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Comparison of Maser Performance

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Executive Summary:

Of the three masers evaluated, the Symmetricom, the Chinese maser (SOHM) and the T4 Science, the Symmetricom maser appears to be the superior maser. Where specifications for the T4 Science and Symmetricom exist, both masers meet all the requirements of the original VLBA maser specification. The SOHM maser does not meet the original VLBA maser specification by a factor of ~2.

In addition the SOHM maser has no 100 MHz output so the 5 MHz output needs to be multiplied up to 100 MHz to be used on the VLBA. The requirement to add a high performance, very low noise, phase lock loop TCXO (to obtain the required 100 MHz reference) will add cost to an otherwise lower cost SOHM maser. This requirement to add a 100MHz output in conjunction with the poorer electrical performance rule out the use of the Chinese maser (SOHM) maser in the VLBA.

Purpose

The purpose of this report is to compare VLBI performance of three different brands of hydrogen masers. The Symmetricom maser (Sym) is model MHM 2010 with the low phase noise option). The T4 Science maser (T4) is an iMaser 3000 with low noise, increased magnetic shielding, finer frequency resolution, Ethernet capability, and additional 10 MHz output options. The proposed Chinese maser (SOHM) has no model number and no available options.

Methodology

The evaluation is based upon coherence times of the two masers. The coherence times are further divided into fast (>1 Hz) and slow (<1 Hz) processes, as is common practice [1].

Table 1: Comparison of the Allan Deviation (AD) specifications of the masers
This specification represents slow processes.

Time scale [seconds]	Comment	AD Sym	AD SOHM	AD T4
1		8.00E-14	5.00E-13	1.20e-13
10		1.500-14	7.00E-14	2.00e-14
100		4.00E-15	1.00E-14	5.00e-15
1000		2.00E-15	8.00E-15	2.00e-15
3600	1 hour	1.50E-15	7.00E-15	
86400	1 day	2.00E-16	5.00E-15	2.00e-16

In table 2 below, the phase noise is measured at the 100 MHz output of the T4 and Sym maser. The SOHM maser is measured at 5 MHz (the SOHM maser has no 100 MHz output). In order to guarantee good electrical performance at 100 MHz from the SOHM maser a high quality oven stabilized crystal oscillator phase locked to the 5 MHz output must be used. Typical price for such a device in low quantities is about $5200, but does not include the cost of packaging, assembly, testing and design time. The 100 MHz PLL usually has a bandwidth of at most a few 10s of hertz. Within this bandwidth the phase noise will track the 5 MHz maser while outside this bandwidth the phase noise will be determined by the 100 MHz crystal. The quality and associated cost of the oscillator will determine whether or not it is an improvement over the phase noise specifications of the SOHM 5 MHz maser. To meet the original project requirements the SOHM maser and 100 MHz PLL oscillator combination must have an integrated phase noise (1 Hz-1 MHz) of 0.6 ps maximum [3].

Table 2: Phase Noise (PN) specification for the two masers and the integrated phase noise (per decade and total) This specification represents fast processes.

Offset Fequency [Hz]	Sym [dBc/Hz]	SOHM [dBc/Hz]	T4 [dBc/Hz]	100 MHz RMS Jitter Sym [ps]	5 MHz RMS Jitter SOHM [ps]	100 MHz RMS Jitter T4 [ps]
1	-102	-100	-100			
10	-117	-125	-113	0.02	0.36	0.03
100	-126	-135	-122	0.02	0.12	0.03
1000	-133	-145	-148	0.02	0.12	0.01
10000	-145.00	-134.00	-151	0.022	0.16	0.01
		Total		0.040	0.43	0.04

The Sym 5 MHz output is used in various places in a VLBA antenna such as the RDBE and 1 PPS generator. The effect on these components will not be discussed here rather the effort will concentrate on the local oscillator systems in the antennas. The local oscillator chain is phased locked to the 5 MHz maser and as such, the slow variations of the 5 MHz oscillator will be tracked by the LO.

