

# Design Considerations for an Axion Detector

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**Abstract**— The Axion Dark Matter eXperiment (ADMX) is conducting a search for dark-matter axions trapped in the halo of the Milky Way Galaxy. Axions, originally postulated to solve the strong CP problem in particle physics, would have been created as cold (non-relativistic) very weakly interacting particles in the early stages of the expansion of the universe. If their mass is in the range 2 to 50  $\mu\text{eV}$ , axions could be a significant component of the dark matter in the universe. The discovery of the axion, or placing limits on its abundance, would therefore have very important implications for understanding the nature of dark matter, which is one of the most significant problems in contemporary physics.

**Keywords**—dark matter, axions, microwave, cavity

## I. INTRODUCTION

Axions can be detected by their conversion to microwave photons in a strong magnetic field. The ADMX experiment employs a high-Q, 200 litre microwave cavity that can be tuned slowly through the expected axion mass range. The cavity is held at low temperatures in a field of about 7 T. If the density of axions is close to the value required to account for all of the dark matter in our Galaxy, the signal detected would be of the order of 10-22 W. SQUID preamplifiers followed by broad-band cooled HEMT amplifiers are used to obtain the required sensitivity. The frequency is swept at a rate of the order of 2 MHz/day.

## II. INITIAL AND GEN-2ADMX

To date, ADMX has ruled out axions with masses in the 2.0-3.6  $\mu\text{eV}$  range (mc<sup>2</sup>/h of 480-860 MHz) that would be predicted by the stronger of two standard axion models. ADMX is commissioning a dilution refrigerator to enable 100 mK temperatures for cavity and SQUID thereby increasing the signal-to-noise ratio by 20x, allowing the full

band of the expected axion mass and coupling space, even in the case of pessimistically coupled models, to be scanned by the second generation of ADMX. Expected noise temperature is 150 mK. The left panel of Fig 1 shows the cavity and SQUID amplifier insert being removed from the magnet.

## I. THIRD GENERATION ADMX

Work is underway to design and develop technology for a third-generation axion cavity detector, optimized for searches for the case where the axion mass is above the range searched by the current ADMX, say in the 10 to 50  $\mu\text{eV}$  mass range (3 to 12 GHz range). The detector sensitivity is proportional to  $B^2V$ , so that the dilemma for searches at higher frequencies is that cavity dimensions are comparable to the wavelength, so that the cavity becomes smaller as frequency goes up. The loss of volume can be addressed by increasing the magnetic field strength, say to 25-40 T. A conceptual diagram is shown on the right side of Fig. 1.

## II. CAVITY DEVELOPMENT

At the same time, a method of combining two or more cavities is being developed. The signals emitted from, say, 2 to 16 nominally identical cavities are combined together in phase and brought to the front end of the low-noise amplifier. All the cavities must resonate at the same frequency for the combination to be effective. A locking scheme using phase modulated RF signals and reflection measurements, known as the Pound or Pound, Drever, Hall (PDH) reflection locking method[1-3] is being investigated. This method is used by LIGO, VIRGO and other gravitational wave experiments to bring multiple optical cavities into mutual resonance.

The method used and progress to date will be described.

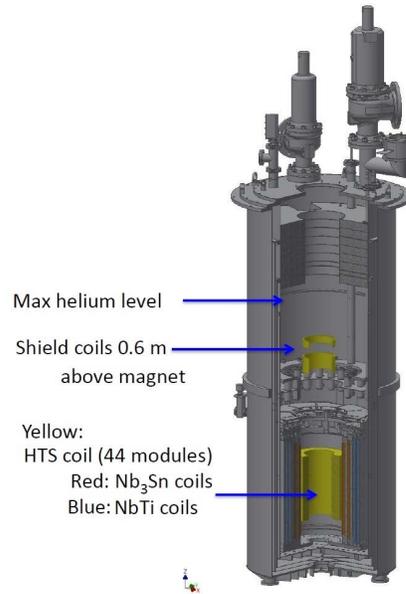


Fig. 1. Left: The ADMX insert, containing (bottom to top) the resonant cavity, SQUID amplifier and cryogenic post amplifier inside a bucking coil to maintain zero field at the SQUID, and helium reservoir is being removed from the magnet. Most of the 7 T magnet is below floor level. Right: Conceptual design of a 25 T HTSC magnet in which 2 to 16 cavities would be located to enable searches in the 3 to 12 GHz range.

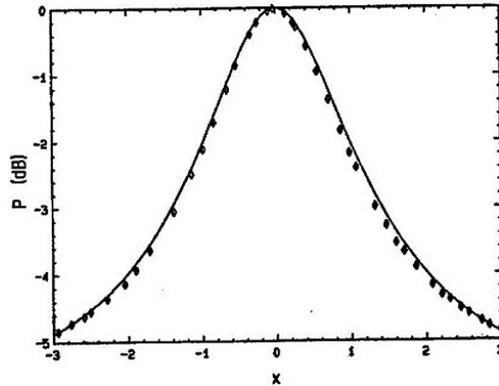
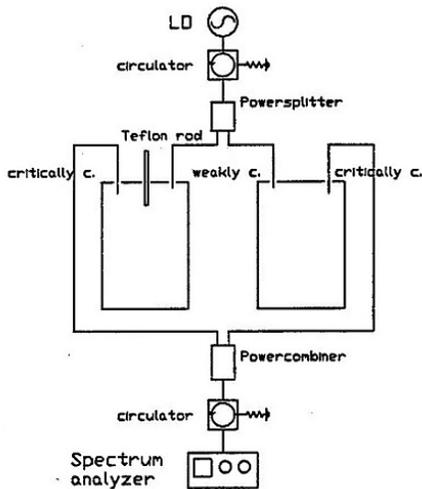


Fig. 2. Left: two TM010 resonant cavities are fed from a single oscillator (LO). The signals are split and injected into two nominally identical cavities through weakly coupled ports. Critically coupled ports extract energy from the cavities. The signals are combined and brought to a spectrum analyzer. Right: Power at the spectrum analyzer as a function of the difference in resonant frequencies of the cavities.

#### ACKNOWLEDGMENTS

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