Measurements in Search for 0.1 meV Axion–Like Particles and Hidden Sector Photons using Copper Resonant Cavities

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We present preliminary measurements from the electronics chain in the 34 GHz photon regeneration experiment at Yale. The experiment is a search for the coupling ($g = 10^{-6}$/GeV) of two photons to a light neutral boson (LNB) in the presence of a strong axial magnetic field. The final setup will consist of two side by side Cu resonant cavities, one of which will be coupled to the pulsed, $\sim$1 MW 34.29 GHz magnicon at Yale. Using the same apparatus, we will look for mixing between photons and hidden sector photons (χ=10^{-7}). The experiment will also have limited sensitivity to galactic halo axions. Preliminary tests of the electronics chain have yielded results that are consistent with original estimates.

1 Introduction

Several proposed extensions to the standard model of elementary particles have motivated a wide array of searches for new particles with sub–eV masses. For example, the axion [1] and other axion–like particles (ALPs) have been postulated to account for broken symmetries and should behave as weakly interacting sub–eV particles (WISPs) (see e.g. [2]). Additional *hidden sector* particles with very low masses arise from supersymmetry and interact only rarely with standard model particles [3][4]. In each case the discovery of a new low–mass neutral particle could also be a possible cosmological Dark Matter candidate.

Many searches for new sub–eV particles in the laboratory have relied upon their coupling with low energy photons. In particular the *light shining through walls* (LSW) experiments (e.g. [5][6][7][8][9]) and resonant cavity searches for galactic halo axions [10] have placed stringent limits on the photon coupling constants, predominantly below 1 meV. In this work we discuss preliminary tests of a LSW experiment utilizing two resonant cavities, one of which will be driven at 34 GHz by the high–power *magnicon* microwave source at Yale [11] [12].

2 Experiment

The apparatus [13] will consist of two side by side Cu resonant cavities, one of which will be driven by the 34 GHz microwave source. The second (signal) cavity will be electromagnetically isolated from the drive cavity, and cooled to below 10 K in a He gas flow cryostat. The cavities and cryostat will sit inside the bore of a 7 T magnet.

The electronics chain begins with a cryogenic low noise HEMT amplifier inside the cryostat and is followed by a room temperature microwave receiver. Tests of the room temperature components are summarized in the next section.

2.1 Receiver

The receiver [14] is a triple heterodyne with a total gain of approximately 130 dB. The room temperature segment of the electronics chain is shown in Figure 1. It is preceded by a cryogenic HEMT amplifier with a typical noise figure of 22 K. The 34 GHz RF signal is mixed down to 4.09 GHz, amplified and filtered, then is mixed down to 590 MHz. After further amplification the signal is mixed down to a few MHz in in–phase (I) and quadrature (Q) paths, where a 4 MHz low pass filter precedes the final voltage preamplifier.

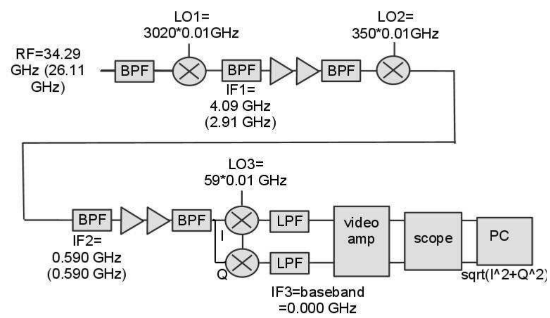

Figure 1: Block diagram of the room temperature electronics chain. Quantities in parentheses are the image frequencies LO–IF.

The first test of the electronics chain was to place a 50Ω terminator at the RF input to the first room temperature mixer. The middle column of Table 1 shows the resulting noise power measured at each component along the receiver chain. The right column denotes the expected power based on the assumption of a flat thermal noise spectrum, and on the specified gains and noise figures of the components cascaded to the point of the measurement. The table indicates good agreement between the measured and expected values.

