VLB ARRAY MEMO No. 62

NATIONAL RADIO ASTRONOMY OBSERVATORY
Charlottesville, Virginia

January 15, 1982

MEMORANDUM

TO: B. Clark
K. Kellermann
S. Knowles (NRL)

FROM: S. Weinreb/C. Moore

SUBJECT: Local Oscillator System Draft

Attached is a draft of the local oscillator system write-up for your critique.

Attachments

cc: A. Rogers (Haystack)

NATIONAL RADIO ASTRONOMY OBSERVATORY

VLBA PROPOSAL

Craig R. Moore

January 13, 1982

Local Oscillator System

The requirement to operate at wavelengths shorter than 1 cm and with long coherent integrations for maximum interferometer sensitivity places severe requirements on the stability of the frequency standard(s) employed. The statistics of the stability of frequency and time standards is best expressed as the 2-sample Allan variance, $\sigma^2y(\tau)$ [1] and is plotted as a function of the integration period, τ. The square root of the Allan variance of a hypothetical frequency standard is plotted in Figure 1 to show the four regimes of noise characterized by the slope on a log-log plot. Figure 2 shows the square root of the Allan variance for various state-of-the-art frequency standards. The data for quartz, rubidium and cesium standards are taken from manufacturers' catalogs. The passive hydrogen maser performance, both experimental and projected, is taken from Walls and Howe [2] while the active hydrogen maser experimental data was published by Rueger [3] and the staff of SAO [4]. The superconducting cavity stabilized oscillator performance comes from work by Stein [5].

The coherence of a VLB interferometer is related to the observing frequency and to the Allan variance of the frequency standards used. This relationship is different for each of the four noise regimes of Figure 1. Rogers and Moran [6] have investigated this relationship and calculated a coherence function for several of the frequency standards shown in Figure 2. A portion of their results are plotted in Figure 3 to show the loss of coherence with increases in integration time and observing frequency for the case of a two element interferometer utilizing two active hydrogen masers, or two rubidium frequency standards. It is obvious that each element of the proposed array must have a frequency standard with stability comparable to a hydrogen maser if observations at 22 and 43 GHz are to be useful.

The above analysis considered only the effect of instability of the frequency standard on the coherence. Ionospheric and atmospheric phase fluctuations will affect the received signals and result in loss of coherence as well. Ionospheric fluctuations dominate at wavelengths longer than 15 cm while atmospheric fluctuations, due mainly to tropospheric water vapor, limit coherence of shorter wavelengths. Rogers and Moran [6] have attempted to estimate the Allan variance of the atmospheric fluctuations and their values are plotted in Figure 2. From this it is seen that for coherent integrations less than 10^4 seconds, interferometers employing active hydrogen masers will be limited by ionospheric and atmospheric fluctuations and not by the performance of the frequency standards.

Currently, active hydrogen masers are in widespread use in VLBI for radioastronomy, astrometry and geodesy. The newer units developed at NASA/Johns Hopkins Applied Physics Lab (NR) and at the Smithsonian Astrophysical Observatory (VLG-11) are a significant advance both in performance and in field reliability. OSA, Oscilloquartz in Switzerland, has developed an active hydrogen maser and is currently building several units for customers in Europe. Sigma Tau Standards Corporation of Tuscaloosa, Alabama is developing, with Air Force support, a small, active hydrogen maser which has the potential for considerable cost reduction with, it is hoped, only a modest reduction in performance from that of the large units. In addition, Hughes Research Laboratories, Malibu, California is developing a space qualified hydrogen maser for use on one of the NAVSTAR Global Positioning Satellites.

In the past there has been concern about the use of hydrogen masers in VLB interferometer systems relative to rubidium or cesium beam standards because of initial cost, difficulty in maintenance or repair, and susceptibility to environmental effects which limited long-term (> 3 hour) stability. With all of the development activity noted above, these disadvantages have been, and will continue to be, reduced in importance.

Another device under development is the Superconducting Cavity Stabilized Oscillator (SCSO) which can give an order of magnitude improvement in phase stability over an active hydrogen maser out to several hundred seconds. However, the SCSO is not stable over longer time scales and must be locked to another frequency standard in order to be useful for high sensitivity experiments. The SCSO is a laboratory device at present which is inherently susceptible to mechanical shock and vibration and must be cooled to near the λ point of He^4. As such, the real cost, performance, and reliability in the field have not been demonstrated. A single SCSO is being evaluated at Owens Valley Radio Observatory and is expected to give valuable information on their suitability as a frequency standard for independent oscillator interferometers.

