PRELIMINARY MEASUREMENTS OF QUALITY FACTORS OF MONOCRYSTALS

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Abstract

High Q's have been obtained with silicon and sapphire crystals on four points mechanical suspensions. Instrumentation has been developed to observe the approach to thermal equilibrium at cryogenic temperatures and study thermal noise level and fluctuations. High Q crystals with low thermal noise level are promising candidates as high stability time references.

INTRODUCTION

Thermal noise is one of the limiting factors in the stability of mechanical oscillators used as time standards. For this reason, it is attractive to investigate the noise characteristics of monocrystals.

An important feature of such monocrystals is that they are expected to have very high mechanical quality factors (Q) at cryogenic temperatures and corresponding very low thermal noise ($\propto 1/Q$). It is not known which mechanism will ultimately limit the Q. Experiments will indicate what can be achieved with developed techniques of instrumentation and available monocrystals.

Measurements with a 800g Silicon Crystal

Q measurements have been carried on a 800g 17cm long silicon monocrystal produced by the Czochralsky process. Figure 1 illustrates a possible scheme of instrumentation. The monocrystal is supported on a four point suspension and instrumented with a microwave cavity. Figure 2 illustrates the suspension used for the Q measurements described here. A piezo-electric element was used to drive the crystal in a bending mode at 11337 hz and to detect the oscillations.

The temperature was varied from 4.2 K to 16 K by changing the pressure of helium gas surrounding the crystal thus altering the cooling in the presence of a fixed residual heat leak in the assembly. The pressure of helium gas was however always low enough to have a negligible effect in the Q of the crystal ($\lesssim 5$ microns of hg).

Figure 3 shows the results obtained from 4.2 K to 16 K and a measurement made at liquid nitrogen temperature. A very rapidly varying Q is observed around 13 K for the bending mode observed. A similar effect was observed[1] for the 19550 hz longitudinal mode of a silicon crystal on a wire suspension. The similarity of these results which were obtained with different instrumentation virtually eliminates the possibility that one is here observing spurious resonances and losses in the suspensions.

Instrumentation for noise measurements

It has not been established yet that monocrystals will reach thermal equilibrium within a practical time after being cooled at cryogenic temperatures. We have developed and instrumented a "center ring" suspension to be used to study the approach to thermal equilibrium of a 5 feet 15.5 kg. silicon crystal at 4.2 K. It is shown on figure 4. The sensor is a small piezo electric crystal mounted on a weakened link between two "ring supports". If a fet preamplifier having a noise temperature of 0.2 K is used, a βQ of 20 with optimum matching at 4.2 K would be adequate to observe fluctuations of $\sim K_B T/20$ at T = 4.2 K. Smaller βQ's would still allow temperature measurements. At present a Q ~ 93,000,000 and βQ of ~1 has been achieved at room temperature. βQ is expected to reach ~10 at 4 K with no further improvements.

Measurements with a 4.2 Kg Sapphire monocrystal

Preliminary measurements of the mechanical quality factor of a 4.2 Kg Sapphire monocrystal have been carried at liquid helium temperatures. The sapphire was suspended on a four point aluminum suspension and instrumented

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1 D. H. Douglas et al., 8th International Conference on General Relativity and Gravitation, Waterloo, Ontario, Canada, August 1977.

with capacitance pick up plates facing the end of the crystal, themselves coated with an aluminum film deposit (fig. 5). At 4.3 K, the Q measured 402×10^6 at the fundamental mode of the crystal, 18429 hz.

CONCLUSION

Very high Q have been measured for silicon and sapphire monocrystals. Further investigation is planned to determine their usefulness as cryogenic time reference.

