3:40-4:10 P.M.—COFFEE BREAK

2.4: A Dual Frequency VLF Timing System

Lowell Fey
National Bureau of Standards, Boulder, Colorado
Chesley H. Looney, Jr.
Goddard Space Flight Center, Greenbelt, Maryland

Two basic methods are used for synchronizing high precision clocks. One is the transportation of operating clocks between locations where clocks are to be synchronized, the other is the propagation of signals which contain timing information.

Until recently High Frequency propagation offered the highest practical precision of synchronization, with modest investment in receiving equipment. Improvements in the uniformity with which time scales can be kept, and the development of portable quartz crystal clocks and atomic oscillator clocks have reversed this situation. While the capabilities of H.F. propagation remains at precisions of around one millisecond and is limited by ionospheric fluctuation, synchronizations with precisions in the order of one microsecond are now being made with portable clocks. Since many of the demands in such areas as satellite and missile tracking, geodosy, seismology and sophisticated communications systems are in the range which can only be provided by portable clocks, increasing use is now being made of these devices. The difficulty with this approach is that extreme reliability is required of clocks to maintain synchronization for long periods after they have been synchronized. Furthermore, even without clock failures it has been shown that time kept by clocks driven by crystal oscillators may be expected to depart from that of a uniform standard in a random walk fashion, necessitating periodic resynchronization. One obvious approach as a solution to this problem is to make use of the extreme stability of

Very Low Frequency propagation compared to that of H.F. propagation. A further advantage to this approach is the reliableness of this mode of propagation and its extremely low attenuation rate, permitting world-wide reception from a single station. The simplest way to make use of these advantages is to synchronize a remote clock by use of a portable clock, then maintain the remote clock's synchronization by manual adjustment of its oscillator, obtaining the necessary corrections from VLF reception. For direct time synchronization, however, the VLF approach has serious limitations when carried out in the same way as the High Frequency case—that is, using pulse modulated timing information. The limitation is due essentially to inherent bandwidth restrictions and necessitates the use of rather elaborate receiving equipment in order to achieve high precision.

An alternative approach is not to use pulse modulation, but rather to transmit two VLF frequencies whose difference frequency contains the timing information necessary to identify a given cycle of the carrier frequency. The phase of that cycle would constitute a timing signal which could be received with the stability inherent in VLF propagation. Knowledge of the value of propagation delay when determined by portable clocks or possibly calculation, would, then permit resynchronization to be made, if it was lost. The two carrier frequencies would be received with usual VLF narrow band phase lock techniques rather than wide bandwidth pulse techniques.

A system based on this approach has been developed jointly by the NBS and NASA. It consists of the VLF transmitter, WWVL, located at Fort Collins, and controlled by atomic standards from Boulder, Colorado, and has been under test using receiving equipment located primarily at Goddard Space Flight Center, Greenbelt, Maryland.

The two carrier frequencies are broadcast alternately for ten second periods each using the same transmitter and antenna. The two frequencies are synthesized from a common source which is phase locked to the United States Frequency Standards at NBS Boulder using telemetry techniques. The antenna output phase of each frequency is maintained in constant relationship to the synthesized transmitter input phase by means of short time constant phase lock servos. The phase of each frequency as transmitted is maintained constant with respect to the NBS-U constant frequency offset approximation to the UT2 time scale.

The receiving system may consist of either one or two VLF receivers, a linear phase detector, multichannel recorder and a calibrator in addition to oscillator and dividers necessary to establish a time scale. The function of the calibrator, when driven from the receiving station clock, is to simulate the phases of the carrier frequencies as broadcast from the transmitter. An interchange of signals from the receiving antenna and the calibrator provides the phase information necessary to establish the relationship between the local time scale and the propagated time scale as received. A portable clock is used to establish propagation delay between transmitter and receiver.

From late October, 1965 until January 4, 1966, the two frequencies, 20.0 and 20.5 kHz, were transmitted. Since January 4, 1966 the two frequencies, 19.9 and 20.0 kHz, have been transmitted. Using one measurement each day during the most stable time of propagation, around midday, cycle identification was achieved more than 90% of the days on the path from Fort Collins to Greenbelt. The same technique resulted in cycle identification, on about two-thirds of the days with 19.9 and 20.0 kHz frequencies. These results were improved using various types of averaging.

2.5: An Improved 5MHz Reference Oscillator for Time and Frequency Standard Applications

H. S. Pustarfi

Bell Telephone Laboratories, Inc., Allentown, Pennsylvania

A 5MHz reference oscillator for use in time and frequency standards has been developed having improved characteristics. This oscillator utilizes a new 5 MHz crystal unit which provides an initial aging improvement of better than ten-fold over previously reported performance and a reduction of time for initial aging from many weeks to several