Frequency Control Symposium

Asbury Park, N. J., May 8, 1958

A Report by ***H. H. Plotkin***

IN the June 1956 issue of *Physics Today* we reported on the first meeting devoted to papers dealing with progress toward using atomic and molecular resonances as high-precision frequency standards. Since then, the Frequency Control Division of the US Army Signal Research and Development Laboratory has included papers in this field at its annual meetings. This year's meeting indicated the striking progress accomplished in all of the related phases of research and development, so that those present were again treated to an interesting and complete survey.

The various systems which have been considered can be broken down roughly into two types: passive and active systems. The passive system relies upon a good "flywheel", such as the conventional quartz crystal resonator, to maintain a coherent sinusoidal oscillation whose frequency drifts, if any, are relatively slow. The frequency of this flywheel is, in turn, referred to the sharp resonance response of some atomic or molecular transition, and the result of this comparison may then be used to lock the flywheel very precisely at some standard value. The active type of system involves the use of the now well-known maser devices. Here, the reference molecules are continually put into a cooperative radiating state, so that one actually derives a phase-stable and constant frequency reference signal from the molecules themselves. An external oscillator may now be phase-locked directly to the maser signal, giving sufficient power output to drive any appropriate frequency translator.

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In the design of passive systems for practical applications, it is important that the correction network be capable of handling the rapid perturbations to which the flywheel may be subjected. R. T. Daly of TRG, Inc., showed that under some rough environmental conditions, a broad atomic resonance is necessary to provide the required flexibility, thereby sacrificing some precision in the knowledge of the center frequency. In principle, such a compromise should not be necessary in an active system.

The ammonia-beam maser oscillator shows promise as a small mobile standard with excellent short-time stability. Papers on this subject covered the problems involved in its use, and showed that we have come a long way toward their solution since the first meeting. The difficulty of maintaining a high vacuum in the face of a large influx of ammonia has not prevented the Signal Corps and Polytechnic Research & Development Co. from developing small portable sealed-off models capable of several days' operation before requiring a simple rejuvenation procedure. F. Reder described the Signal Research & Development Laboratory's design for a small package, including maser and frequency translator, capable of use in missiles. Difficulties that are perhaps more intrinsic arise from the fact that the microwave spectrum of normal ammonia has a complex hyperfine structure, and that the geometry of the cavity and state-separator have a troublesome effect upon the maser's frequency of oscillation. An investigation of these effects was described by W. Higa of the Jet Propulsion Laboratory, who experimented with double-cavity masers. J. Bonanomi of the Laboratories of the

NOTABLE ACHIEVEMENTS AT JPL...

PIONEERS IN MOBILE MISSILE SYSTEMS

The "Sergeant's" excellent mobility characteristics, including the ability to operate under conditions of winter snow, ice, mud, desert sand and heat, significantly extend the capabilities of the system for close support of a ground command in our modern United States Army. The ease of operation and handling permits the weapon to be unloaded from airplanes or landing craft and be ready for firing with a minimum of preparation.

The system concept demonstrated in the "Sergeant" has permitted excellent mobility and speed of operation to be attained. The requirements of the Army have been stressed, resulting in outstanding characteristics of the weapon meriting the title of "America's first truly 'second generation' surface-to-surface tactical missile."

The responsibility for accomplishing this important achievement has been placed on JPL by the United States Army Ordnance Missile Command.

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Swiss Watch Industries at Neuchatel spoke about criteria which enabled him independently to reset a single maser repeatedly to within 10^{-10} of its mean frequency, an encouraging accomplishment for those hoping to use the maser as a primary standard. Further research will be directed toward using ammonia spectral lines with simpler structure, such as in $N^{15}H_3$, and cavities in which the frequency is less dependent upon dimensions, in order to remove the ambiguity from the maser's output frequency.

