RECENT PROGRESS ON ATOMIC FREQUENCY STANDARDS *

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Introduction

During the past few years development efforts on a variety of atomic frequency standards have remained active as new applications for precise time and frequency instrumentation continue to emerge. Such applications as synchronized communication systems, high-accuracy navigation techniques, deep-space tracking networks, aircraft collision avoidance systems, long-baseline-interferometry measurements, and relativity experiments have stimulated the development not only of higher-performance versions in terms of achieved accuracy, stability, and environmental insensitivity, but also of atomic standards that are smaller, lighter, more reliable, and at least potentially less costly. Levels of performance which only a few years ago could be obtained only from large, elaborate laboratory-type devices are now being made available to systems designers and applications engineers in commercial instrument packages small enough and rugged enough for convenient field use under very unfavorable environmental conditions. The designers of the more elaborate laboratory-type atomic standards have not been content to stand idly by, however, and performance of these devices has also improved dramatically.

In addition to the continuing development of the more familiar cesium atomic beam standards, rubidium gas cell standards, and hydrogen masers that will be described in more detail in the remainder of this paper, some promising newer types of atomic standards are also receiving attention and possibly offer hope for even better standards of the future. These include devices using the methane saturated absorption technique at a frequency of 88 THz, ion-storage devices, and several forms of atomic beam machines operating with the familiar atomic hydrogen resonance at 1420 MHz, but without maser oscillation.

Progress on Cesium Standards

Both laboratory-type and commercial cesium beam standards have been improved significantly during the past few years. Several national standards laboratories have succeeded in building cesium standards with documented accuracies (1 σ) near 5×10^{-13} and efforts are continuing to push this measure even lower to the 1×10^{-13} level [1]. These achievements have resulted primarily from (1) improved control and measurement of cavity phase shifts by using such techniques as reversible beams or velocity-modulated beams, (2) improved C-field magnetic shielding, and (3) better excitation and servo electronics. Measurement stability for these standards tends to be in the 4 to 10×10^{-12} range for 1-second averaging times and about 1×10^{-13} for averaging times longer than 0.5 to 3 hours, depending on the particular standard involved.

In the commercial area the emphasis has been both on better performance and on improved suitability for field use and other severe-environmental applications. Commercial 16-inch (41 cm) beam tubes will soon be available with a few parts in 10^{12} accuracy specifications, a 1-second stability of $<1 \times 10^{-11}$, and much-reduced sensitivity to various environmental influences [2]. An even smaller 6-inch (15 cm) beam tube has been developed specifically for severe-environment applications, such as on aircraft, and produces present commercial state-of-the-art performance in a complete-standard package that is one-half the weight and one-third the volume of present units [2].

Progress on Rubidium Standards

As in the case of cesium standards, the number of rubidium units now in use runs well into the hundreds. Recent development efforts on this type of standard have produced somewhat better short-term stabilities in the 5×10^{-12} range for 1-second averaging times, but have been concentrated more towards extending the operating environmental range and reducing the physical size. One version has been reported which provides 5×10^{-11} stability over an extended temperature range of - 55 to + 65° C [3]. Another rubidium standard, developed in England, has used a modified design approach to achieve a complete standard in a 100 cubic inch (1640 cu. cm) package that features a 5-minute warmup time and intermediate level stabilities of better than 1×10^{-8} [4]. Still other efforts have been directed, with considerable success, to developing a rubidium standard suitable for spacecraft use in the Apollo Applications Program.

Progress on Hydrogen Masers

Although this type of standard is not presently available commercially, significant progress has been made by other laboratories during recent years. Performance has been documented for field-operable units which shows stabilities in the 1×10^{-14} region for averaging times from 100 seconds to at least 100,000 seconds [5]. Another version is being developed with excellent overall performance that may be used in a spaceborne application to test certain aspects of relativity theory. Several national standards labs are also maintaining active programs to develop improved hydrogen masers. Problems associated with the hydrogen maser wall shift have received much attention, but the overall accuracy of the standard still remains somewhat inferior to that of evaluated cesium beam devices.

References

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