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PRE-CONVERSION CAVITY FERRITE MEASUREMENTS

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AGS Division Technical Note

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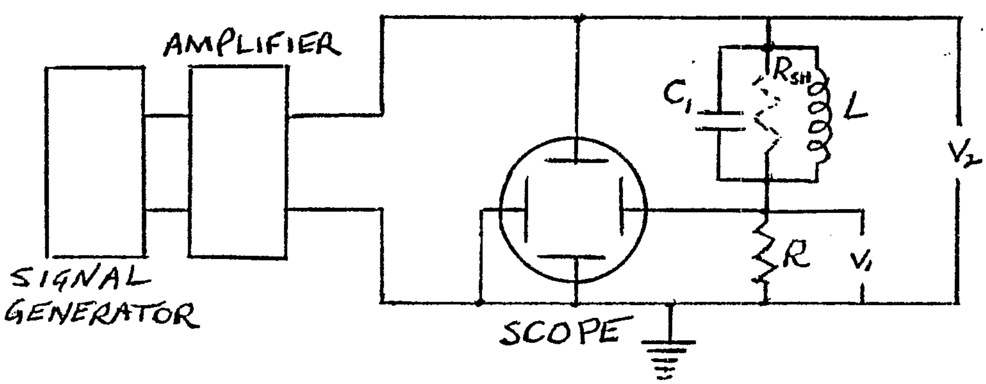
Note: In a number of Tech Notes and other papers the pre-conversion AGS rf cavity ferrite has been called Ferroxcube 4L. This has been an error. The ferrite is correctly Ferroxcube 4H.

The first phase of the heavy ion acceleration in the AGS requires rf acceleration with 17 kV rf peak voltage and a frequency range from 0.5 to 2.0 MHz. The ferrite in the AGS pre-conversion cavities is a Philips 4H which was designed for 8 kV (cw) peak per cavity, and a frequency range of 1.35 to 4.46 MHz. Acceptance testing of the ferrite was based upon 1.5 MHz (unbiased) at $\sim$135 gauss peak flux density. This flux density corresponds to 8.0 kV peak per cavity at 1.5 MHz.

Tuning, with a fixed total capacitance, was accomplished by dc biassing the cavity to vary the inductance over a range of $\sim$11:1, $(f_2/f_1)^2$. The use for heavy ions involves a different frequency range, higher voltage and a 16:1 inductance range. Using known extrapolation relationships it was estimated that, at 0.5 MHz and 8.5 KV pk, the losses in the ferrite would be about 500 mw/cc which is twice that in the original design. The duty factor, however, is much lower in the heavy ion case so the average dissipation in the ferrite is low enough for the existing water cooling to be effective. The amplifier, must, in all cases, supply the actual power in the ferrite during the "on" time.

To measure the actual behavior of the ferrite at the new frequency and flux density, small ring samples were cut from pieces of the Philips 4L material. The rings were about 3.5 cm OD, 2.5 cm ID and .8 cm high. Each pair of rings was made from a 2.1 cm high ring sliced into two and then ground to the same height. The rings were wound with a figure "8" rf winding and then were placed in a brass shield can. A dc bias winding of 75 turns was wound over the shield. In operation, shorting the dc winding had no effect on the rf measurements, indicating complete dc/rf isolation.

The test set-up initially was as follows:



L - ferrite core inductance

C_1 - tuning capacitance

R_{sh} - ferrite loss resistance

R - small (50-100Ω) non-inductive resistor

It can be readily shown that:

$$R_{sh} = \frac{R(V_2-V_1)}{V_1}, \quad P_{diss} = \frac{(V_2-V_1)V_1}{R}$$

$$B_{pk} = \frac{k(V_2 - V_1)}{nAf}$$, n = number of rf turns
A = area of two ferrite rings
f = frequency
k = 22.49 for A-cm^2, f-MHz

In operation, the tuning capacitance is adjusted for a straight line Lissajous pattern, indicating a pure resistive tuned circuit. Since the power dissipation, w/cc, is readily calculated knowing the core volume, the curve of w/cc vs B is easy to obtain. There are two problems with this set-up. The set-up accentuates harmonics in V_1 resulting in higher than actual readings at high flux densities. The harmonics are generated at higher voltages in the rf power amplifier being used. The other problem is finding low reactance resistors and possible heating in the resistor during operation at high flux densities. The first effect, higher harmonics, causes the P vs B curve to deviate from a straight line on a log-log plot.

