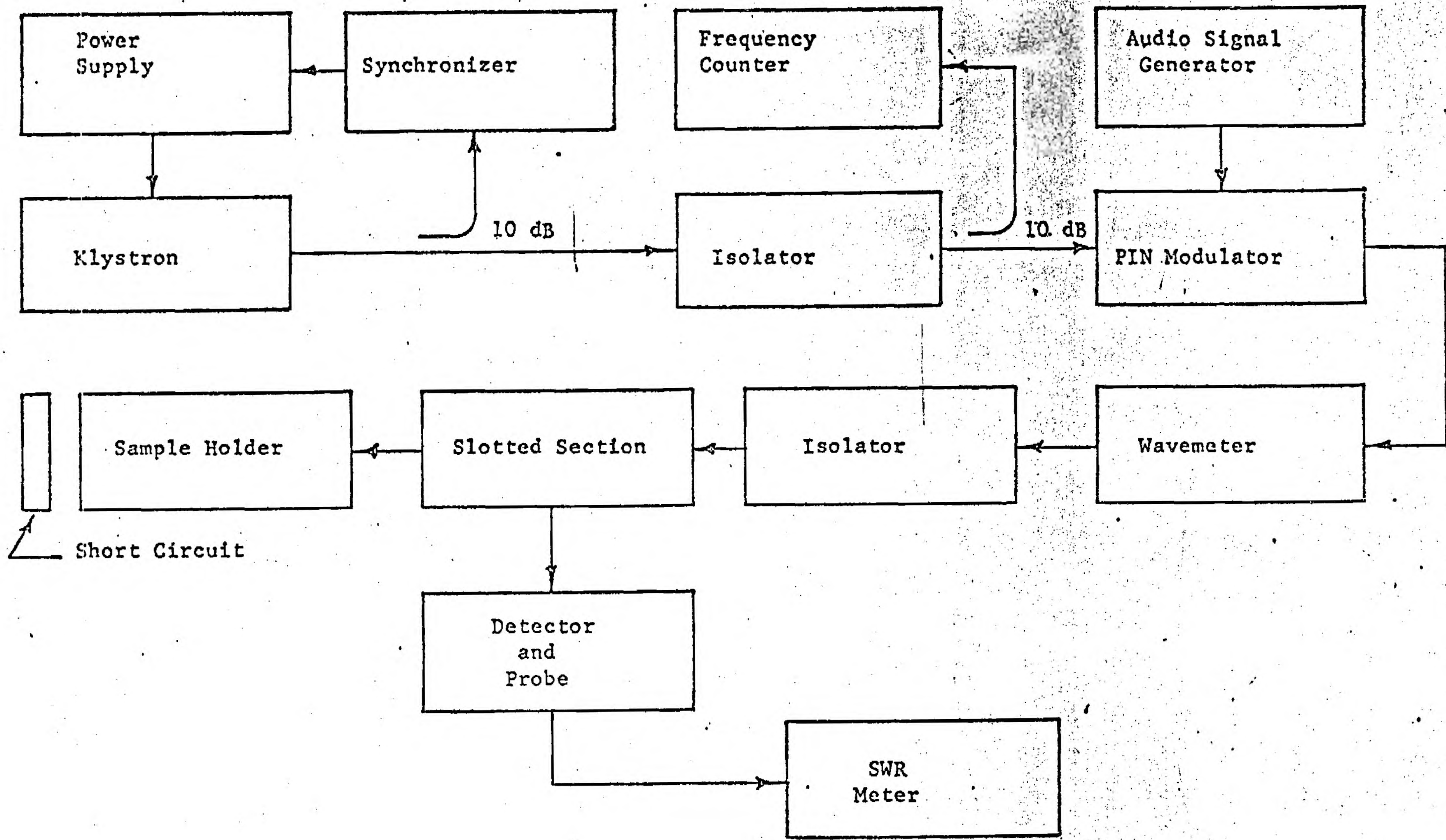

Figure 1. Block Diagram of Apparatus for Measurement of Dielectric Constant and Loss Tangent (Short-Circuit Waveguide Technique)