We have also considered the use of a direct round trip phase link using a geostationary satellite. Several successful experiments have already been performed using the Hermes [7] and ANIK-B [8] satellites with encouraging results. In addition, the European Space Agency ECS satellite is being used by Dutch radio astronomers as part of a program aimed toward developing a phase-stable link to join radio telescopes in the UK, The Netherlands, Germany, Sweden, and Italy to form a truly phase-stable array. A major problem in implementing a geostationary satellite phase link is the motion of the satellite which introduces phase shifts of up to 10^6 turns per day. However, it seems that this can be satisfactorily cancelled by using a two-way link [7]. The problem of differential dispersion in the up and down link frequencies can be mitigated by employing one of the newer satellites with the 12/14 GHz link frequencies. The problem of atmospheric phase fluctuations will remain, however.

The cost of a suitable satellite circuit is not well established, nor, in fact, is there a straightforward mechanism for the use of satellite transponders with one's own ground equipment. All of the exerpiments to date have used experimental satellites, and it is not clear if a satisfactory solution can be found to the full time use of a satellite phase link. We note also that all of the previous experiments have used radio telescopes already available at the site for the up and down links. While the requirements on the ground station to support a satellite phase link are not excessive, the cost of acquisition and maintenance of the necessary ground stations is not negligible.

For these reasons we consider a hydrogen maser at each array element as the best method at present of obtaining a stable local oscillator system. We shall, however, continue to follow the progress of the Canadian-American ANIK-B and Dutch ECS experiments, and at the same time explore the cost and availability of other suitable satellite facilities.

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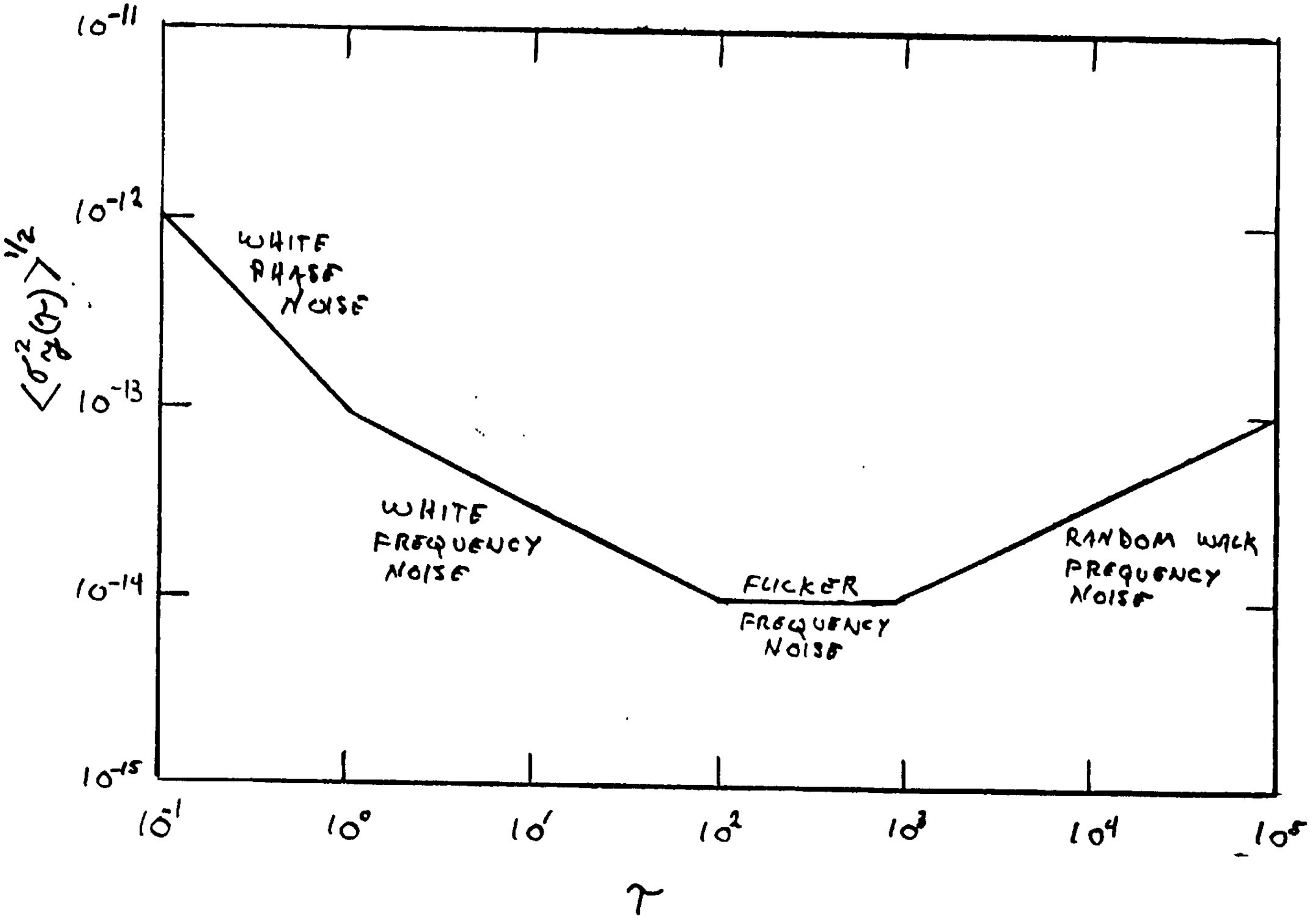

