IX. MOLECULAR BEAMS[*]

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RESEARCH OBJECTIVES

The distributions of electric charge and magnetism in an atomic nucleus are usually described in terms of multipole moments limited in number by the magnitude of the nuclear angular momentum. In this laboratory, atomic-beam techniques are used to determine such electric and magnetic moments. In addition, information about the radial distribution of nuclear magnetism can be obtained in cases in which more than one isotope is available. These techniques lend themselves to such precision that they will be used in this laboratory for the development of atomic clocks. These clocks are being used to make studies of the nature of time. Precision apparatus is under construction to observe not only the dependence of atomic time on gravitational potential but also the epochal dependence of nuclear, gravitational, and atomic time. Studies of the velocity of light are being made.

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A. SHORT-TERM STABILITY OF CESIUM ATOMIC CLOCKS

1. Introduction

During the past quarter, two areas of interest have received attention. A cesium beam tube assembly has been ordered from the National Company on a rental basis, and preparations are being made to generate a crystal-controlled X-band excitation signal at the cesium resonance frequency. Before closed-loop "clock" operation is attempted, measurements will be made of the beam-tube characteristics that are of importance in the servo-loop design (for example, response to frequency transients).

Superconductive cavity oscillators are being investigated as possible alternatives to the quartz-crystal oscillator and frequency-multiplier chain for applications in which a microwave source with extremely high short-term stability is required. A cavity is being constructed to operate at one-third of the frequency of the cesium resonance. Two possible oscillator configurations are described below.

2. Crystal-Controlled X-Band Source for Cesium Beam Excitation

Present plans for obtaining the X-band signal that is needed for exciting the cavities of the beam-tube assembly require that a crystal oscillator signal at 16.415414 mc be multiplied up in steps of 5, 7, 2, 2, 2, 2 to 9192.631770 mc. Preliminary investigation

of the microwave portion of the multiplier chain indicates that reasonable efficiencies can be obtained only with low-order multipliers. As a result, the following order of multiplication has been chosen: 16.4 mc (×7) to 115 mc, (×5) to 575 mc. The multipliers from 575 mc to 9192 mc will be a passive chain of four doublers, with sufficient filtering between stages in order to minimize power loss in undesired harmonics. It appears that a 200-mw signal power will be required at 575 mc in order to generate sufficient X-band drive to the beam tube. The possibility of generating the 575-mc signal passively in a quintupler and eliminating an active stage at this frequency is being considered.

3. Superconductive Cavity Oscillators

Noise analyses of crystal oscillators, which usually consider the effective noise temperature of the amplifier as the source of frequency fluctuations, indicate theoretical stabilities of the order of 1×10^{-14} for 1 second. However, considerably more instability is measured than can be accounted for by thermal noise and shot noise. Thus, the quartz resonator itself appears to be a major source of short-term instability. It has been suggested that internal friction and the accompanying changes in elastic constants resulting from imperfections in the quartz crystal, which are known to be causes of crystal-aging properties, may also account for short-term instability.

An attempt is being made to develop an oscillator whose stability is clearly determined by amplifier noise. It appears that if Q's comparable to those of the best piezoelectric crystals can be obtained with purely electromagnetic resonators, then considerable improvement in stability should result. Superconductive microwave cavities have, in the past, yielded Q's of the order of 10 million, and the theoretical limits are higher still.

Requirements to be considered in the choice of a superconductive material are:

(a) The critical temperature, at which superconduction occurs, must be approximately three times that of the operating temperature in order to realize a significant reduction in surface resistance at microwave frequencies.

(b) The material must be workable, and it must be available in a highly pure state.

The first requirement is satisfied by two metals, niobium and lead, with critical temperatures of 9.2°K and 7.3°K, respectively, and by certain metallic compounds. Of these, only lead is readily available in purities of 99.99 per cent, and better.

We are now preparing to construct a resonant cavity at 3065 mc from a lead of high purity, and operate it at the temperature of liquid Helium II (approximately 2°K). Two oscillator circuits with which these cavities could be employed are shown in Fig. IX-1. The first consists of a low-noise S-band amplifier (Fig. IX-1a), with feedback provided through a cavity of high Q to sustain oscillation. This oscillator was developed by H. G. Yates at Research Laboratory of Electronics several years ago, using cavities

of high Q at room temperature. The second scheme shown here (Fig. IX-1b) was sug-
gested by R. S. Badessa. The feedback path in this case contains two mixers driven
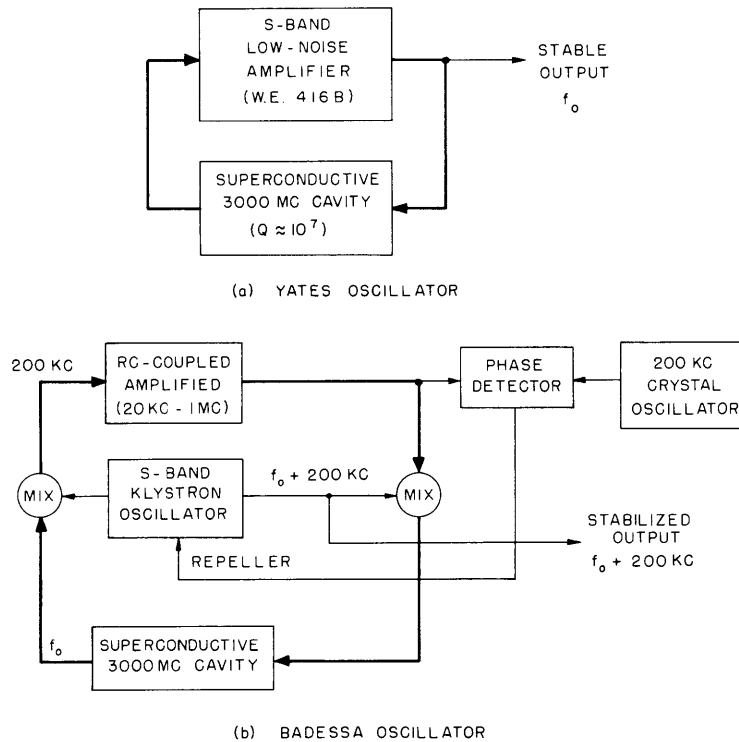from an auxiliary S-band oscillator to provide down conversion of the cavity signal to a

Fig. IX-1. Ultrastable microwave oscillator configurations.

convenient frequency such as 200 kc, and up conversion to the S-band cavity frequency.
The loop gain to maintain oscillation is provided at low frequency. This configuration
offers several advantages over the Yates circuit:

(a) A high-gain amplifier can be used, permitting very loose coupling to the cavity.
Thus the cavity is effectively isolated from external circuit variations.

(b) Amplifier phase drift, ordinarily a source of oscillator frequency drift, can be
minimized by appropriate design of the low-frequency amplifier.

A low-level output could be obtained from this oscillator at the cavity frequency
by introduction of an output coupling loop into the cavity. An alternative scheme
is used, however, which provides a high-level output and requires no unnecessary
loading of the cavity. The 200-kc amplifier signal is phase-locked to a 200-kc
crystal-controlled reference oscillator by means of a control loop that is closed
through the auxiliary S-band oscillator. Thus the auxiliary oscillator is forced to
be at a frequency that is exactly 200 kc away from the cavity frequency. No

difference in stability between the output frequency and that of the cavity has been observed in the initial experiments in which a cavity at room temperature was used.

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