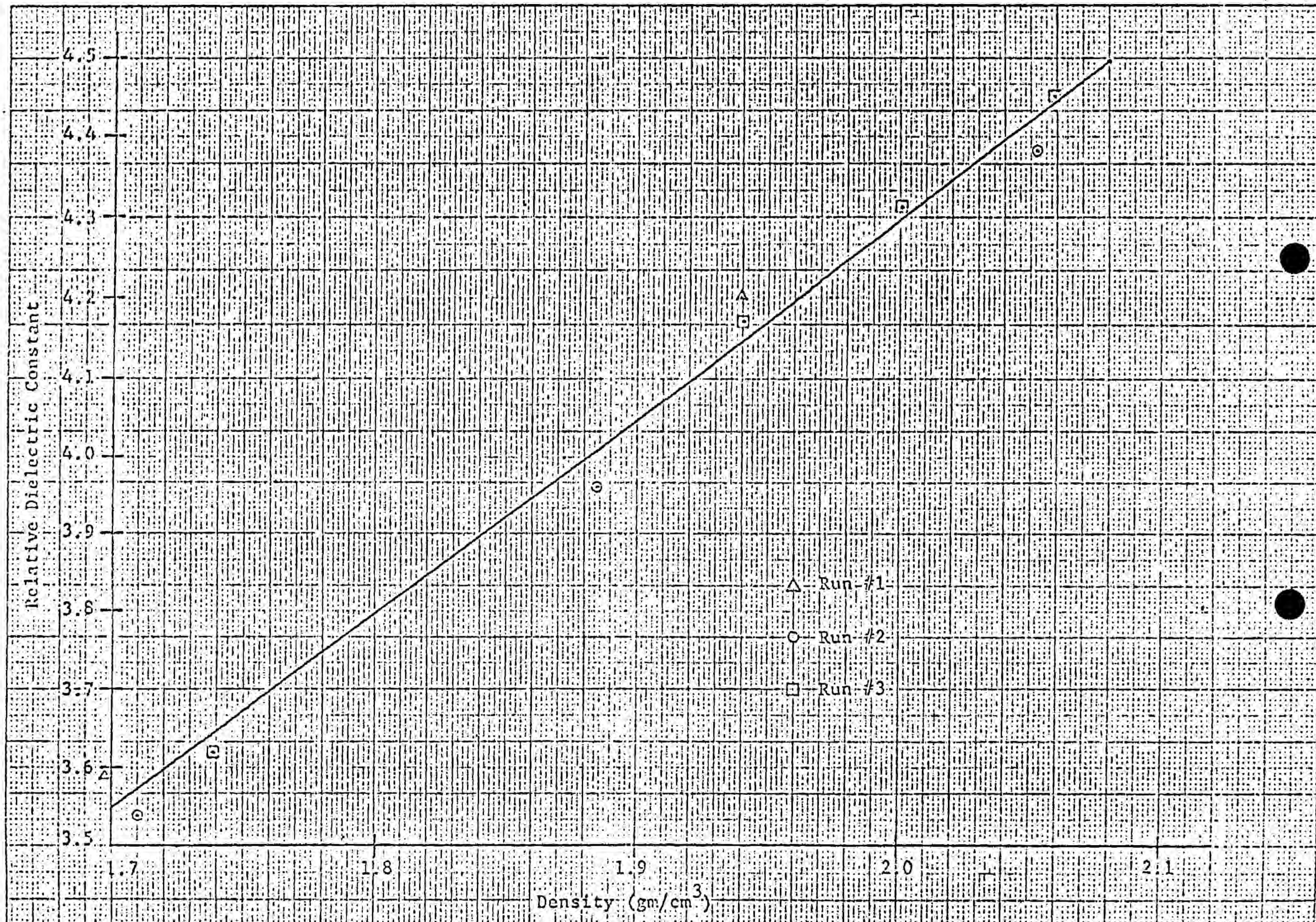

Figure 2. Dielectric Constant vs. Density at 9.375 GHz for Sample 14163, 164

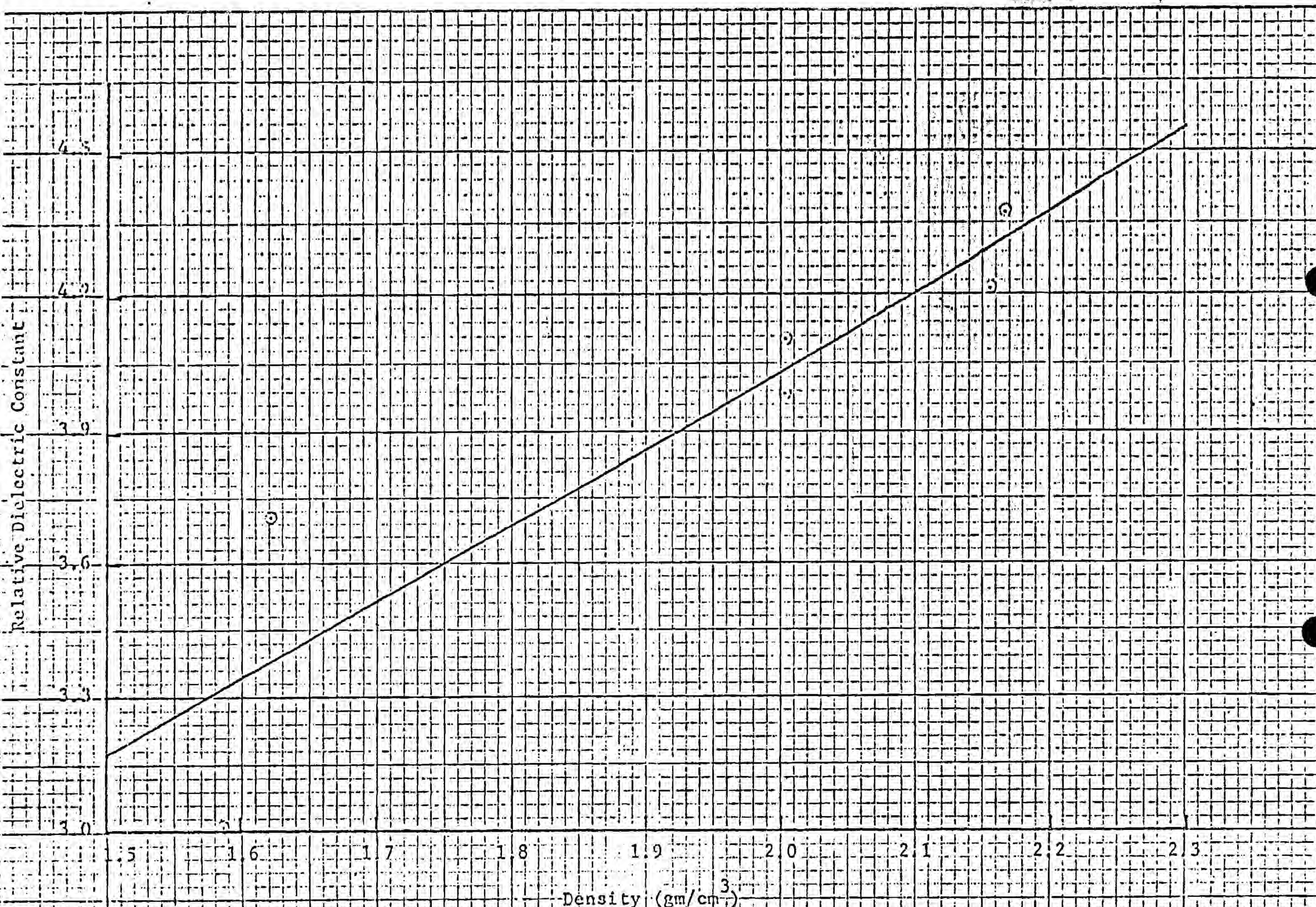

Figure 3. Dielectric Constant vs. Density at 24 GHz for Sample 14163, 164

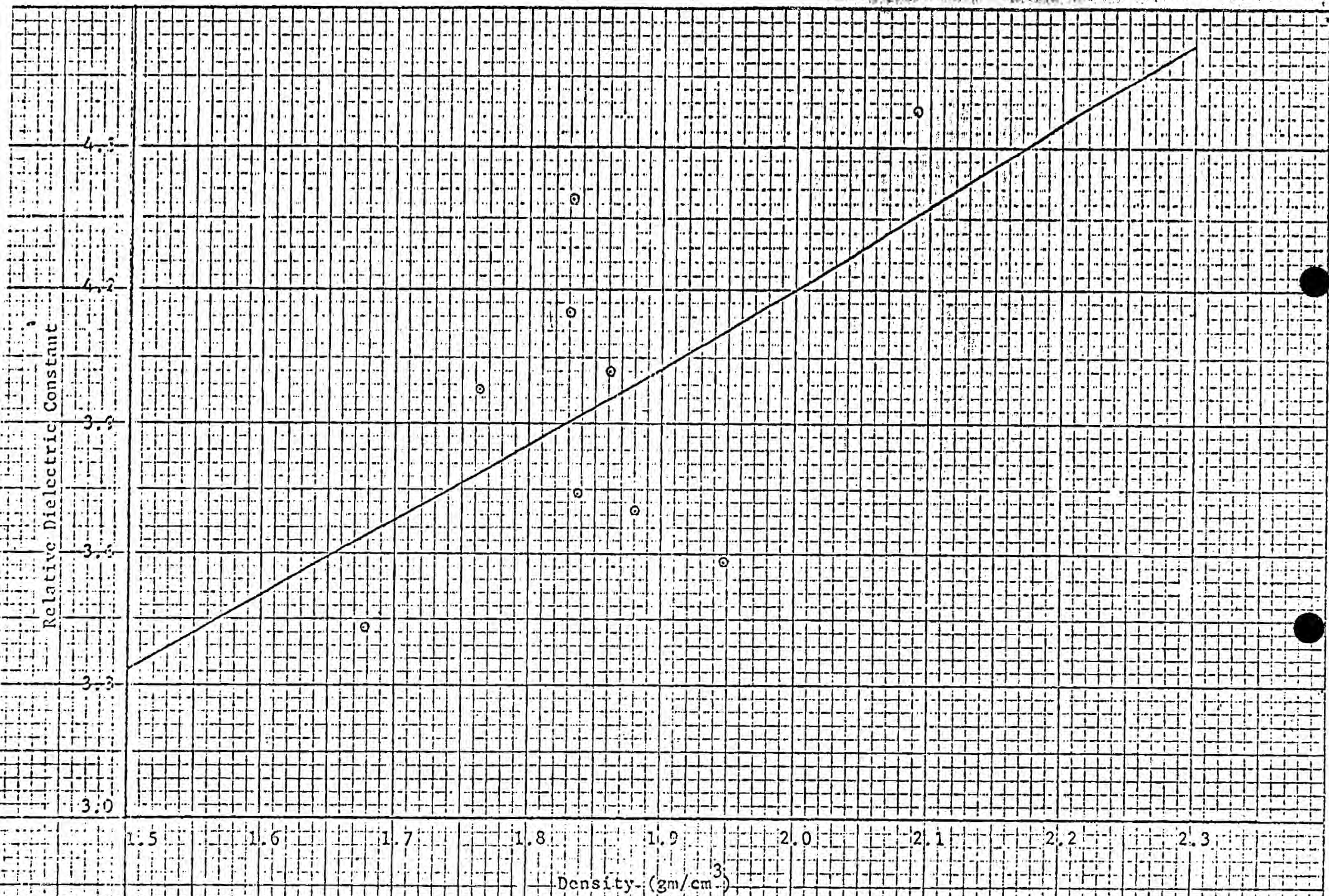

Figure 4. Dielectric Constant vs. Density at 60 GHz for Sample 14163, 164

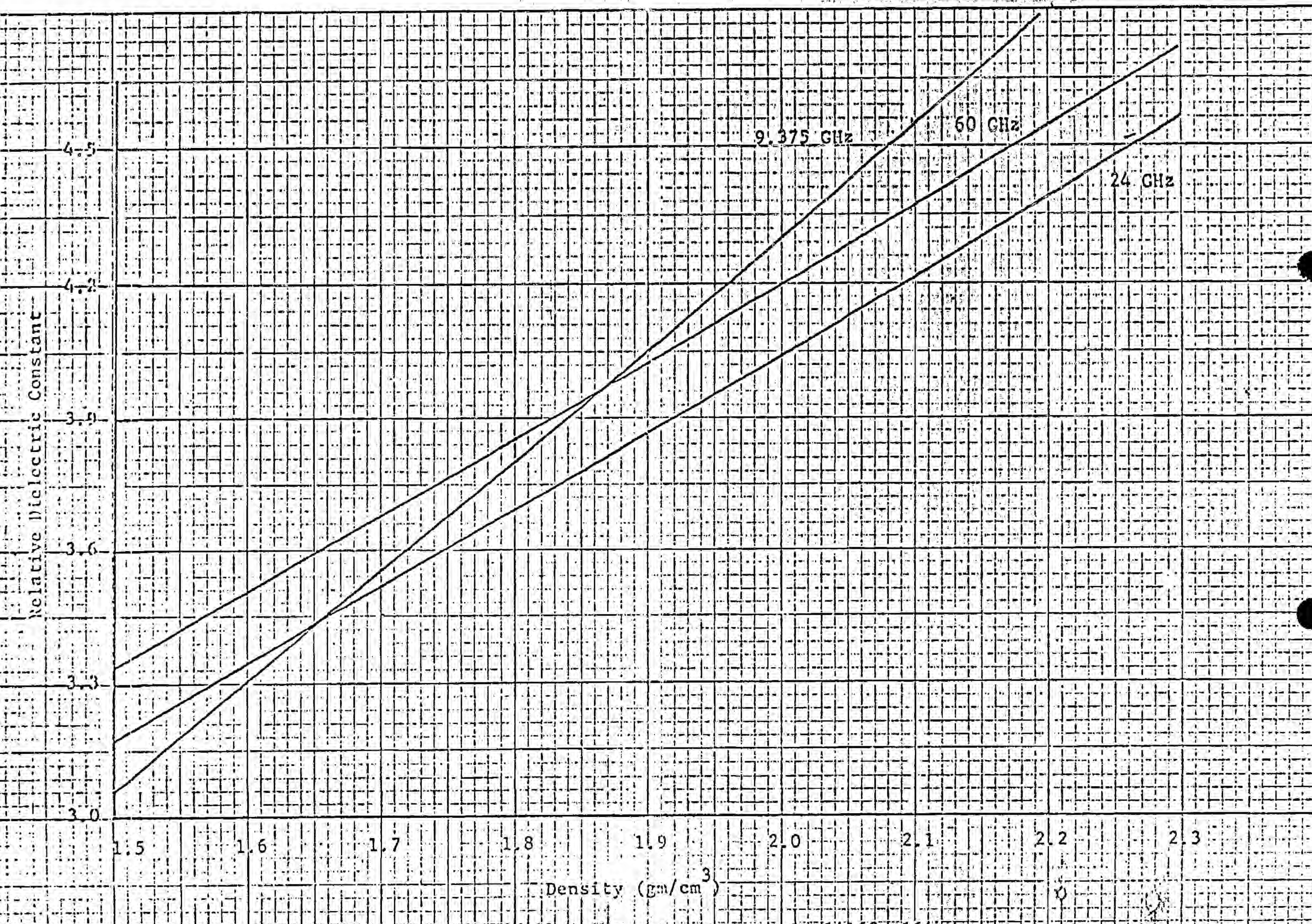

Figure 5 Dielectric Constant vs. Density for Sample 14163, 164

FINAL REPORT

COMPLEX PERMITTIVITY MEASUREMENTS OF LUNAR SAMPLES AT MICROWAVE AND MILLIMETER WAVELENGTHS

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March 1972

Contract NAS9-11574
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ABSTRACT

The relative dielectric constant and loss tangent of lunar sample 14163,164 (fine dust) have been determined as a function of density at 9.375, 24, 35, and 60 GHz. In addition, such measurements have also been performed on lunar sample 