If the resistor is replaced by a capacitor with $1/\omega C < 0.1\ R_{sh}$, then resonance is indicated by a circular pattern on the oscilloscope, harmonics are reduced somewhat since $1/\omega C$ decreases with frequency, there is no heating problem and the voltage across the resonant circuit is within one percent of the applied voltage. The equations for the ferrite properties reduce to:

$$P_{diss} = V_1 V_2 \omega C_2 \ , \ R_{sh} = \frac{V_2}{V_1 \omega C_2}$$

$$B_{pk} = \frac{k\ V_2}{naf}$$

At 0.5 MHz the resonant circuit was tuned with C_1 at each flux density. The ferrite permeability varies with the flux density, increasing as the flux increases. With dc bias, above 0.5 MHz, the tuning was accomplished by varying the dc bias with the capacitance, C_1, left at the value for the high flux density point (0.5 MHz) since this represents the actual operating point.

Many measurements were made on two pairs of rings, one with 8 rf turns, the other with 12 rf turns. With 12 rf turns, the power amplifier harmonics to achieve the maximum flux density were quite severe. Except with no bias, the readings were dependent on the magnetic history of the rings. In some cases the rings were biassed to saturation and then demagnetized by reversing the bias as it was reduced to zero. In most cases, the rings were biassed, unidirectionally, for ten cycles to just beyond the operating range. During some runs the 10 cycles were applied at each frequency change.

Figure 1 represents the results of about 8-10 runs under the different conditions mentioned above. Most of the readings cluster about a loss dropping from $\sim$620 mw/cc at 0.5 MHz to $\sim$430 mw/cc at 2.0 MHz. Six hundred twenty mw/cc corresponds to a total power level of about 68 kW, dropping to $\sim$47 kW at 2.0 MHz. Figure 1 includes results from tests with the resistor as well as with the capacitor. Figure 2 is representative of a run using the capacitor, C_2.

To bias the core to 2.0 MHz required a current of about 1.5 amperes in 75 turns, 112.5 AT. The average path length in the ferrite with OD-3.55 cm and ID-2.55 cm is 9.58 cm. Thus, 11.74 AT/cm are required. The average path length in the large rings, OD-35 cm and ID-20 cm, is 86.4 cm. The required bias current is about 1014 amperes. The core was very easily biassed to 2.2 MHz (about 2 amperes dc), and to 2.5 MHz (about 3 amperes dc). The corresponding currents in the large rings would be 1352 amperes and 2029 amperes. The rf losses at 2.5 MHz are at about the same level as at 2.0 MHz. In one run the circuit was turned to 3.15 MHz at a bias current of about 5 amperes (3382 amps in the large rings). The rf losses were, by extrapolation, about 600 mw/cc.

The measurements must be corroborated on the full cavity. The dc bias can be checked roughly using a supply borrowed from EP&S or CBA and measuring low rf level inductance. The actual bias currents will be less than the values measured in this fashion since the permeability increases with flux density and, the higher the initial μ, the easier it is to effect a given μ change. The rf measurements can be made, initially, with the Gates amplifier. Since the curves are straight lines on a log-log plot we can measure up to perhaps half power and extrapolate to check agreement with the small sample measurements.

A third pair of small rings is now prepared with a smaller cross sectional area. These cores can be run to the operating rf flux density at lower voltage output from the amplifier. This should reduce the harmonics in the V_2 reading so no anomalous errors will be introduced in the power loss calculation.

