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TRANSMISSION LINE MODE DAMPING IN THE BOOSTER MAGNET SUPPLY

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By nature, resonant power supplies for rapid cycling accelerators are subject to magnetic field unbalance due to delay or transmission line resonances. These modes have been discussed along with several approaches to damping in other papers[1]. A few are summarized as follows.

1. Damping loops formed by interconnecting secondary windings on various magnets.
2. Restriction of the Fourier spectrum of the magnet voltage and current to remove the excitation source of the resonant modes.
3. Damping resistors at virtual grounds along the magnet system.

For reference, the series pumped Booster magnet supply is shown in Figure 1. Secondary windings are provided on the choke secondaries to aid in tuning the supply. At resonance, a virtual ground appears between the "F" and "D" magnets as indicated.

The most straight forward approach is the use of damping loops. However, at the present time, it may not be practical to consider the use of secondary windings on the Booster magnets. The secondary windings on the choke are effectively by-passed by the resonant capacitor and, therefore, are unsuitable for this purpose.

The restriction of the Fourier spectrum is only a means for circumventing the problem and could be used if necessary to supplement some other damping technique.

To evaluate the final damping approach, it becomes necessary to study the supply in some detail. First, the effective ac resistance of the magnets and choke was computed with the aid of the computer program ACREST. The results have been compiled in Figures 4 and 5 for the Booster magnets. The winding capacitance for each magnet has been evaluated by considering the magnet as a two-port device (magnet steel taken as ground). The capacitance can be simplified to that shown in the network of Figure 2a.

To examine the effects of resistive damping, we can consider a lumped transmission line consisting of sections shown in Figure 2b. We assume that $|R_{ac} + j\omega L| << |1/\omega c_3|$ and that the reactance of the resonant capacitor effectively by-passes the choke at transmission line mode frequencies.

The attenuation α and the phase advance per section β are given respectively by[2]:

$$1)\quad \alpha = \sqrt{\frac{R_{ac}G}{2}}\sqrt{\sqrt{\left(1+\frac{\omega^2L^2}{R_{ac}^{\;2}}\right)\left(1+\frac{\omega^2C^2}{G^2}\right)}+1-\frac{\omega^2LC}{R_{ac}G}}$$

$$2)\quad \beta = \sqrt{\alpha^2 + \omega^2LC - R_{ac}G}$$

Where $G = 1/R_{damping}$ and $C = C_{1f} + C_{1d} + C_{2f} + C_{2d} + C_{choke}$

The computer program TRANLIN was written to show errors between the approximate approach presented and the actual system. This program considers a typical section as shown in Figure 3. The characteristic impedance is found and the attenuation and phase advance are calculated by conventional ac circuit techniques for a line of 48 such sections terminated in its characteristic impedance. The phase advance for 48 sections is compared with the approximate case in Figures 6 and 7. The attenuation figures are presented in Figure 8 for the case where $R_d = \infty$, $R_d = 4700\ \Omega$, and $R_d = 2400\ \Omega$. It can be seen that the resonant frequency is lowered as the damping resistance is decreased. The lower limit on the size of this damping resistor is set to limit the ac leakage current to less than 1 pp 10^4 of the magnet current at injection (7.4 ma). If we assume a 1%

voltage unbalance at the virual ground (11.4 V peak), the minimum value of resistance would be 1540 Ω. DC leakage currents are blocked by C_d which is chosen as that $X_{cd} = R_{d/10}$ at the frequency where the phase advance is $\lambda/2$. For the two cases presented here, C_1 = 2.0 μf for R_d = 4700 Ω and 5.0 μf for R_d = 2400 Ω.

References

The Excitation and Elimination of the Delay Line Modes of Resonance in the Magnet Power Supply System of a Fast Cycling Electron Synchrotron, N. Marks. Symposium on Magnet Technology, 1967.

