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 micro-watts. 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 $1 \times 10^{-11}$. To prevent the error from exceeding $1 \times 10^{-12}$, for a locking range of ±5 cps, the permissible drift rate of the second oscillator is

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

or

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

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

---

*This work was supported in part by National Aeronautics and Space Administration under Contract NASw-143; and in part by Purchase Order DDL B-00306 with Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology under the joint support of the U.S. Army, Navy, and Air Force under Air Force Contract AF19(604)-5200.
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 $1 \times 10^{-10}$, averaged over a 2-minute interval, are common, with occasional drifts of $2-3 \times 10^{-10}$ occurring during the same interval.

Power spectrum measurements were also conducted with the use of a modified General Radio 738 A 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 $4 \text{ cps} / 40,000 \times 1 \text{ mc}$ or $1 \times 10^{-10}$. 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 $1 \times 10^{-10}$ occurring at rates faster than 0.4 cps, this rate being determined by the length of tape data used.

C. L. Searle, R. S. Badessa, V. J. Bates, D. Buhl, R. L. Kent