

III. MOLECULAR BEAMS

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A. CESIUM BEAM TUBE INVESTIGATION

During the past quarter a new control system was investigated which has the desirable property of minimizing the effects of the transient behavior of the cesium beam tube. As we mentioned in Quarterly Progress Report No. 67 (page 45), the transient occurring in the beam tube when the X-band excitation frequency is modulated could make circuit phase tolerances so severe as to preclude obtaining a stability of one part in 10^{12} . The technique used in the new system consists essentially of utilizing square-wave frequency modulation of the excitation at a sufficiently low repetition rate (11 cps) to provide intervals that are comparatively free of transients, and then gating these transient-free intervals for use in the control loop.

The various waveforms generated in the system are shown in Fig. III-1. Figure III-1a is the 11-cps square wave from which all subsequent waveforms are derived. Its duty

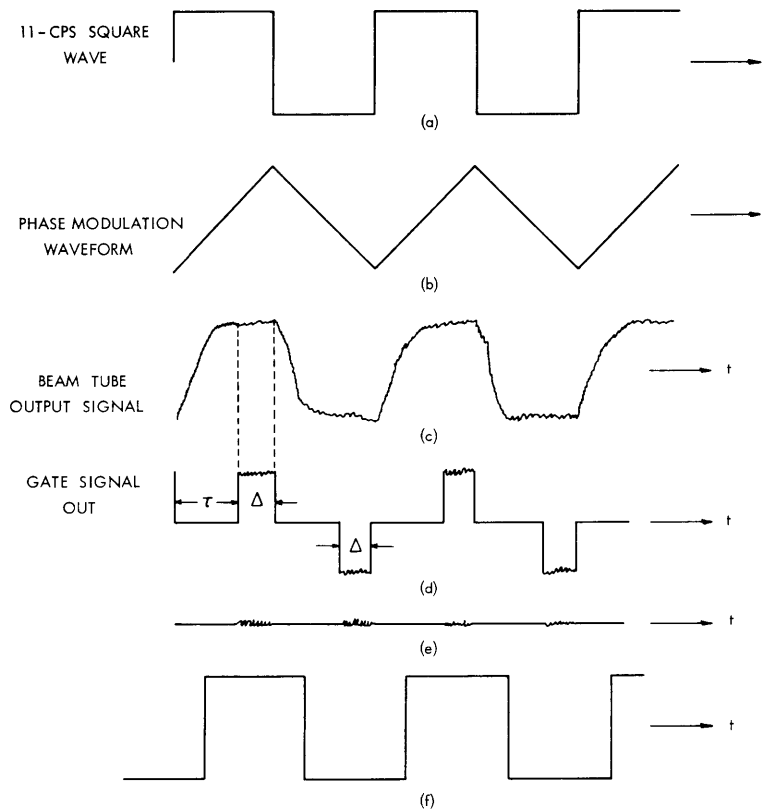


Fig. III-1. Waveforms present in the cesium clock system.

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cycle of 50 per cent is guaranteed by driving a 2:1 flip-flop from a 22-cps pulse. The square wave, appropriately delayed, also serves as the reference for the synchronous detector of the loop. Figure III-1b is a triangular waveform obtained by integration of the square wave of Fig. III-1a. It is used for phase modulation of the 16.4-mc crystal oscillator that, by frequency multiplication to X-band, serves ultimately as the excitation signal. Triangular phase modulation conveniently yields the desired square-wave frequency-modulation waveform. Figure III-1c is the waveform observed at the output of the beam tube electron multiplier, when the average excitation frequency is located on one side of the cesium resonance peak. The exponential rise and decay is the transient, and represents a time constant approximately equal to the time of travel of the cesium atoms down the beam tube. It will be noted that the low repetition rate of 11 cps permits a relatively flat region to exist just before the next frequency excursion. It is this flat region that is gated for use in the loop, as is shown in Fig. III-1d. Figure III-1e shows how the fundamental component of the signal of Fig. III-1d disappears to form a 22-cps series of random noise bursts when the excitation frequency coincides exactly with that of cesium resonance. Figure III-1f is generated by delaying the signal of Fig. III-1a, and represents the reference signal for the synchronous detector. Figure III-2 is a block diagram of the complete system.