2. Transmission Lines and Filter Networks, J. Karakash, Macmillan Co., N.Y., 1950

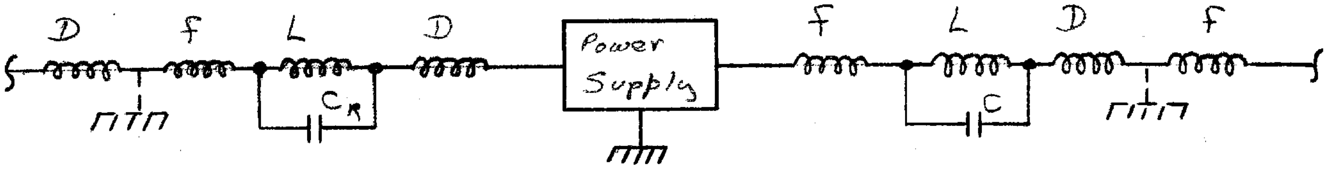


Figure 1

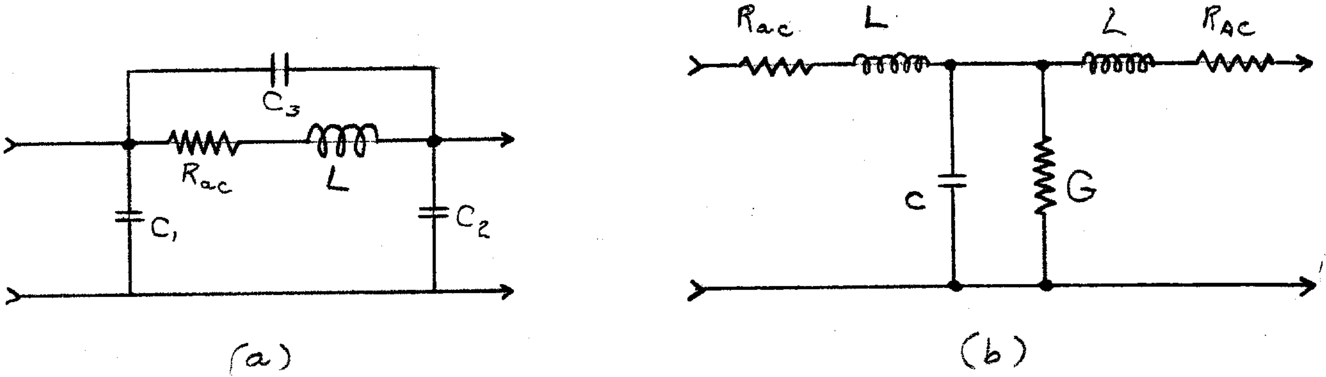


Figure 2