The most advanced atomic frequency control system continues to be that based upon a beam of cesium atoms which remain undisturbed in an electromagnetic field long enough to give rise to an extremely sharp resonance line. Recently, an opportunity arose to subject several of these devices to a dramatic test. An apparent discrepancy was detected in trans-Atlantic comparisons of National Company's "atomichron" and the cesium-beam standard at the National Physical Laboratory in England. In order to trace the source of the trouble, the Signal Corps flew two atomichrons plus an experimental beam tube to NPL. A. McCoubrey of National Co. presented preliminary results of a continuing series of tests made there. Immediately after their trip, and with only rough adjustment, the atomichrons were within one part in 10^{10} of each other and 3.5 parts in 10^{10} away from the NPL standard. They remained in this range during many deliberate misalignments and readjustments. These measurements are being supplemented by radio comparisons and astronomical time checks conducted in this country at the Naval Research Laboratory, National Bureau of Standards, and Harvard University. They serve to fix the cesium frequency more precisely and to increase our confidence in the use of these devices as standards.

A group of papers was devoted to progress in work on gas-cell frequency standards. The atomic beam apparatus achieves narrow lines by allowing the unperturbed atom to sample the probing field over as long a flight as possible. In the gas cell, on the other hand, the reference atom is confined to a smaller space by an inert environment which does not interrupt its radiation or absorption of microwave energy. Hyperfine transitions in the ground states of the alkali metal atoms have been observed with line widths of less than 100 cycles/sec while the normal Doppler width is several kilocycles/sec. So far, these narrow lines have been achieved with the use of "buffer" gases, such as the rare gases. However, several laboratories will attempt to obtain narrow lines in cells coated with "buffer walls" such as paraffin, which have already been shown to be inert in the sense that the magnetic polarization of colliding alkali atoms is not disturbed seriously. It has been found best to employ optical detection methods in this work since, under certain conditions, the absorption of the optical resonance radiation in the metal vapor changes considerably when the microwave frequency passes through resonance. H. Dehmelt of the University of Washington reported on his work concerning buffer gases and walls and optical detection. At the moment, it seems that the collisions between active atoms and buffering materials, which play so vital a role in making gas-cell devices possible, may also be a drawback in their use as primary standards. Several laboratories have noticed that the apparent resonance frequency is affected by buffer gases. P. Bender of the National Bureau of Standards reported that the cesium resonance increased in frequency by 580 cycles/sec per mm of neon while it decreased 200 cycles/sec per mm of argon. Similar findings were reported by M. Arditi of Federal Telecommunication Laboratories, where development of a gas-cell standard is well advanced. There was optimism that this difficulty could be overcome and that the gas cell could become a very valuable mobile and rugged frequency standard.

Several papers dealt with topics of general interest to those in the frequency control field. W. Markowitz of the US Naval Observatory described the astronomical procedure of measuring ephemeris time, and pointed out the difference between this time and what will be measured by integrating the output of an atomic frequency standard. T. R. Carver of Princeton University bravely ventured to "inquire into difficulties which lie beyond the practical problems" of extending the precision and stability of frequency standards and clocks beyond the now attainable part in 10^{11}. These "practical" difficulties are hardly trivial: inhomogeneous electric and magnetic fields, Doppler shifts, cavity pulling, pressure shifts, etc. However, by handling the atoms efficiently and with a "light touch" he concludes that one might achieve a precision of one part in 10^{15} before intrinsic signal-to-noise problems and the uncertainty principle bars further progress.

Some of the most exciting proposed applications of atomic clocks are those which will attempt to check the theory of relativity. C. H. Townes of Columbia University discussed some of the experiments which now appear possible. These include: putting a clock into a satellite to measure the transverse doppler effect, or time dilation in a system in relative motion; measuring the gravitational red-shift either from a satellite, balloon, or high mountain; and repeating the Michelson-Morley experiment using beats between masers oriented differently with respect to the "ether drift". J. Zacharias of MIT began by describing an experiment designed to measure the velocity of light to greater precision, by measuring the dimensions of a cavity accurately in terms of the wavelength of the mercury green line, and its resonant frequency in terms of the cesium hyperfine transition. However, this led him to a more general discussion of units and physical constants. Since c is so basic a quantity, should we be satisfied to know it only imperfectly in terms of arbitrary and vague notions of length and time? Perhaps it would be more to the point to accept the fundamental nature of c and to eliminate, say, length as one of our fundamental dimensions. The experiment just mentioned would then become merely a measurement of the mercury wavelength in terms of the cesium resonance frequency. We will probably be hearing more about this concept.