Figure III-3 shows the method used for checking the quadrature level. The synchronous detectors are mechanical choppers to prevent spurious direct current from being

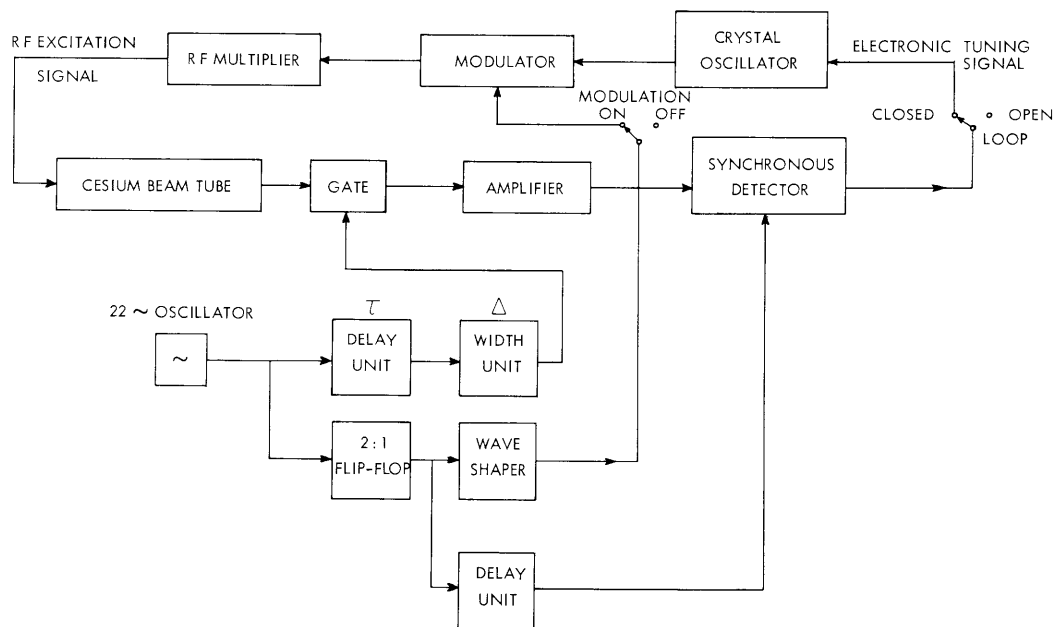


Fig. III-2. Cesium clock system utilizing time-domain filtering for minimizing transient effects.

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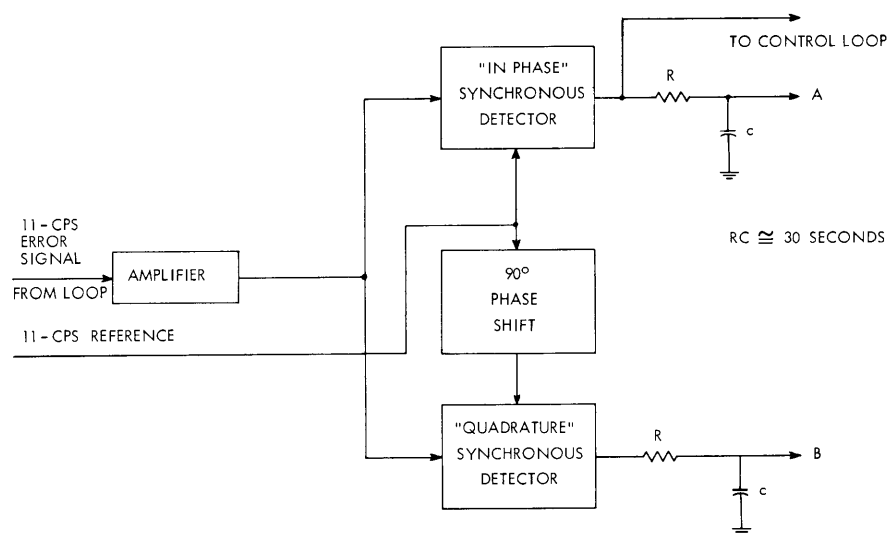


Fig. III-3. Double synchronous detectors for measurement of quadrature.

produced by reference unbalance. Because the references are 90° out of phase, the occurrence of zero direct current simultaneously at A and B can be achieved only by the complete absence of an 11-cps component in the incoming error signal. To obtain a calibration for the measurement, the loop is opened and the excitation frequency is detuned to one side of the resonance peak, to give maximum dc voltage at A. After measuring this voltage, the excitation frequency is recentered to the peak of the resonance, and the loop closed. Under the closed-loop condition the voltage at A will be very close to zero. The voltage at B will be a measure of quadrature and can be expressed as a fraction of the voltage that was observed at A under the open-loop condition. When measurements were made on the system of Fig. III-2, with a gate width Δ equal to one-third of a modulation half-period (see Fig. III-1d) and the gate was positioned just ahead of the next frequency excursion of the modulation, the quadrature level was well below that of the noise passing through the 30-sec time-constant filter. As the position of the gate was advanced toward the transient region, the quadrature appeared, as would be expected. The worst quadrature occurred when the gating was completely removed so that the signal to the synchronous detectors had the form shown in Fig. III-1c. Under this condition the quadrature was approximately 1.6 per cent of the in-phase signal level, or approximately 78 times the error voltage that would appear at the in-phase synchronous detector if the crystal oscillator were to detune one part in 10^{12} .