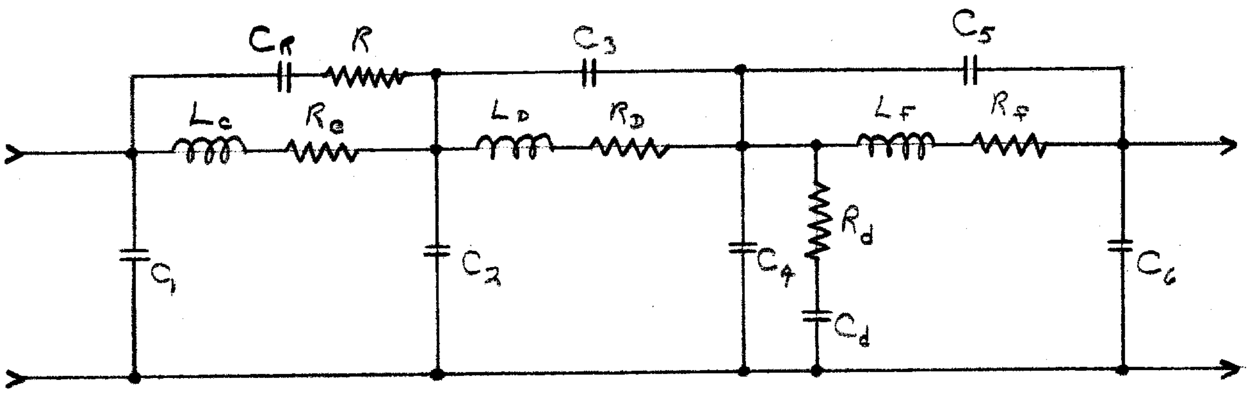


Figure 3

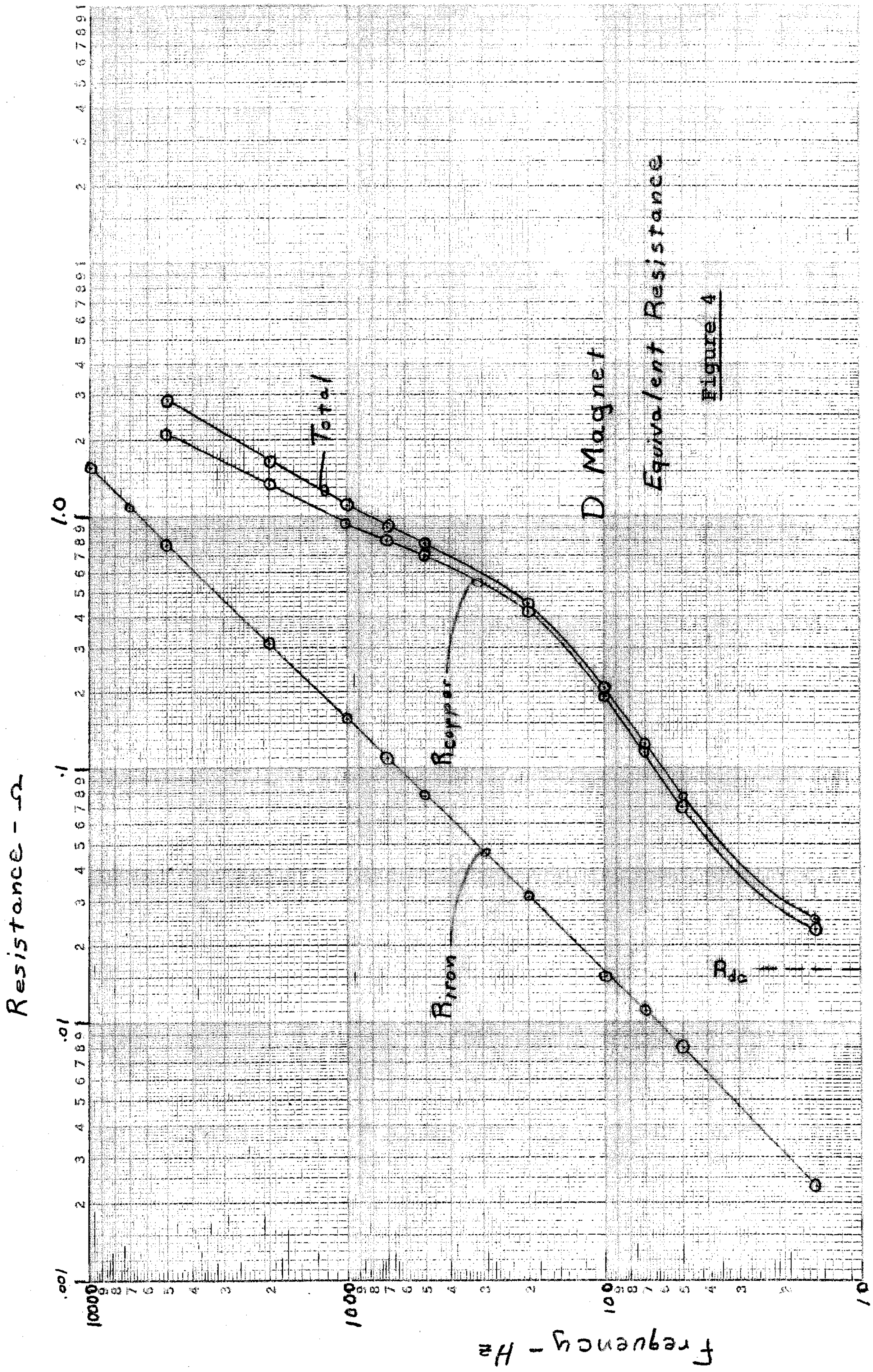

D Magnet
Equivalent Resistance
Total
R_{copper}
R_{iron}
R_{dc}
Resistance - Ω
Frequency - Hz
.001
.01
.1
1.0
10
100
1000
10000

