Hardware/Software configuration of the Time & Frequency laboratory at the Medicina Observatory

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Introduction

Since the primordial history, man looked at the stars aiming to understand his origin and his evolution within the observable universe. In that perspective, Time has been recognized as the way to order and quantify the beat sequence of events that build up our lives. Nowadays the modern technology has pushed the measurement of Time at the forefront of our knowledge of the fundamental laws of the Physics. Mainly radioastronomy and in particular VLBI now play exciting roles in this respect. Without entering in the theoretical details relevant for our case (to be written in a following article) we want to present here the results of more than thirty years in implementing, operating and forecasting new applications of Time & Frequency measurements, starting from the VLBI specifications of the Medicina observatory. These can be summarized (in the most stringent way) with the following sentences:

1. The highest possible level of reliability. Time and Frequency signals generated at the station have been considered, up to now, only a ***service***, not a direct science observable, with the following electrical properties:

a. a fractional frequency stability of a few parts in 10^{-14} over a few hours (Max degradation of less than a phase radiant in the rms residuals of the VLBI cross correlation up to 22GHz and due only to the local frequency reference);

b. a phase noise suitable not to degrade acquisition of Sky frequencies up to 40GHz.

2. A local UTC estimation at the order of a few tens of nanosecond, shortly recoverable, after any possible malfunction. Actually, in principle, VLBI does not need such timing at all. As a matter of facts, any strong celestial calibrator, received at the beginning of a VLBI experiment can give such info. At the same time, it is clear that the a-priori knowledge of the so called Clock Offset, between a common, reliable, easily accessible, timing signal source like the GPS and each atomic standard located at every radio astronomical station (as the synchronizer of the local data streams), will speed up a lot the initial *fringe search* operation, needed to "align in time all the data streams coming from the participating stations to a VLBI session.

Our experience has confirmed, after almost 40 years, that a combination of an H-Maser, a secondary atomic frequency standard (like a Rb clock) and a single frequency, timing GPS receiver, can cope satisfactory with all that. Ancillary, but compulsory, equipment is a redundant power supply system, a few high isolation distribution amplifiers and a daily data recording system. This last will estimate the Clock Offsets of each of the station atomic standards, by a set of dedicated counters set for Time Interval measurements, between the local 1PPS (one peak per second) generated by each atomic clock of the station, and the 1PPS of the GPS, taken as the common reference.

Just for historical reasons (but also to ask for your present appreciation of our effort spent in the past), we want to mention here the big trouble we had many years ago when the only timing systems available were restricted to the "TV

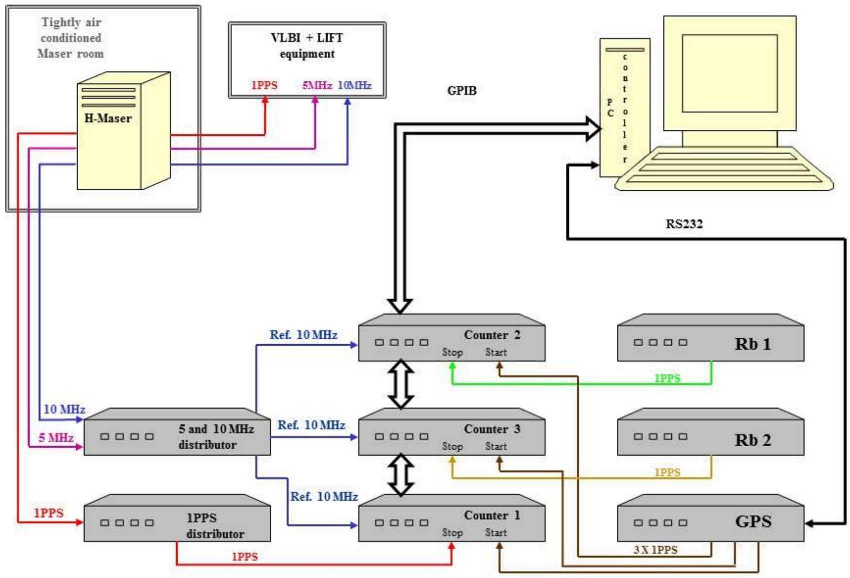
Sync carrier comparison method", or the Loran-C navigation signals or, more recently, when the initial GPS service was degraded by the so called Selective Availability and when no proper timing receivers were available.