14310,74 (solid rock) at 9.375 GHz. The loss tangent was found to be frequency independent at these test frequencies and had a value of 0.015 for the lunar dust sample.

DIELECTRIC PROPERTIES OF APOLLO 14 LUNAR SAMPLES AT MICROWAVE AND MILLIMETER WAVELENGTHS

INTRODUCTION

The dielectric constant and loss tangent data of lunar sample 14163,164 (fine dust) have been determined as a function of density at 9.375, 24, 35, and 60 GHz. In addition, the dielectric constant and loss tangent of lunar sample 14310,74 (solid rock) have been measured at 9.375 GHz.

MEASUREMENT TECHNIQUE

The short-circuit waveguide technique,[1,2] where the rectangular test sample is formed by compressing the powdered sample (14163,164) in the short-circuited waveguide test cell, was used to determine the dielectric properties. A block diagram of the 9.375 GHz test setup is presented in Figure 1. As indicated, the material undergoing test rests in the sample holder against the metal short-circuit. In the case of the powder sample measurement, care was taken to keep the front surface of the lightly compressed sample parallel with the plane of the short-circuit. Careful alignment of the compression mandrel and placement of the slotted section and the sample holder in a vertical plane resulted in more than adequate parallelism.

Sample holders and mandrels were fabricated for each frequency band of interest so that microwave measurements could be made as a function of sample density. The mandrels were machined from high carbon steel to withstand the pressures required to compress the powdered material to 77 percent integral density.

RESULTS

The dielectric constant vs. sample density (lunar sample 14163,164) is presented in Figures 2 and 3. The 9.375 measurement data are plotted in Figure 2 and are compared to the 24 GHz and 60 GHz measurements in Figure 3. The straight lines on the density-dielectric curves are the linear least mean square estimates. For example, at 9.375 GHz, the dielectric constant is 3.59 at a density of 1.71 gm/cm^3 and increases linearly to a value of 4.45 at a density of 2.06 gm/cm^3. The loss tangent remains relatively constant at a value of 0.015 at each density and at each test frequency.

The solid sample relative dielectric constant was found to be 6.46 at a frequency of 9.375 GHz and the loss tangent is 0.0075. The density of this particular sample (14310,74) is 2.814 gm/cm^3. The relative dielectric constant of 6.46 is interesting, since it was noted that one would obtain the same value if the curve of Figure 2 were extended to include the actual density, 2.814 gm/cm^3. Thus, solid sample 14310,74 is the 100 percent dense equivalent of the lunar fine sample 14163,164. It would now be possible to change the abscissa of Figure 2 to "percent theoretical density" as opposed to density, per se.