Figure 4

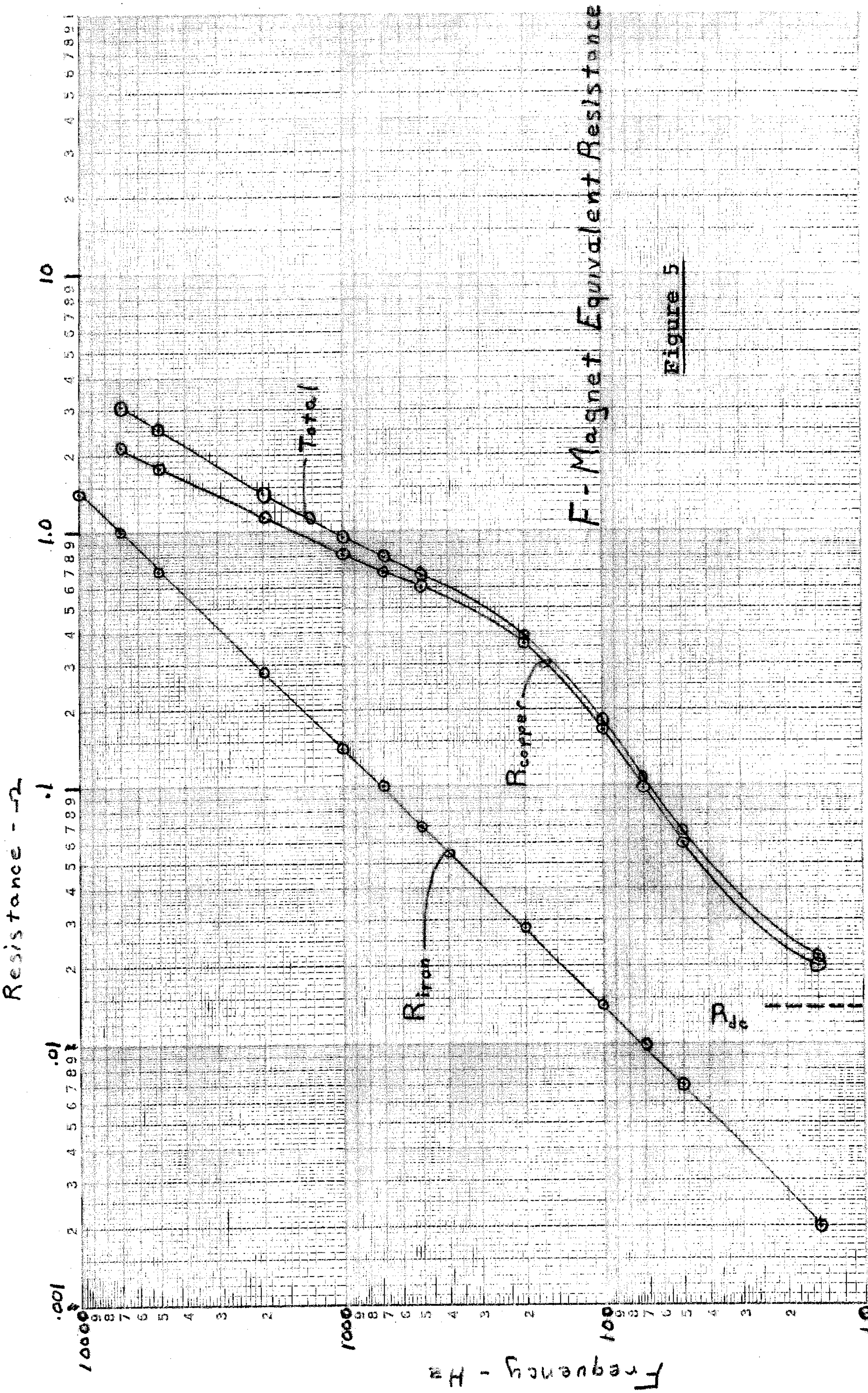

F-Magnet Equivalent Resistance
Resistance - Ω
Frequency - Hz
Total
R_{copper}
R_{iron}
R_{dc}
.001
.01
.1
1.0
10
10000
1000
100
10