As everybody can understand, the overall software needed to handle all such data records had to be continuously updated, across so many years. First the daily program reading the operating parameters of the H-Maser: we had to start with the old EFOS4 model (by the way, without any output interface, so we had to design and build a new one [1]) and modify it to be compatible with the new i74 H-Maser, currently installed at the Medicina T&F laboratory. Secondly we had to cope with different generations of GPS receivers and, above all, with the many brands of PCs and versions of their operating systems that had to be used. So starting from the Apple II we moved to PCs running at first Microsoft DOS 3.3 and then their numberless Windows versions, until the present one that runs under XP.

We stress this fact here because nowadays we find a bottleneck for future upgrades, having to handle both the obsolescence of the XP operating system and of the controlling software (written around eight years ago under LabView version 8.6.3), together with their simultaneous compatibility.

The Hardware/Software configuration

The block diagram of our instrumentation dedicated to T&F is reported here.



The H-Maser is installed in a separate room: a commercial, high performance, PID temperature controller sets its air conditioning running on a complete independent system from the rest of the antenna control building (the system utilizes a large capacity water tank in order to smooth as much as possible any Temp variation). The nearby room hosts the T&F laboratory where we can have full control of all the signals we generated here.

In particular here we are able to make various kinds of cross checks to identify almost any malfunction, through an analytical comparison of the past records of all atomic standards we have.

In the diagram you can see the H-Maser and two Rubidium standards together with the three counters that, running round the clock, acquire the Clock Offsets of each of them, with respect to the TAC32plus timing receiver.

From the actual GPS data, it can be easily shown (even if not diffusely recognized) that the GPS timing cannot be used as it is, but it is compulsory to make averages, long enough to overcome the intrinsic time variability of the Time Interval measurements made across the 1PPS signals of the GPS (start) and of the H-Maser (stop). The reference [2] explains this in greater detail.
The code TAC32plus [3] controls the Motorola module, making out of it, a very good timing receiver. In [4] we describe our implementation of such module. This unit also includes a proper distribution amplifier, with intrinsic Jitter of only a few nanoseconds, for four 1PPS signals (as the maximum number of allowable BNC connectors on the front panel).

Not to lose any bit of info associate with such data, we decided to make averages, almost one hour long, (24 records per day) with only 60 seconds lost every hour, dedicated to the housekeeping. This last includes recording data on the local disk and three optional functions: send data via emails to a selectable list of operators, transfer files to a central server, as well as generate the data base compatible with the "absurd" format of the VLBEER now used in VLBI (*Attention! The selection of the Australian language in the PC is compulsory just for this type of compatibility*).

In order to centre the hourly averages on the 00 minutes of the hour, the program starts taking data at minutes 32 of each hour.

Actually when we have added more frequency standards as backups of the H-Maser, we have accordingly scaled the number of measurements (=number of seconds, because the signals are 1PPS) taken by the first, second and third counters, each dedicated to its respective atomic reference. With atomic Rubidium clocks, as backup, we have dedicated only 120 seconds to the second and (eventually) third counters, leaving the longest possible average to the first counter, dedicated to the H-Maser. Here follows a sketch of the time sequence across each hour, with three counters:

	25'00''	**26'00''**	27'00''	28'00''	**29'00''**	30'00''	31'00''	**32'00''**	

H-Maser	FTP+ email	**OLD Rubidium = Rb1**	FTP+ email	**NEW Rubidium = Rb2**	FTP +email +VLBEER	**H-Maser**
3180 sec **◀| Stop**	60 seconds	120 seconds **Start |▶ ◀| Stop**	60 seconds	120 seconds **Start |▶ ◀| Stop**	60 seconds	3180 sec **Start |▶**

The first row lists the sequence of the MINUTES of every hour to be waited by each counter before starting to take measurements, one per second. For the three counters case reported here: the H-Maser data are averaged over 3180 seconds, Rb1 for 120 seconds as well as Rb2.