The stability of an atomic clock is determined partly by the stability of the resonance characteristic of its beam tube and partly by the stability of the electronics of the servo loop used to lock to it. These two effects are difficult to separate when seeking stabilities

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of one part in 10^{12} . Certain performance requirements must be met by the loop, however, if such stability is to be achieved. For example, suppose that we were to remove the modulation from the excitation signal of the beam tube and open the loop (see Fig. III-2). Since the signal entering the synchronous detector should now be completely uncorrelated with the synchronous detector reference, no direct current should appear at its output. The random variations that do appear should not exceed the dc level that would occur when, in normal operation of the loop, the excitation frequency is detuned by one part in 10^{12} . The measurement is made with a filter having a time constant equal to the measurement time required for one part in 10^{12} on the basis of beam tube signal-to-noise ratio. In Fig. III-4 is shown a block diagram of the noise susceptibility measurement system. The results are shown in Fig. III-5.

In Fig. III-6 is shown a block diagram of a test performed to determine the interchangeability of two independently adjusted electronic systems. Atomic clock No. 1 was operated in the normal manner, but the 11-cps error signal appearing at the output of its electron multiplier was fed to the electronic apparatus of the other clock. Because of the servo action of the first clock's loop, very little 11-cps signal would be expected at the output of the electron multiplier. However, if the loop is not operating properly, for example, because of quadrature effects or overloading on noise peaks, an excessive amount of 11-cps signal could exist. The presence of this component would cause a dc output to appear at the synchronous detector of the second clock in

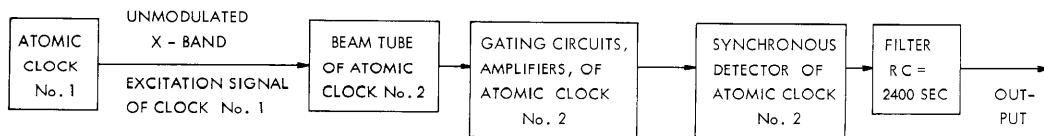


Fig. III-4. Measurement of susceptibility to noise.

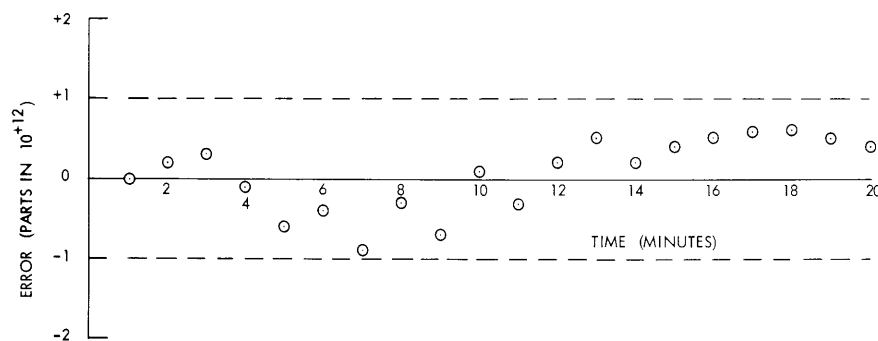


Fig. III-5. Noise susceptibility measurements.

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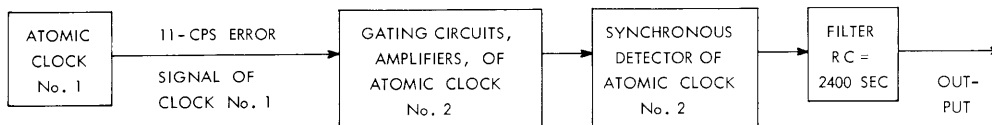


Fig. III-6. Measurement of interchangeability of two independently adjusted systems.

Fig. III-6. On the other hand, if the two electronic systems are in agreement and both are free of spurious effects, an input signal that gives a zero average out of one should give a zero average out of the other. Figure III-7 shows the results of such a test.

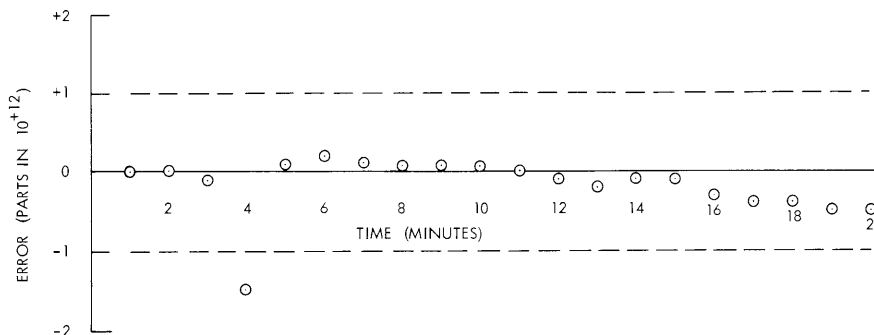


Fig. III-7. Electronics interchangeability measurements.

The two systems were adjusted independently and had in common only the 22-cps oscillator frequencies of Fig. III-2, necessitated by the fact that the synchronous detector of clock No. 2 was required to demodulate the modulation introduced by clock No. 1.

Measurements of frequency stability are now in progress. We hope to present the results of the tests in our next report.

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