CONCLUSIONS

Although it was stated in the Results that the dielectric constant vs. density curve could be extrapolated linearly to obtain the 100 percent dense value, the number of data points is not sufficient to categorize this variation as being linear over all densities. Usually, the variation of dielectric with density of a base material uniformly mixed with air conforms to the empirical relation:[3,4]

$$\log \frac{\epsilon'}{\epsilon_o} = \frac{\rho'}{\rho} \log \frac{\epsilon}{\epsilon_o} ,$$

where

$\frac{\epsilon'}{\epsilon_o}$ is the relative dielectric constant of the sample with air,

$\frac{\epsilon}{\epsilon_o}$ is the relative dielectric constant of the original solid,

ρ' is the density of the material with air, and

ρ is the density of the original solid.

The data do not indicate that this relation holds for the lunar dust. Also, the linear variation of dielectric constant with density is valid only over the limited measurement range. It is possible that the relative dielectric constant varies in a logarithmic manner at very low densities and varies linearly at the higher densities.

The loss tangent of sample 14163,164 is independent of frequency and appears to be independent of density. As indicated by Chung and Westphal,[5] the frequency independence of the loss tangent exists over a very broad range of frequencies, and these data support their conclusion.

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5. Chung, D. H. and W. B. Westphal, "Dielectric Properties of Apollo 14 Lunar Samples," Revised Abstracts of the Third Lunar Science Conference, p. 139, January 1972.

