Maser / Cesium Based Frequency and Time System

F & T System

Key features:

- Providing a controlled environment for the atomic clock.
- Generation of very low phase noise and low ADEV frequency reference signals.
- Generation of highly accurate time reference signals.
- Buffering of all output signals for distribution.
- Monitoring of the atomic clocks versus GPS.
- Improving the reliability of the output signals by fully redundant hardware configuration. Internal signal cross strapping for mutual performance monitoring and for automatic switch over in failure case.
- Monitoring of all the system through a single control system with a single user interface.
- Distribution of frequency and time signals to remote sites.

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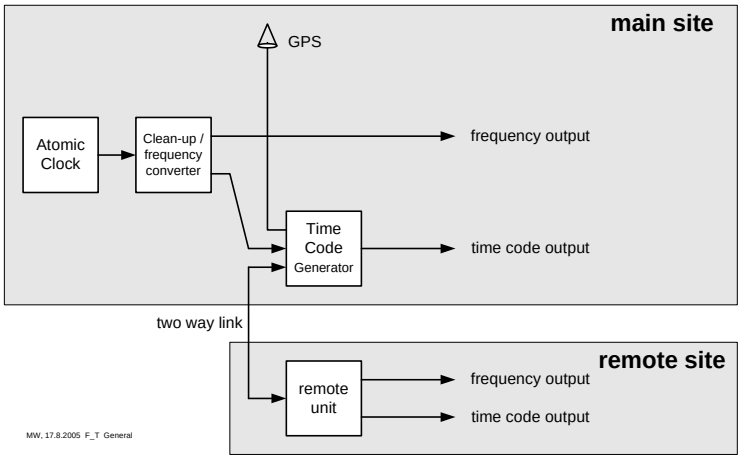
System Description

General

The Frequency & Time System uses an atomic clock input (Hydrogen maser or Cesium) and generates all reference signals. All usual frequencies (100 MHz, 10 MHz, and 5 MHz) and pulses (1 PPS) are strictly coherent.

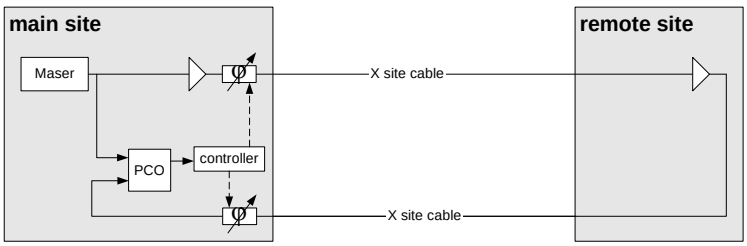
Also time code signals are generated with any real time source being the reference, e. g. GPS. The time code signals being distributed are IRIG (all common codes) and NTP.

The system can support one or several two-way links to remote sites. The two-way link compensates for the transmission delay. Thus the time output on the remote site is accurate to a few nanoseconds independent of the length of the transmission line.



Basic functions of the F & T System with time code distribution to a remote site.

If a stable and low phase noise frequency reference signal needs to be distributed to remote sites the F&T system supports this by use of a coaxial cable connection with a dynamic delay compensation as shown in the figure below. The phase of the loop-back signal is measured by the phase comparator (PCO) and any variation of the phase offset is compensated by action of the controller adjusting the controllable delay functions.



Transfer of a stable reference frequency distribution to a remote site.

A centralised control and monitoring system running on a dedicated system controller (SYSCON) hardware connects all system components to form a concise frequency and time system with a single user interface for all parts of the equipment. The F&T system implements a proprietary LAN. Integration into a computer network is supported by a dedicated public LAN interface of the SYSCON. Thus remote control of the system is possible.

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The F&T system features are

1. Performance Improvements

   The performance of atomic clocks is impacted by environmental effects, especially by the temperature. Therefore the F & T system employs a Heater/Cooler Unit (HCU) for providing the most stable environmental condition to the atomic clock.

   The F & T system further applies a so called CLEAN oscillator for generating output signals of minimised phase noise. The CLEAN is a clock filter that removes the phase noise of its input signal and that adds significantly less phase noise than some atomic clocks have on their output signals. Furthermore the CLEAN implements a micro-stepper function that allows for long term frequency drift compensation once the drift of the atomic clock source is known.

   The phase noise of the 100 MHz signals can further be improved by combining the outputs of two CLEAN oscillators. This yields an improvement of approximately 2 dB. Combining is a configuration option of the internal selector function.