In the following table we report the values to be taken by the significant variables in the other cases when or three or two or only one counter would be used:

Case N	Count2	Count3	Sec for FIRST counter	Wait Min1	Sec for SECOND counter	Wait Min2	Sec for THIRD counter	Wait Min3	
0	ON	ON	3180	32	120	26	120	29	H-Maser +Rb1+Rb2
1	ON	OFF	3360	32	120	29	0	999	H-Maser +Rb1
2	OFF	OFF	3540	32	0	999	0	999	H-Maser

Concerning the ***structure of the program***, we remind here that:

- each hourly average of the H-Maser data is stamped with the value of the hour (xx:00) at the center of the acquisition period (var: “On the hour”, “On the hour”2, “On the hour”3);
- for Rb1 and Rb2 instead the time stamp is XX:30;
- because the program can be launched before or after the minute 32 of any hour, the name stamps have to be adjusted accordingly;
- the vertical scale of all the plots can be modified in real time; at the new hour data batch, the default value will be restored; the scrolling bar allows to view almost one day back;
- the two first frames assign the initial values to the most relevant variables; then follows an indefinitely long WHILE cycle, that can only be interrupted by the general **STOP**; here are contained the 2/3 loops of the counters, each followed by a period of 60s so there is plenty of time for full data housekeeping as follows: committed recording on the local disk first, but also the optional transfer of the daily files both to a list of emails (T&F operators) and to a central local server as a long term backup. Finally in order to satisfy the format imposed by the VLBEER database a special file is generated and uploaded on a daily basis (see examples in the appendix). Each of these functions is controllable in real time by a dedicated pushbutton on the front panel of the program (green ON / gray OFF);
- some efforts have required to define in real time the so called “on hour” variable; other specific instructions were required to compute MJD at the time of the first run of the program, as well as at every new hour; these last numbers allow to check since when the program is running without interruption.
- new data are appended and/or created to the files on the ***local disc*** in the default Directory. Then there is NO trouble if the expected directories and files are not present. The same is NOT true for the VLBEER database on the Bologna VLBI server. **Here, they must be present in advance (typically update them each new year, for the following one)!**

- just historical reasons motivate the following list of the IEEE488 counter addresses:

VISA session	Address number	Counter
1	4	Agilent 53230a FIRST
2	3	HP 5334 SECOND
3	5	Agilent 53230a THIRD

Final considerations

The more than 30 years old Rubidium atomic clock made by Rohde Schwarz is still working but it cannot be considered a reliable backup for the H-Maser. So that is why we have purchased a new atomic Rubidium standard made by Stanford Research Systems, type FS-725.

Again this has been a new occasion to revise our previous work with a more ordinated version of the software code controlling the station, as explained before. We must say that the old HP 5334 counter remains the easiest machine to control and probably a bit more accurate with respect to the cheaper new units by Agilent. In particular these units had to be controlled by a rather complicated setting sequence in order to let their displays ON along all measurements. We warn you that, in case you had sent wrong commands to these counters, they can lock up and cannot be reset from remote; then to be sure anyway of a real clean startup, you have to *switch them locally OFF and ON again* in advance (even if we have inserted commands like INIT, CLS and RST in their initialization sequence).

Conclusions

The authors have designed, built and operated a T&F frequency station with extremely high reliability since the beginning of the VLBI era at the Medicina radioastronomy station. All performance requirements have been fulfilled satisfactory. These results have been obtained through a continuous work of ordinary maintenance as well as of many original upgrades to exceed the previous achievements. By the way, all these information have been transferred to our colleagues of Cagliari and Noto to let them use or our software or rewrite their own.

At present we use two programs:

- **Maser-Rb.vi** controls two counters: the first monitors the H-Maser; the second Rb1;
- **Maser Rb1 Rb2.vi** controls three counters: H-Maser, Rb1 and Rb2.

Anybody interested to have a copy of the code can ask one of the authors. Recently we have installed in a WIN7 machine, running LabView 9, the automatically upgraded version of the present program MASER-Rb.vi (suitable for 2 counters). We plan to have shortly a new PC running Win10 and the latest version of LabView: it remains to verify if the present drivers for the IEEE488 card will remain compatible. As an alternative we are investigating the possibility to control the new counters via Ethernet and not via the IEEE488 protocol, but this will require to learn in details the new network procedures.