Figure 5

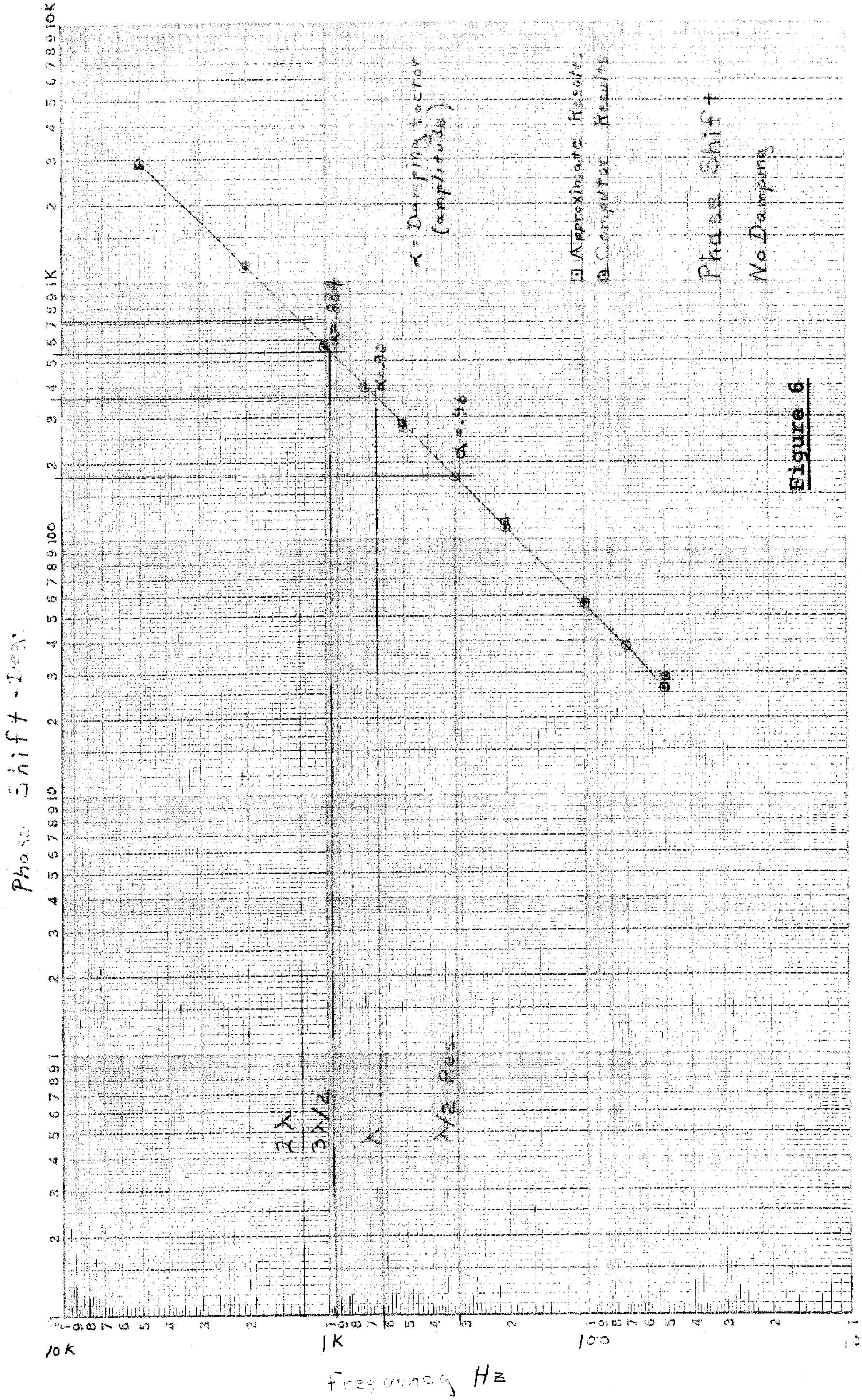

Phase Shift - Deg.
Frequency Hz
α = Damping factor (amplitude)
□ Approximate Results
⊙ Computer Results
Phase Shift
No Damping
α = .884
α = .90
α = .96
2λ
3λ/2
λ
λ/2 Res.
10K
1K
100