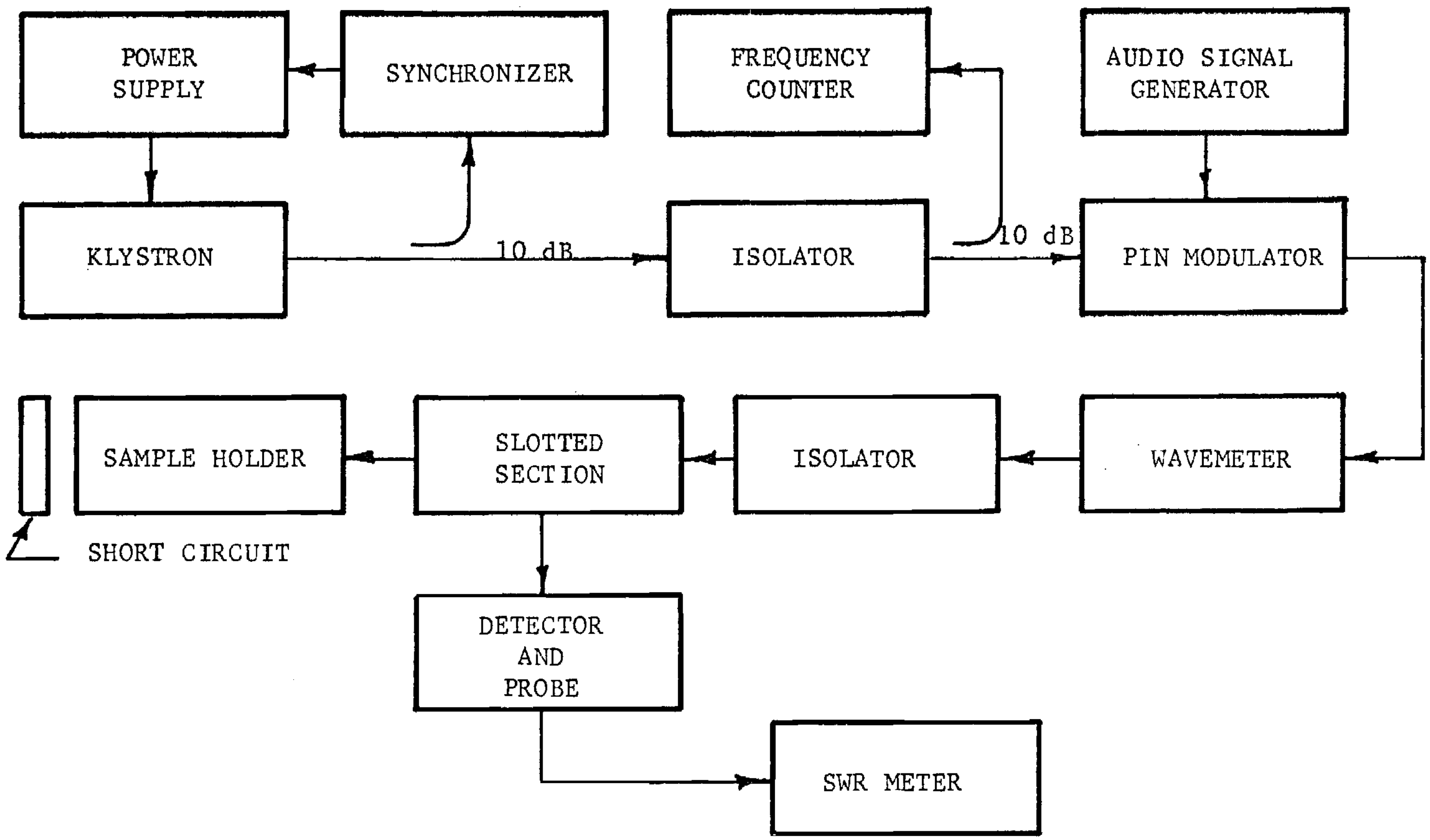

Figure 1. Block Diagram of Apparatus for Measurement of Dielectric Constant and Loss Tangent (Short-Circuit Waveguide Technique).

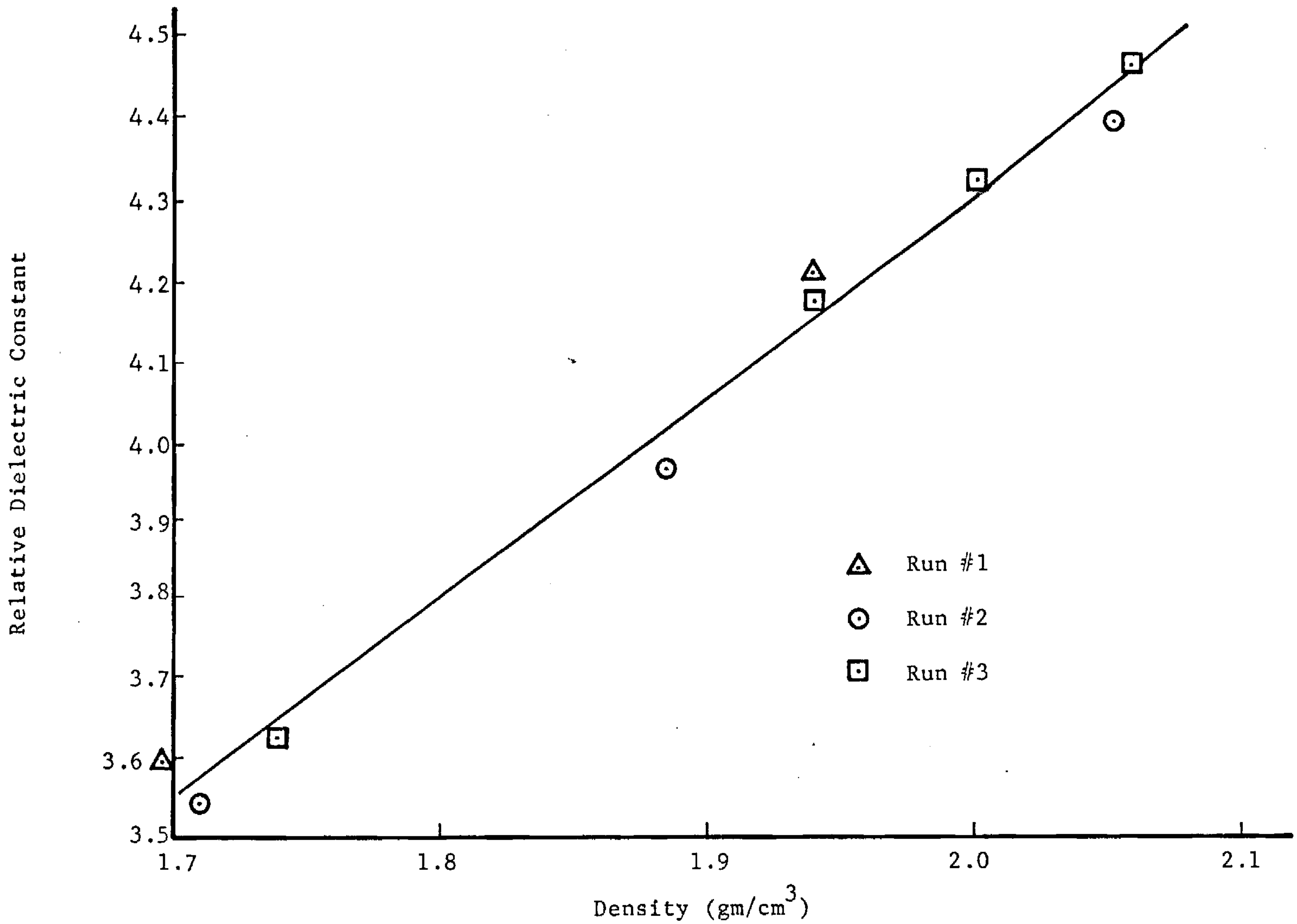

Figure 2. Dielectric Constant vs. Density at 9.375 GHz for Sample 14163,164.

