VIII. SATELLITE TIME-DILATION MEASUREMENT[*]

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A. CRYSTAL OSCILLATOR STABILITY STUDIES

1. Crystal Locked-Oscillator Development

For applications in which long-term stability (that is, low drift rate) is of primary importance, crystal dissipation is usually held to a low value, approximately 10 microwatts. This tends to slow down the aging process in the crystal, but results in a relatively low signal-to-noise ratio for the oscillator, with accompanying phase fluctuations. Hence the requirements of good long-term and short-term stability are somewhat incompatible. In an effort to obtain high stability over time intervals ranging from a few seconds to several hours, we used two oscillators in cascade. The first, a Hycon Model 101C Ultra Stable Oscillator, employs low-level drive on the crystal to obtain long-term stability. The second crystal oscillator circuit is similar except that the crystal dissipation is greatly increased to provide a high signal-to-noise ratio at the expense of reduced long-term stability. A small signal is injected from the Hycon oscillator into the resonant circuit of the second oscillator to produce a phase lock. The locking bandwidth is kept small (approximately ±5 cps at 5 mc) so that only the slow variations of the injection frequency will be followed by the locked oscillator. The output is a signal whose short-term stability is self-determined and whose long-term drift is controlled by the injection signal.

In order for the locked oscillator to maintain the long-term stability of the injection signal, the locking phase must remain constant over the interval that is of interest. For example, a 1°/min rate-of-change of locking phase is equivalent to a frequency error at 5 mc of 1×10^{-11}. To prevent the error from exceeding 1×10^{-12}, for a locking range of ±5 cps, the permissible drift rate of the second oscillator is

$$\Delta\dot{f} \approx \Delta f_{max} \quad \dot{\phi} \approx 2.5 \times 10^{-5} \text{ cps/sec at 5 mc}$$

or

$$\frac{\Delta\dot{f}}{f} \approx 3 \times 10^{-10}/\text{min}$$

where Δf_{max} is the locking half-bandwidth, and $\dot{\phi}$ is the rate-of-change of locking phase.

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Rather than employing oven-temperature control on the locked oscillator crystal, the thermal time constant was increased by embedding the crystal in a large block of glass-wool insulating material. Typical locking phase drift rates that have been achieved fall in the range 0.05°/min to 0.1°/min.

2. Short-Term Stability and Spectrum Measurements

Using the system described in Quarterly Progress Report No. 58 (pages 127-130) with the oscillators described above, we performed short-term comparison measurements of two similar crystal oscillators. These measurements indicate that instabilities of 1×10^{-10}, averaged over a 2-minute interval, are common, with occasional drifts of $2\text{-}3 \times 10^{-10}$ occurring during the same interval.

Power spectrum measurements were also conducted with the use of a modified General Radio 738A Wave Analyzer. In these experiments, a 10-sec interval of the 1-kc beat from the oscillator stability-measurement system is recorded on tape at 15 in./sec and played back as an endless loop at 60 in./sec. Since the wave-analyzer bandwidth is approximately 4 cps and the net multiplication is now increased by a factor of 4 to 40,000, the fractional resolution bandwidth referred to the original oscillators is 4 cps/40,000 × 1 mc or 1×10^{-10}. The power spectra obtained have essentially the same shape that they would have if a clean audio signal had been fed directly to the analyzer. This shows that there are no instabilities greater than 1×10^{-10} occurring at rates faster than 0.4 cps, this rate being determined by the length of tape data used.

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