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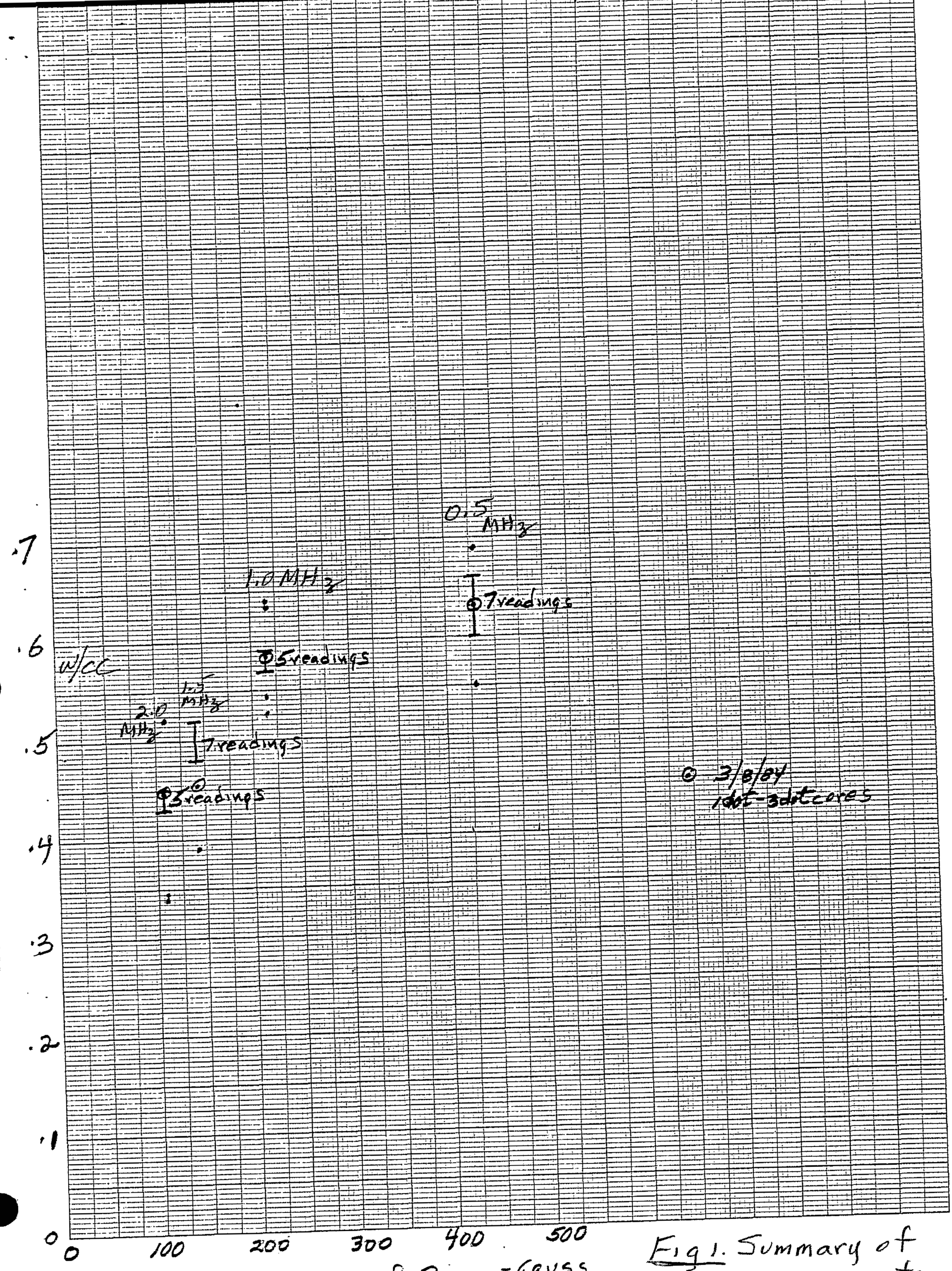