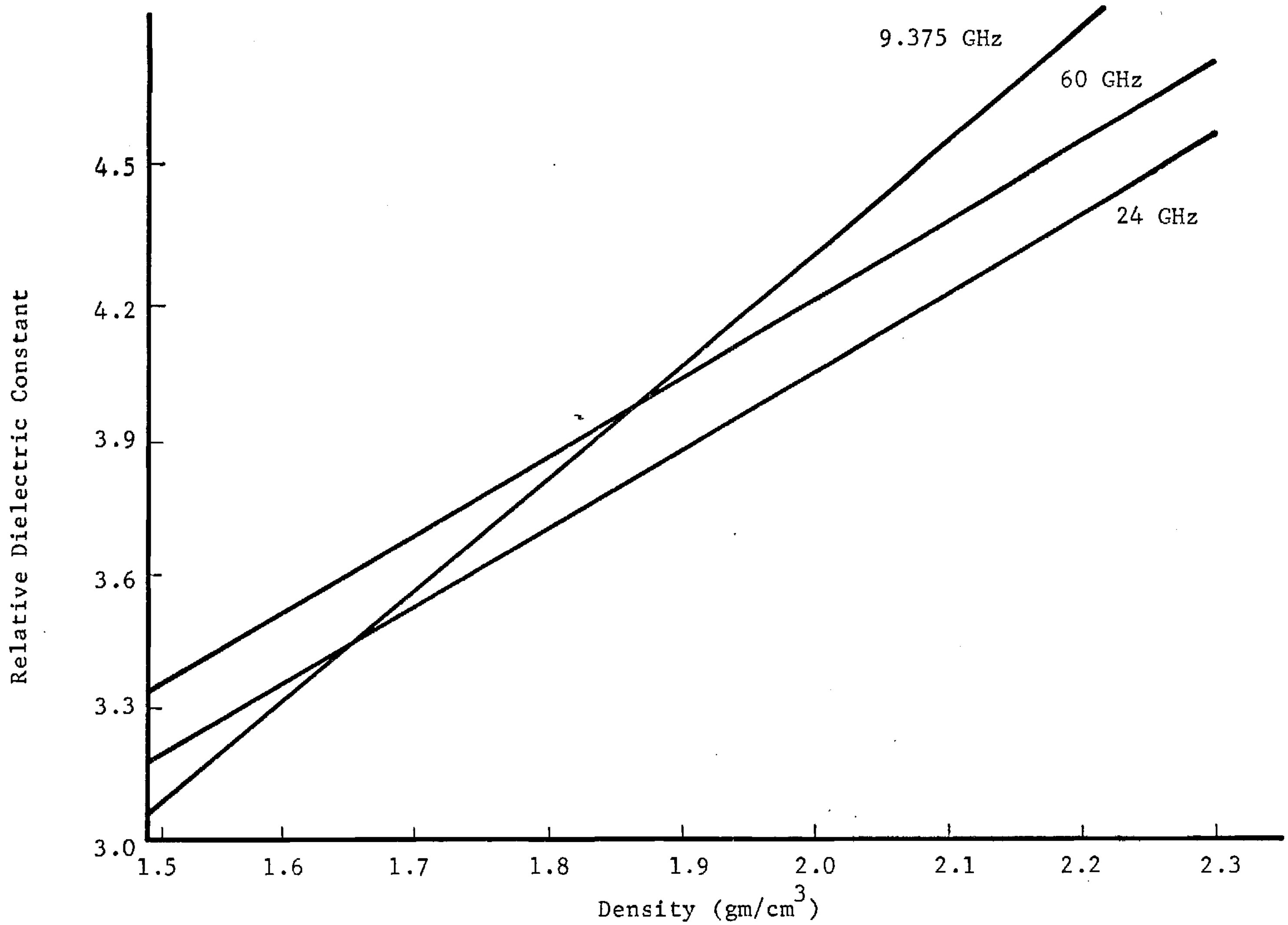

Figure 3. Dielectric Constant vs. Density for Sample 14163,164.