FIGURE 1 LOCAL OSC.

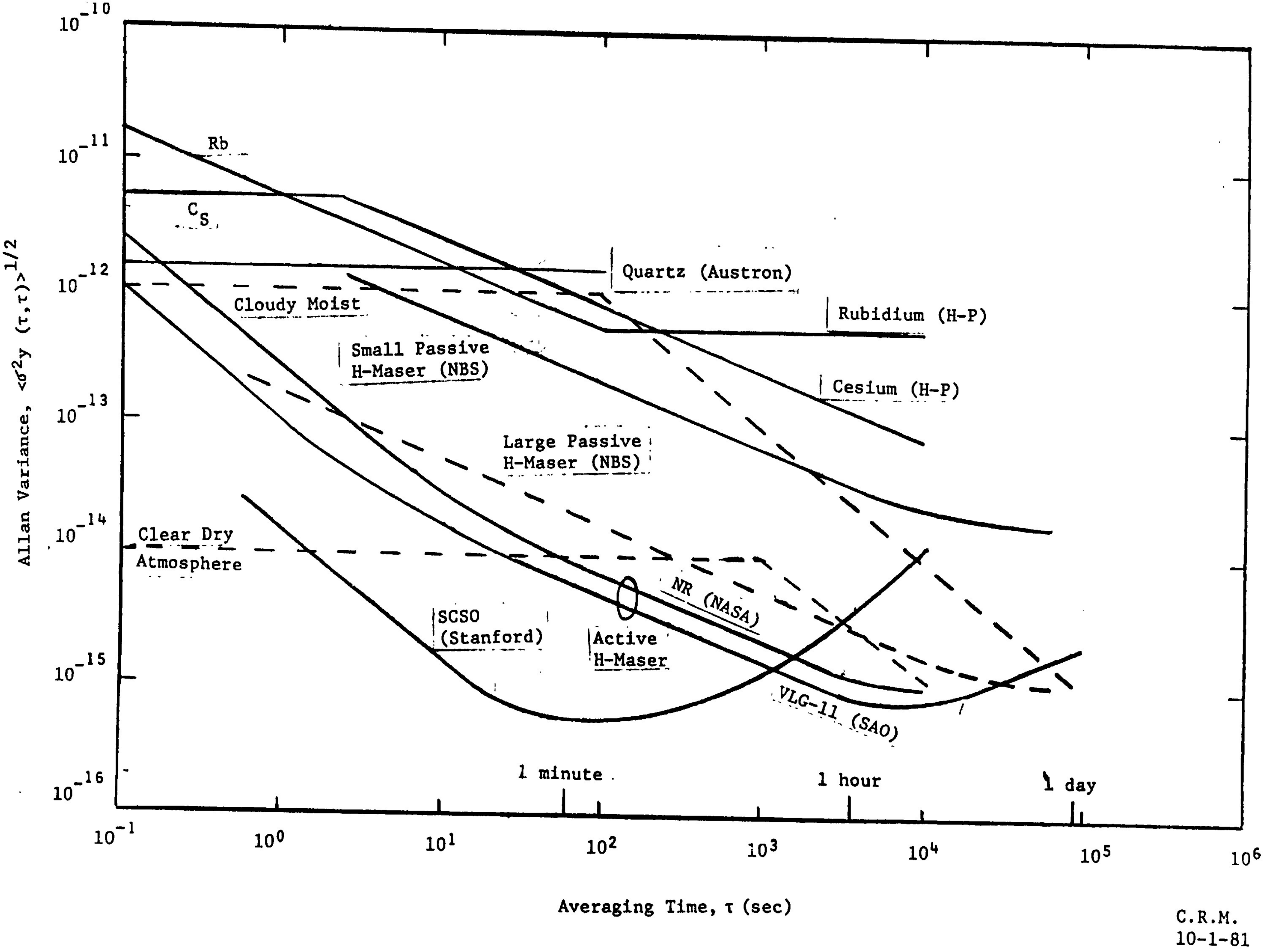