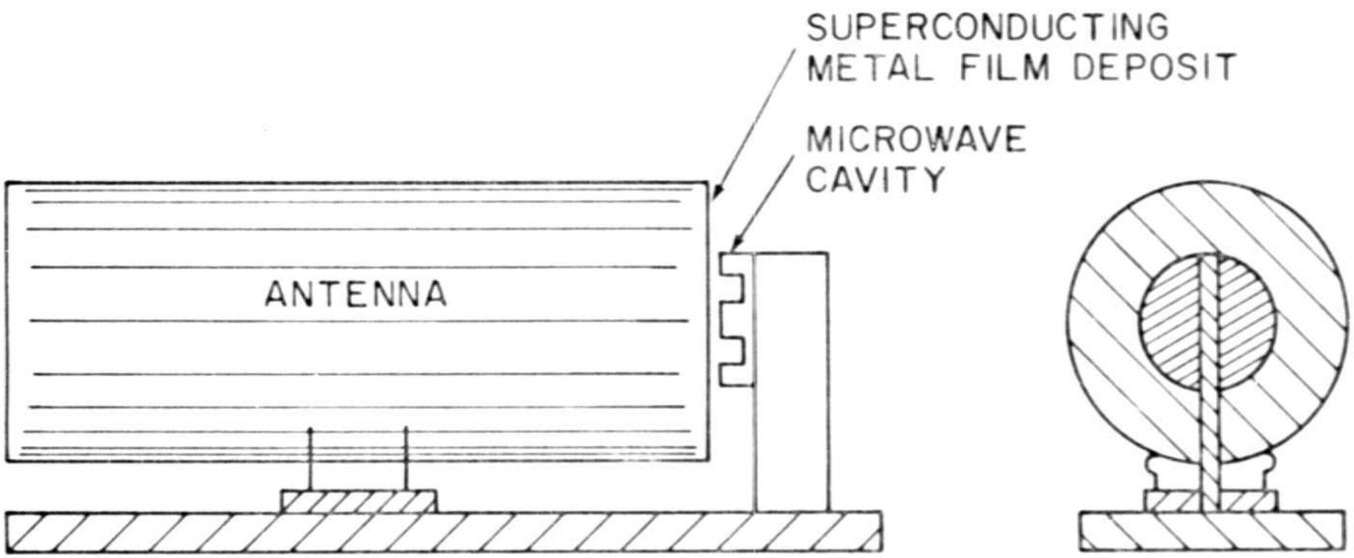

SUPERCONDUCTING
METAL FILM DEPOSIT
MICROWAVE
CAVITY