Fig 1. Summary of some measurements with various magnetic histories

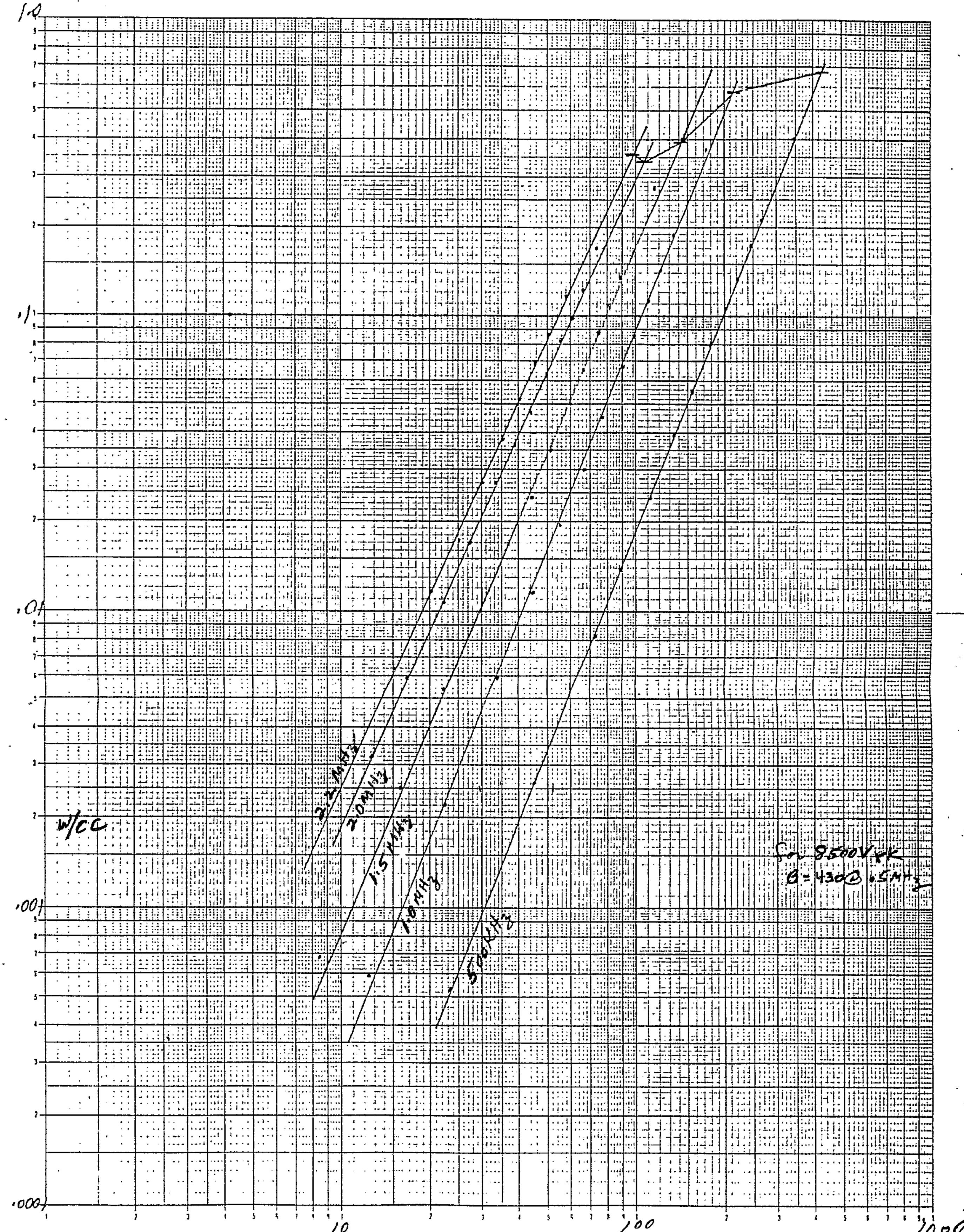

Fig 2. Ferroxcube 4H
dc bias tuned to 2.2 MHz.