The quantity of interest in VLBI is the coherency time. Thompson, et al [2, equation 9.119] give an approximation for coherency time: $2\pi\ \nu_0 \tau_c \sigma_y(\tau_c) \approx 1$, where ν_0 is the (sky) frequency, τ_c is the time scale and $\sigma_y(\tau_c)$ is the Allan Variance which will result in a one radian rms phase error. As an example we will look at 100s time scale. From table 1, $\sigma_y(100)$=4e-15 for the Sym maser. We can solve for the frequency and get ν_0 = 160.8 GHz. For the SOHM maser ν_0 = 112.5 GHz [$\sigma_y(100)$=1e-14]. This calculation assumes one antenna with either a SOHM, T4 or Sym maser and one antenna with a perfect time base. In reality, we must look at two antennas with both SOHM, T4 or Sym masers where the variances of the two masers add. Or we can multiply the Allan Variance of one maser by √2.

Using the values for the Allan Variance in Table 1 and the factor of √2, we can find the frequency versus integration time that result in a one radian phase error. The graph is shown below.

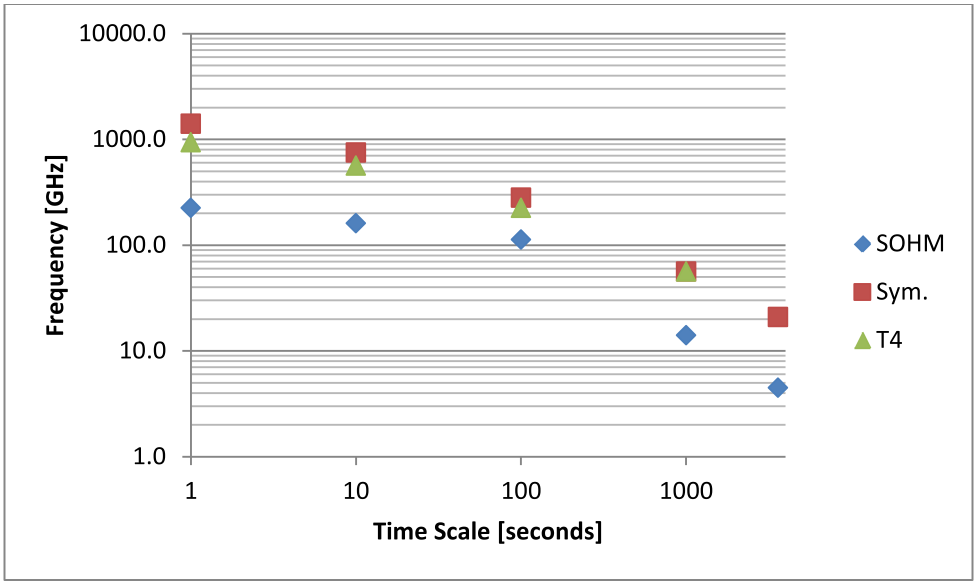

Figure 1: Frequency versus time scale resulting in a 1 radian RMS phase error due to slow process Allan Variances.

Of course, at the higher frequencies the variance due to the atmosphere dominates most of the time.

Table 3 shows the data from figure 1. On time scales of 10 to 100 seconds, the SOHM maser can only integrate for 1/10 the time before accumulating 1 radian of RMS phase error for the equivalent sky frequency of the Sym maser. The T4 maser could integrate 100 times longer than the SOHM maser (at 225 GHz). A more realistic result based upon the highest observing frequency of 86 GHz, the SOHM maser can only integrate one fourth the time of the Sym maser before accumulating 1 radian phase error. The T4 maser is a little worse at 3.6 times longer than SOHM maser. Using this metric, the Sym maser performance looks superior to the SOHM and T4 maser. However, the T4 performance is very close to the performance of the Sym maser.