ANTENNA

Figure 1

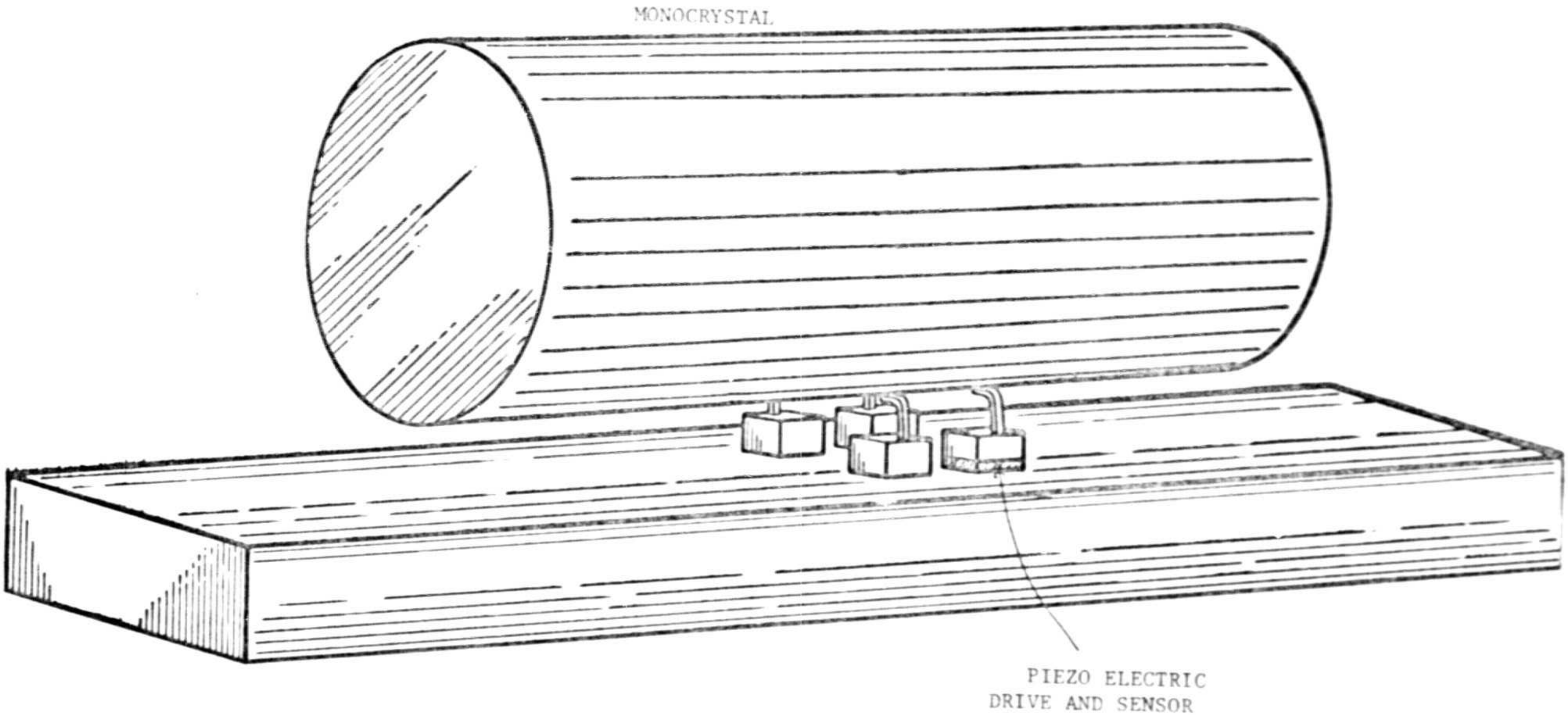
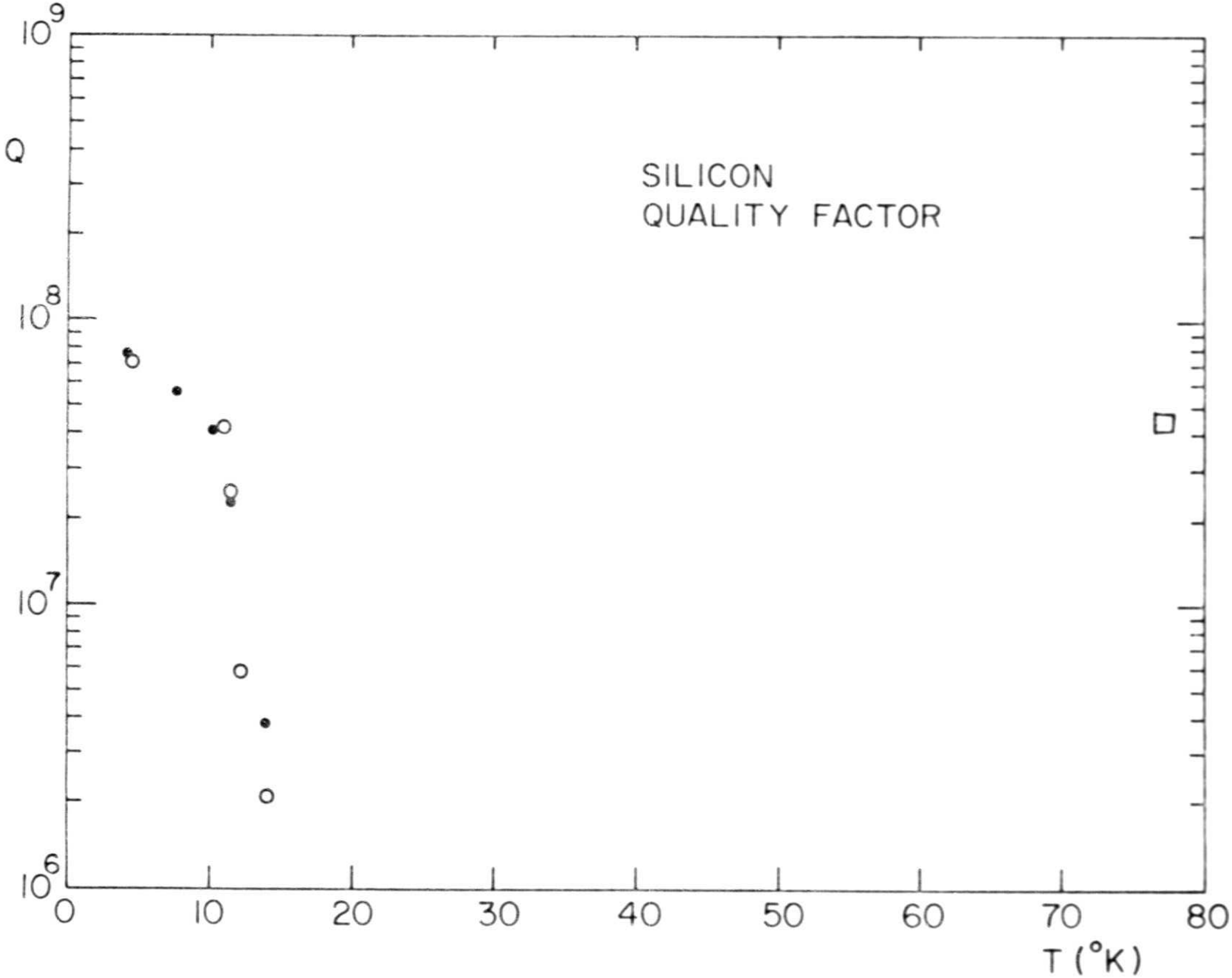