Figure 6

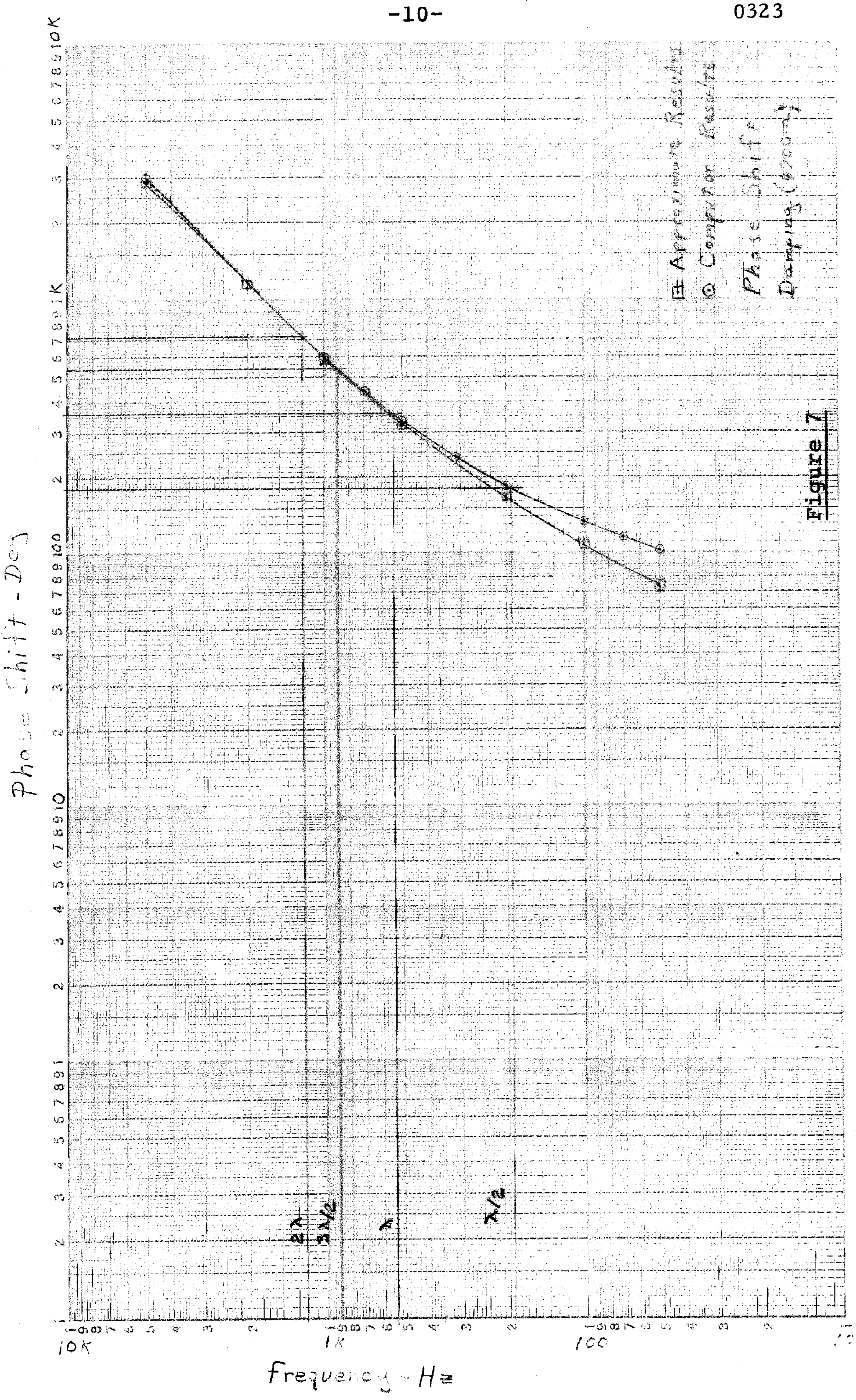
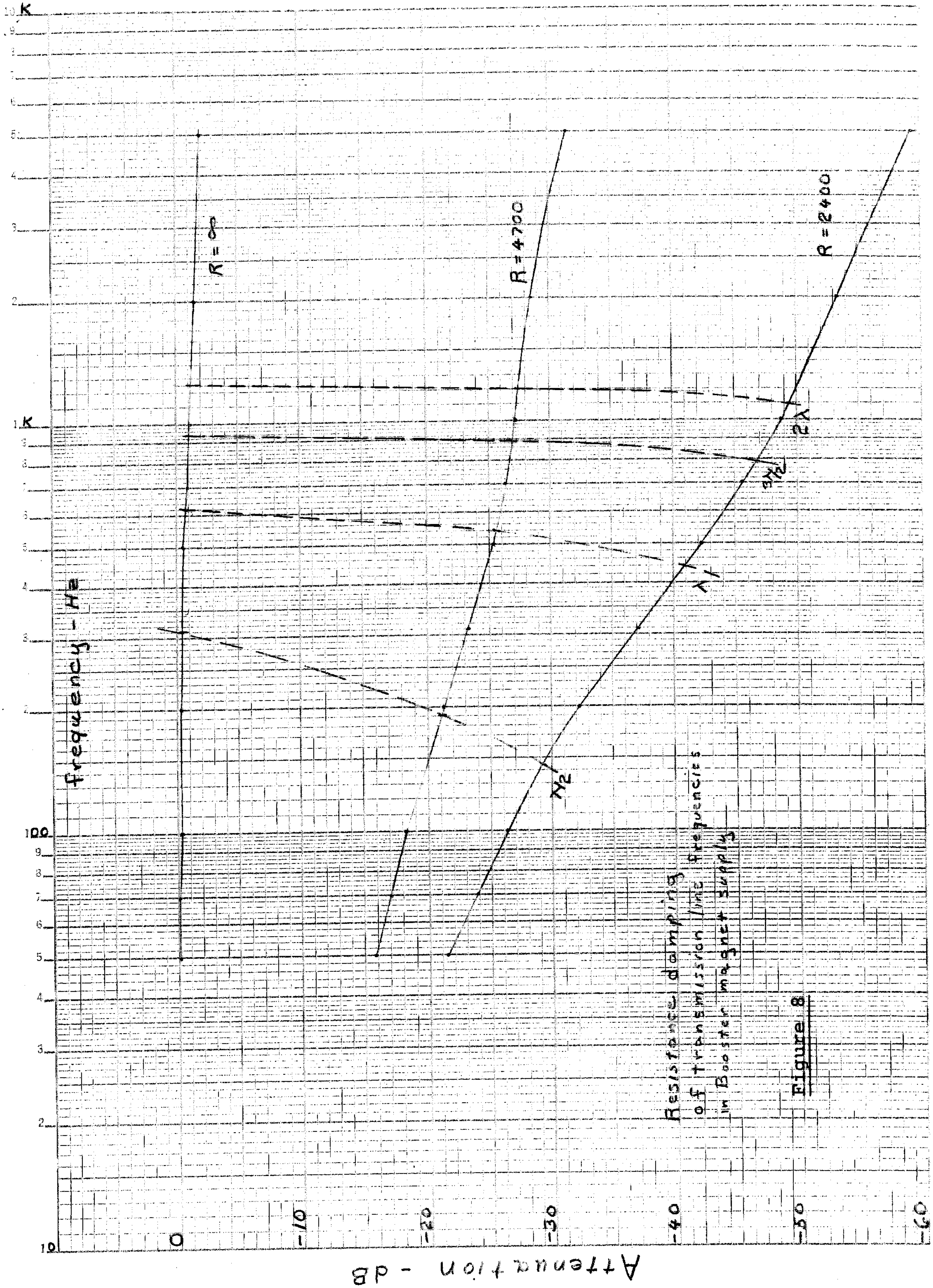

Phase Shift - Deg
Frequency - Hz
Approximate Results
Computer Results
2λ
3λ/2
λ
λ/2
10K
1K
100

Figure 7



Resistance damping of transmission line frequencies in Booster magnet supply

Figure 8