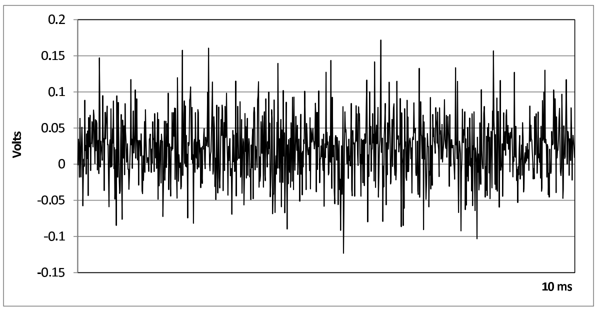

Figure 2: Oscilloscope trace showing the output of the voltage preamplifier with a 50Ω terminator at the input to the first mixer in the room temperature electronics chain.

The final component of the receiver is a pair of broadband voltage amplifiers each with gain adjustable

component	measured (dBm/Hz)	expected (dBm/Hz)
300K 50Ω term.		-174
(IF1=4.09 GHz)		
mixer 1	<-150	-173
BPF	<-150	-173
IF1 amp	-112	-112
BPF	-112	-112
(IF2 590 MHz)		
mixer 2	-116	-118
BPF	-118	-119
IF2 amp	-85	-85
BPF	-87	-86
(IQ mixer)		
LPF (I)	-92	-95
LPF (Q)	-94	-95
(V amp in)		
input (I)	-95	-95
input (Q)		-95

Table 1: Measured power and expected power along the room temperature components of the receiver chain using a 50 Ω terminator at the input to the first mixer. The "measured" values of the voltage amplifier inputs are reconstructed from the oscilloscope trace shown in Figure 2.

from 5× through 625× and maximum output of 1 volt. Figure 2 shows an oscilloscope trace of one amplifier's output in the I path, using a room temperature 50 Ω terminator at the RF input to the first 34 GHz mixer.

The trace shown in Figure 2 is related to the power at the output of the IQ mixer. First the standard deviation of the voltage fluctuations σ_V is calculated as

$$\sigma_V = \sqrt{\frac{\sum_i (V_i - \mu)^2}{N}}$$

where V_i is the ith voltage sample on the trace, μ is the mean voltage, and N is the number of points on the trace. The power P_N at the input is then

$$P_N = \sigma_V^2/G^2/R/B$$

where G is the voltage gain of the amplifier (5×) and R is its input impedance (50Ω). B is the 4 MHz bandwidth of the low pass filter. Table 1 contains the power reconstructed at the input in the I path (-95 dBm/Hz).

3 Outlook

3.1 Halo Axions

Like the photon regeneration experiments, the sensitivity of the apparatus to galactic halo axions is limited by the thermal noise power

$$\begin{aligned} P_N &= k_B T_N B \\ &= (10^{-23}\text{ J/K})(20\text{ K})(3.4\text{ MHz}) \\ &\approx 10^{-15}\text{ W}. \end{aligned}$$

where T_N is the typical noise temperature of the cooled HEMT amplifier and B is the bandwidth of the cavity in the TE011 mode, $B = f/Q$ =34 GHz/10^4.

The signal power P_S is estimated to be

$$P_S = \rho V \Pi Q E.$$

The halo axion concentration ρ is taken to be 0.45 GeV/cm^3 [15], or 10^{13}/cm^3 at 34 GHz. The probability of conversion Π is estimated by $(1/4)(gBL)^2$[16][17]. For g$\sim 10^{-4}$/GeV P_S is approximately 10^{-17} W or 1% of the noise power. This sensitivity could and should be improved, for example, with a lower noise amplifier, a cavity with a higher Q, or by implementing an experiment with more than one cavity (e.g. [18]). In the meantime the current apparatus can be useful for a measurement that is less sensitive but is still valuable as a proof of concept.

3.2 LSW experiment

Tests of the room temperature electronics chain and data acquisition are complete and the results are consistent with expected values. Fabrication and testing of the resonant cavities is ongoing, and the cryostat is being cooled routinely to temperatures below 10 K. The next steps will be to check the output of the electronics with a cold resonant cavity and HEMT amplifier at the input. Sensitivity of the experiment is expected to be on the order of g$>10^{-6}$/GeV for LNBs and $\chi>10^{-7}$ for HSPs [13].

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