Figure 2



10^9
Q
SILICON
QUALITY FACTOR
10^8
10^7
10^6
0
10
20
30
40
50
60
70
80
T (°K)

Figure 3

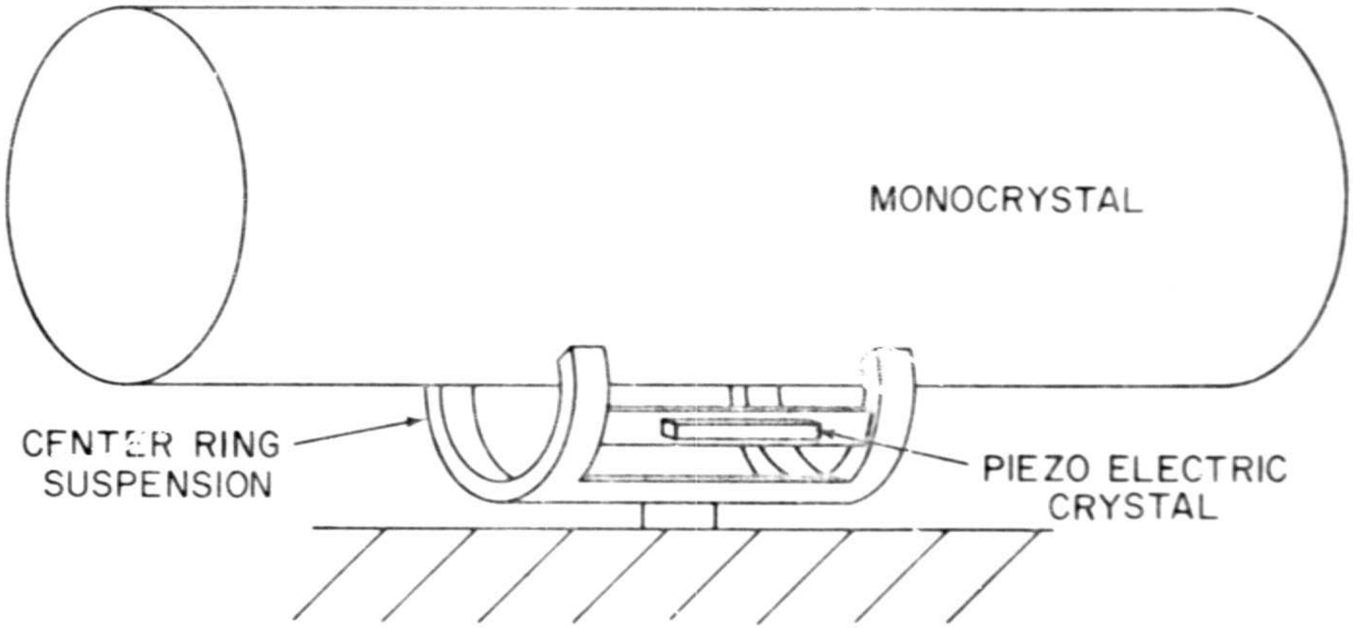