Table 3: Data from figure 1 and interpolated data at 86 GHz for the Sym, SOHM, and T4 masers

Integration Time [seconds]	Frequency [GHz]		
	Sym.	SOHM	T4
1	1406.7	225.1	937.8
10	750.3	160.8	562.7
100	281.3	112.5	225.1
185	---	86	---
667	---	---	86
738	86	---	---
1000	56.3	14.1	56.3
3600	10.4	4.5	---

Lifetime

The SOHM maser has a published lifetime of 8 years. It has been our experience that the Symmetricom Masers will last at least 20 years.

Conclusions

The requirement to add a high performance, very low noise, phase lock loop TCXO (to obtain the required 100 MHz reference) will add significant cost to an otherwise lower cost SOHM maser. That cost in conjunction with the poorer electrical performance rule out use of the Chinese maser (SOHM) maser at the VLBA.

Of the three masers, the Symmetricom, the Chinese maser *(*SOHM) and the T4 Science, the Symmetricom maser appears to be the superior maser. Where specifications for the T4 Science and Symmetricom exist, both masers meet all the requirements of the original VLBA maser specification [3]. The SOHM maser does not meet the original VLBA maser specification.

References

[1] S. Weinreb, *Short-Term Stability Requirements for Interferometric Coherence,* Electronics Division Internal Report No. 233, June 1983.

[2] Thompson, Moran, Swenson, *Interferometry and Synthesis in Radio Astronomy*, Second Edition, Wiley-VCH, Weinheim, Germany, 2004.

[3] D'Addario, Thompson, Weinreb, *Hydrogen Maser Frequency Standard*, VLBA Project Specification: A53308N001, June 13, 1985.

Appendix

The data from the previous section are presented here in the time domain. The maser manufacturer Vremya-CH (V-CH) was added to the analysis of this section. The performance of their maser is roughly equivalent to Symmetricom and T4 Science masers.

Table 4: Same as figure 1 except in terms of time stability.

Time scale, τ_c [seconds]	Stability [ps]			
	SYM	SOHM	T4	V-CH
1	0.1	0.5	0.1	0.2
10	0.2	0.7	0.2	0.3
100	0.4	1.0	0.5	0.6
1000	2.0	8.0	2.0	2.0
3600	5.4	25.2		5.4
86400	17.3	432.0	17.3	60.5

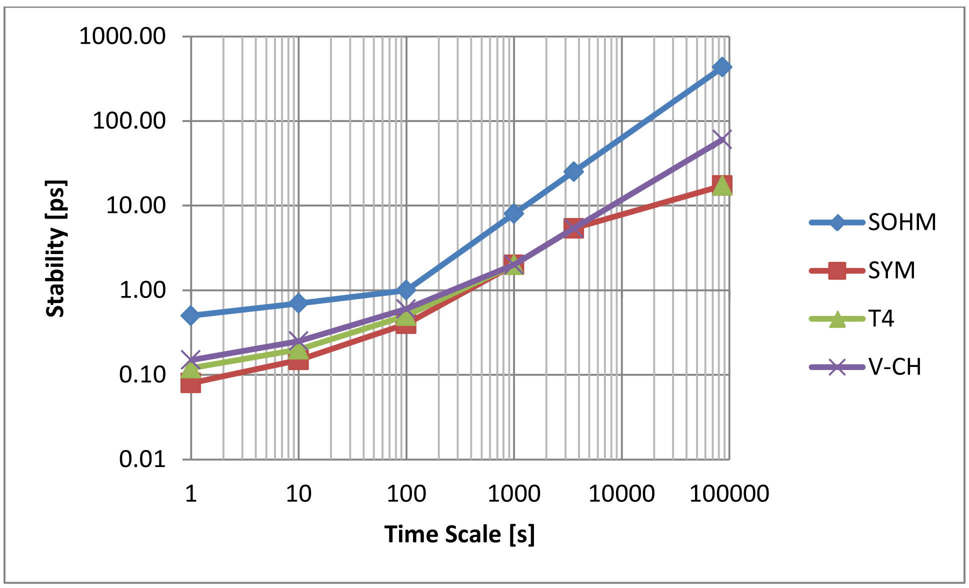

Figure 2: Stability in the time domain [$\tau_c\,\sigma_y(\tau_c)$] for a single antenna.