VLBI has not been the only scientific target for the T&F lab at Medicina. In the past we have qualified even space hardware for the Cassini mission [5], where we utilized our original [6] measuring Allan Variance estimators. Our T&F signals have been utilized in all other radio astronomical or GEO related experiments organized by ASI or other scientific institutions that asked to be hosted at the Medicina station. More recently we have successfully participated to the LIFT project and its follow-up, aiming at making direct comparisons among atomic clocks linked via optical fibers and the VLBI observables [7].

Acknowledgments

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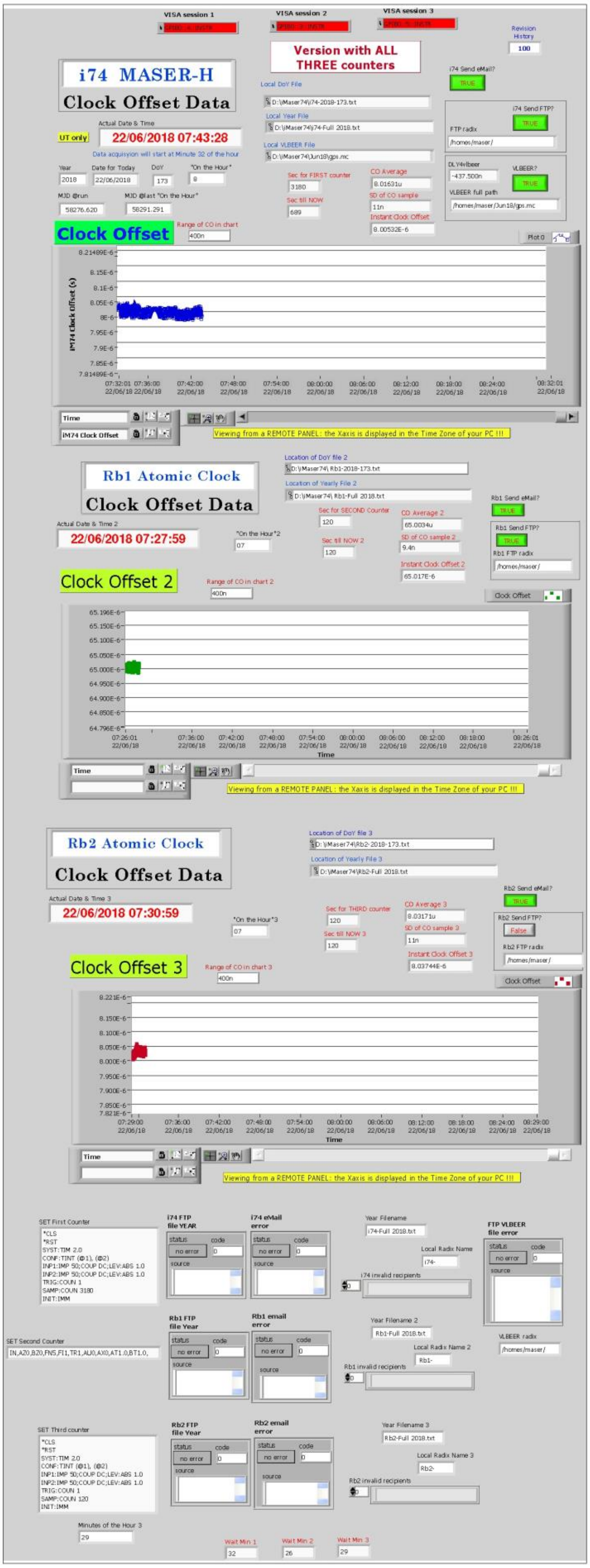
Appendix

Here is an example of the real time Front Page with three counters data



Typical output files for each counter/atomic standard:

i74-2018-172.txt - Blocco note

File Modifica Formato Visualizza ?