2. Reliability Improvements

   The system concept supports a full hardware redundancy. This allows for replacing any system unit without any impact on the system output signals. This facilitates especially the maintenance on the atomic clock references. The phase transient being generated by manually selecting another signal path through the system is limited to a few picoseconds. An automatic fail-over function protects the system functions against HW failures. All the equipment in one of the redundant signal paths is called a “chain”. Thus the system consists of two parallel chains with several cross-straps between them for redundancy switch over or for mutual monitoring.

   The hardware redundancy can be extended to the control system and to the AC and the DC power supply of the system.

3. Signal Integrity Monitoring

   The signals of the both redundant system chains are monitored against each other. The atomic clock outputs are monitored versus the GPS.

   The F&T system can support up to 5 atomic clocks. If there are at least three atomic clocks of almost equal performance the stability performance of each individual clock can be measured absolutely as if the reference clock for measurement would be ideal. Such measurement uses the tree-corner-hat principle that is described in more detail with the phase comparator product (product number 10265).

4. Real Time Synchronisation

   The system generates time signal outputs (IRIG, NTP, 1 PPS) that are synchronised to the GPS time at start up of the system, or on user request. The system time is driven by the selected atomic clock and it is monitored versus the GPS throughout the system lifetime.

5. Output Coherency

   All output signals are strictly coherent. The IRIG outputs are aligned to the 1 PPS outputs.

6. Centralised Control and Monitoring System

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There is a single control and monitoring entity providing a single user interface for controlling all parts of the system. The LAN interface allows for integrating the F & T System into the local computer network.

7. Physical Assembly

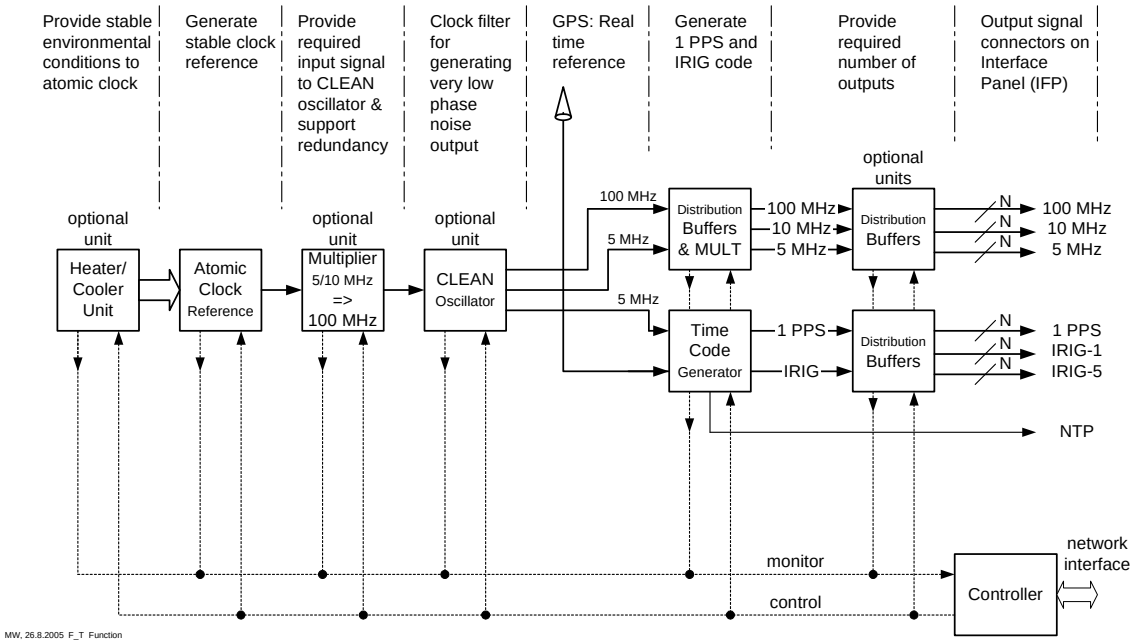
The heater/cooler unit is used for increasing the stability of the atomic clock reference. Normally this equipment is placed in a separate room, e. g. a dedicated maser room.

All other equipment (including any Cesium clock source) is mounted in a single rack. The rack can also hold a TFT screen and a keyboard for locally controlling the system. The output signals are provided on interface panels.

High performance cable is supplied for connecting the atomic reference clock outputs to the rack. This allows for covering several ten meters without significant impact on the frequency stability due to delay variation (e. g. by temperature effect).