MONOCRYSTAL
CENTER RING
SUSPENSION
PIEZO ELECTRIC
CRYSTAL

Figure 4

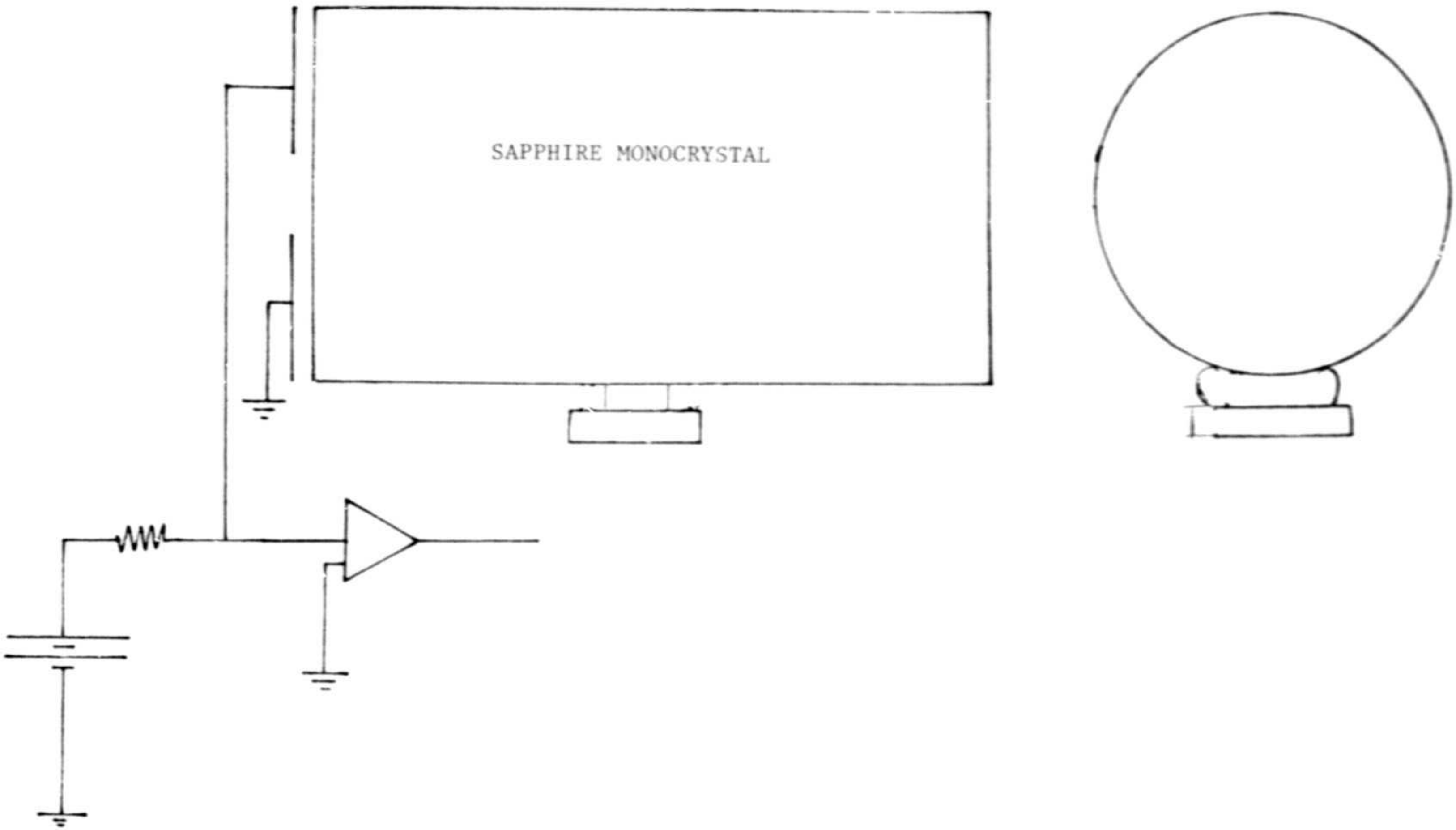


Figure 5