21/06/2018	00:00	8.0123E-6	15E-9
21/06/2018	01:00	8.0238E-6	11E-9
21/06/2018	02:00	8.0131E-6	15E-9
21/06/2018	03:00	8.0140E-6	13E-9
21/06/2018	04:00	8.0124E-6	12E-9
21/06/2018	05:00	8.0195E-6	12E-9
21/06/2018	06:00	8.0187E-6	15E-9
21/06/2018	07:00	8.0180E-6	11E-9
21/06/2018	08:00	8.0201E-6	13E-9
21/06/2018	09:00	8.0302E-6	10E-9
21/06/2018	10:00	8.0209E-6	13E-9
21/06/2018	11:00	8.0158E-6	13E-9
21/06/2018	12:00	8.0132E-6	15E-9
21/06/2018	13:00	8.0235E-6	11E-9
21/06/2018	14:00	8.0126E-6	16E-9
21/06/2018	15:00	8.0110E-6	12E-9
21/06/2018	16:00	8.0221E-6	10E-9
21/06/2018	17:00	8.0299E-6	9E-9
21/06/2018	18:00	8.0235E-6	11E-9
21/06/2018	19:00	8.0234E-6	9E-9
21/06/2018	20:00	8.0241E-6	9E-9
21/06/2018	21:00	8.0278E-6	9E-9
21/06/2018	22:00	8.0191E-6	10E-9
21/06/2018	23:00	8.0156E-6	12E-9

Rb1-2018-172.txt - Blocco note

File Modifica Formato Visualizza ?

21/06/2018	00:30	65.221E-6	13E-9
21/06/2018	01:30	65.221E-6	9E-9
21/06/2018	02:30	65.196E-6	13E-9
21/06/2018	03:30	65.178E-6	10E-9
21/06/2018	04:30	65.192E-6	9E-9
21/06/2018	05:30	65.162E-6	11E-9
21/06/2018	06:30	65.138E-6	11E-9
21/06/2018	07:30	65.132E-6	9E-9
21/06/2018	08:30	65.128E-6	10E-9
21/06/2018	09:30	65.133E-6	9E-9
21/06/2018	10:30	65.100E-6	9E-9
21/06/2018	11:30	65.091E-6	9E-9
21/06/2018	12:30	65.120E-6	5E-9
21/06/2018	13:30	65.079E-6	15E-9
21/06/2018	14:30	65.092E-6	7E-9
21/06/2018	15:30	65.087E-6	10E-9
21/06/2018	16:30	65.093E-6	9E-9
21/06/2018	17:30	65.091E-6	9E-9
21/06/2018	18:30	65.078E-6	9E-9
21/06/2018	19:30	65.078E-6	9E-9
21/06/2018	20:30	65.075E-6	9E-9
21/06/2018	21:30	65.074E-6	10E-9
21/06/2018	22:30	65.058E-6	9E-9
21/06/2018	23:30	65.050E-6	12E-9

Rb2-2018-172.txt - Blocco note

File Modifica Formato Visualizza ?

21/06/2018	00:30	8.022E-6	14E-9
21/06/2018	01:30	8.039E-6	9E-9
21/06/2018	02:30	8.022E-6	9E-9
21/06/2018	03:30	8.024E-6	9E-9
21/06/2018	04:30	8.037E-6	13E-9
21/06/2018	05:30	8.033E-6	9E-9
21/06/2018	06:30	8.025E-6	8E-9
21/06/2018	07:30	8.034E-6	10E-9
21/06/2018	08:30	8.042E-6	9E-9
21/06/2018	09:30	8.046E-6	9E-9
21/06/2018	10:30	8.035E-6	13E-9
21/06/2018	11:30	8.018E-6	10E-9
21/06/2018	12:30	8.043E-6	8E-9
21/06/2018	13:30	8.038E-6	13E-9
21/06/2018	14:30	8.019E-6	9E-9
21/06/2018	15:30	8.030E-6	10E-9
21/06/2018	16:30	8.042E-6	9E-9
21/06/2018	17:30	8.042E-6	9E-9
21/06/2018	18:30	8.039E-6	9E-9
21/06/2018	19:30	8.039E-6	9E-9
21/06/2018	20:30	8.041E-6	9E-9
21/06/2018	21:30	8.041E-6	9E-9
21/06/2018	22:30	8.032E-6	9E-9
21/06/2018	23:30	8.033E-6	9E-9

Legend:

Column 1 = Date
Column 2 = Hour in Universal Time
Column 3 = Clock Offset (s)
Column 4 = Standard Deviation of Clock Offset (s)