Hardware Architecture

1. Functions of the F & T System



Functional block diagram of the F & T System on main site location

A Heater/Cooler Unit provides a stable environmental condition to the atomic clock (e. g. active H-Maser). The atomic clock output signal phase noise performance is improved by filtering with the CLEAN-up oscillator that has a very low intrinsic phase noise. The 100 MHz and the 5 MHz outputs of the CLEAN-up are used for feeding the output distribution buffers. If 10 MHz outputs are required the distribution buffer unit can be equipped with a multiplier for generating 10 MHz from the 5 MHz input.

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The CLEAN 5 MHz output is also being used for clocking the Time Code Generator. It derives its internal 1 PPS signal from its received 5 MHz input. On start up this 1 PPS signal is adjusted with 200 ns granularity to the 1 PPS being received from the GPS. Following this initial setting the Time Code Generator monitors the phase offset of its internal 1 PPS versus the GPS 1 PPS. On user request the 1 PPS re-alignment can be triggered. The Time Code Generator further generates the IRIG signals and the NTP output. The IRIG output is phase aligned to the internal 1 PPS output of the system.

All output signals are provided on interface panels being mounted in the rack. According to the signal quality requirements the connectors should be N-type for any high performance clock output, or SMA for medium quality signals. The IRIG outputs are provided with sufficient performance on BNC connectors.

Basic Functions		
Unit	**Function in the system**	**Monitoring functions**
Heater/Cooler Unit	Provide stable environment to the atomic clock. House sensors for environmental parameters.	Humidity Temperature Magnetic field
Atomic clock	Generate the frequency reference signal for the system.	All parameters being monitored by the actual atomic clock implementation.
Multiplier	Generate 100 MHz input to the CLEAN. This function can be integrated into the CLEAN, however, this impacts the redundancy function of the system. If the atomic clock provides a 100 MHz output this function reduces to a buffer function or may not be needed.	
CLEAN	It “cleans” the clock signal from phase noise. The CLEAN employs a multi channel phase comparator. This is used for monitoring the synchronisation performance of the CLEAN. In case of maintenance of the atomic clock the CLEAN can run in the fly wheel mode holding the accurate frequency for some while.	Phase stability of all input signals against the CLEAN output signal
GPS	12 channel GPS receiver.	All typical GPS monitoring functions
Buffer & MULT	Buffers signals for distribution purpose. Generates 10 MHz from 5 MHz input	
Time Code Generator	Generates 1 PPS from 5 MHz input. Contains the GPS receiver Generates the time signals (IRIG, NTP, 1 PPS) Compares the system internal time versus the GPS time.	System 1 PPS offset versus GPS

In addition to the monitoring functions being listed in the table above every component of the system is monitored for any vital internal operation condition such as voltages, currents and the internal temperature.

Examples for controlled parameters are the following

- Multiplier input frequency setting (5 or 10 MHz),

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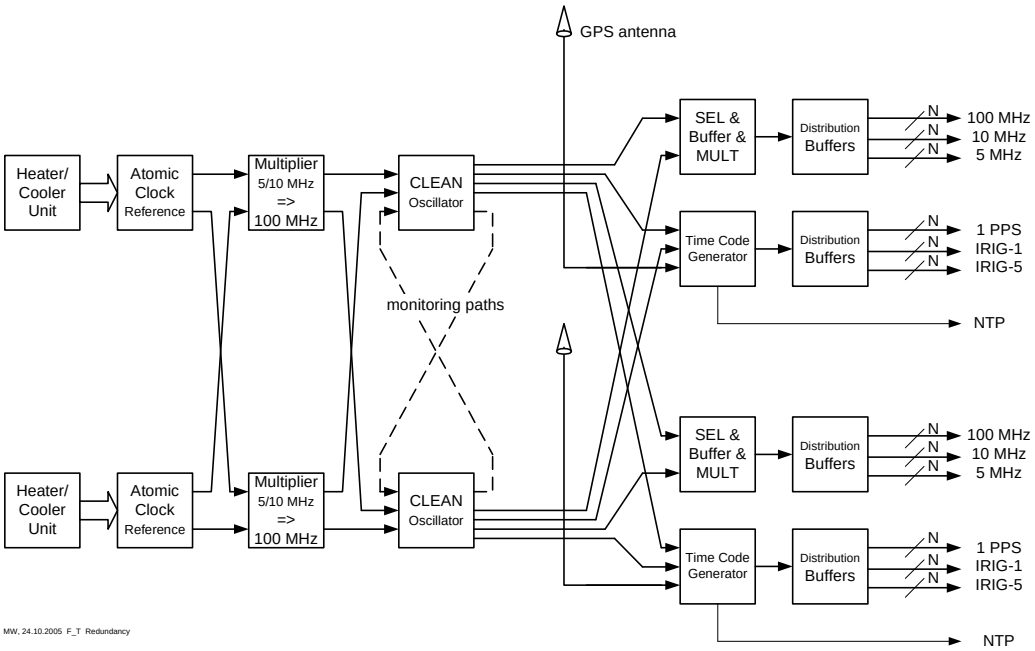
- CLEAN control loop setting to tracking the input signal, or to fly wheel mode.