FIGURE 2 LOCAL OSC

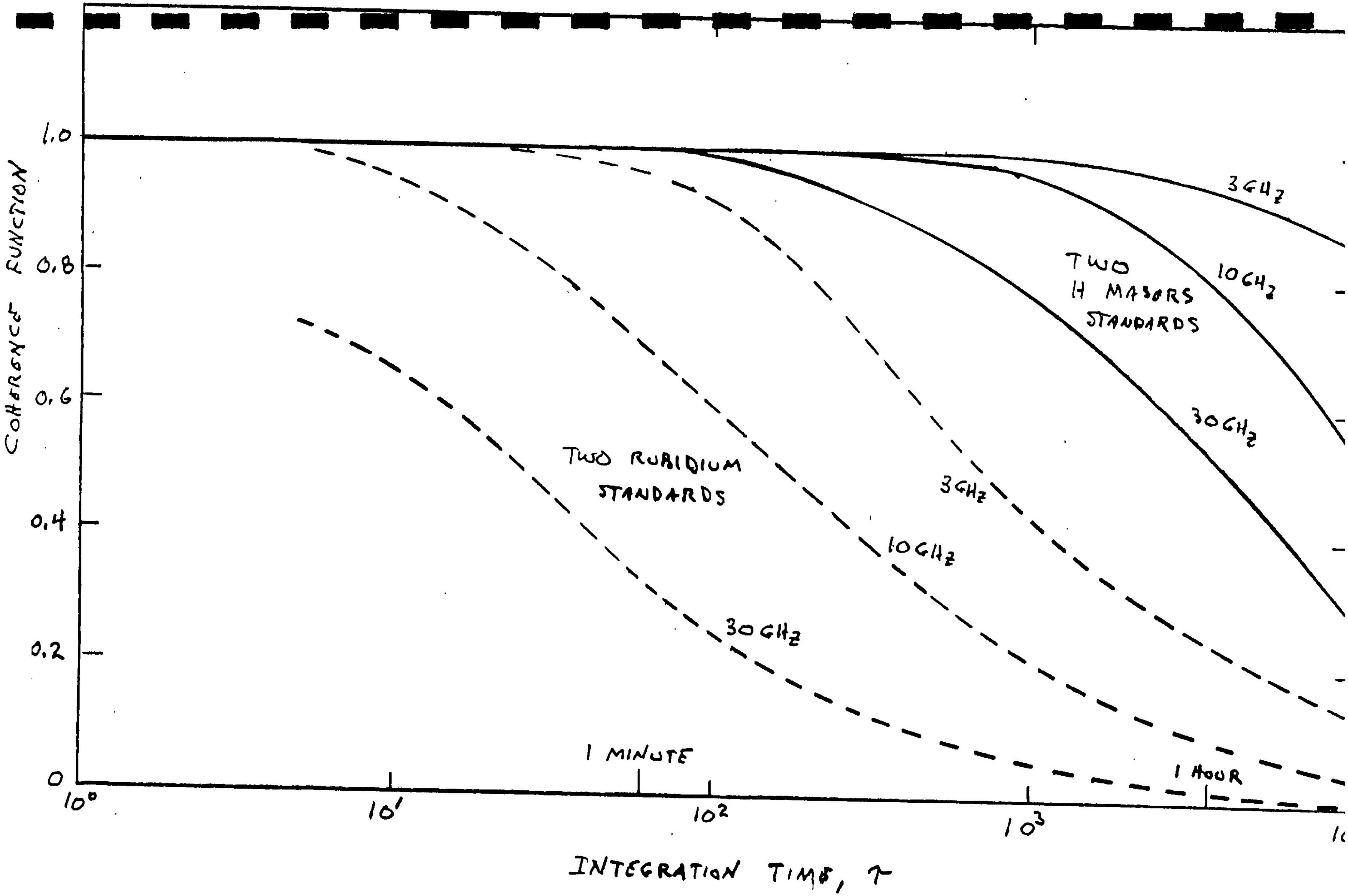

FIGURE 3 LOCAL OSC.