2. Functional Redundancy of the F & T System

The following figure shows the cross over paths for supporting functional redundancy in the system.



Redundant functions block diagram of the F & T System on main site location

Redundancy Supporting Functions		
Unit	**Function in the system**	**Monitoring functions**
CLEAN	The CLEAN employs a multi channel phase comparator. This is used for cross monitoring the clock performance on the both system chains.	Phase data of cross strapped signals
SEL & Buffer & MULT	Selects one of the redundant CLEAN outputs. Combines the 100 MHz from both CLEAN 100 MHz outputs (configurable option).	
Time Code Generator (REFGEN)	Selects one of the redundant CLEAN 5 MHz outputs. Compares the phase of the both atomic clocks based on 1 PPS.	Atomic clock phase offset over time.

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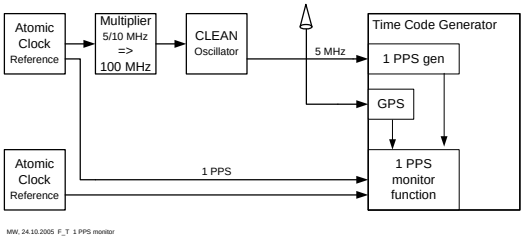
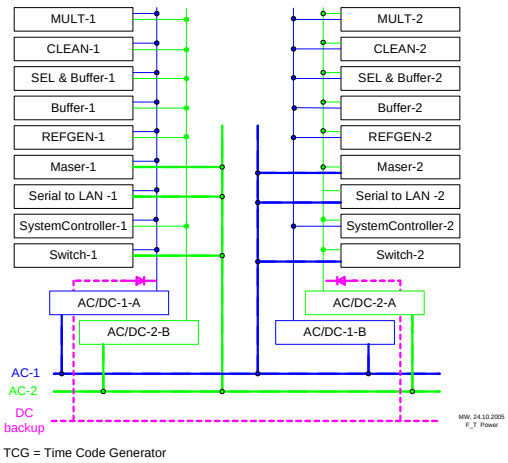


Detail of 1 PPS monitoring

The 1 PPS output signals of the masers are monitored for early detection of any maser degradation. The system 1 PPS signal is monitored against the GPS 1 PPS for checking the system time against GPS. If the 1 PPS offset exceeds a certain threshold the user may manually re-synchronise the system 1 PPS to the GPS 1 PPS.

3. Power and Control Redundancy of the F & T System



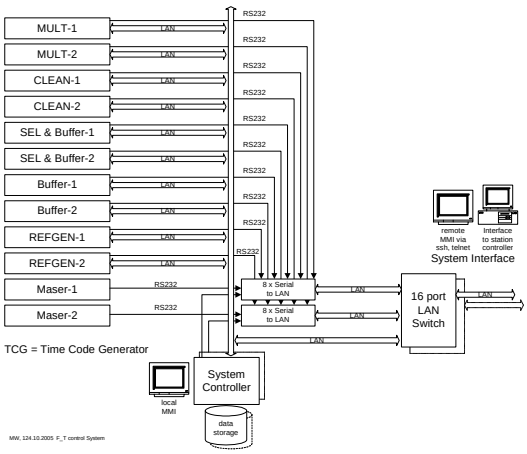
TCG = Time Code Generator

Redundant power supply concept of the F & T System

The F & T System has a redundant AC and DC power supply system. It is fed by two redundant AC inputs and one back-up DC input. Optionally a battery pack can be connected to this DC input.

The system power supply provides two redundant power buses. Every system component is connected to both of them.

The control system of the F & T system is redundant as far as possible. Every system component supporting redundant control interfaces is connected to both, the internal LAN and to a serial to LAN converter via a RS232 interface



Redundant control system hardware of the F & T System

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Performance

1. Phase Noise

The phase noise of the clock output signals of 5 MHz, 10 MHz and 100 MHz is as low as it is specified for the TimeTech Synchronized Oscillator Clean-up & Offset Oscillator.

The following table gives typical values for the phase noise performance that had been measured on an F&T system implementation in May 2005.

		F & T system output phase noise performance (measured)			
	100 MHz maser spec	100 MHz from single CLEAN	100 MHz combined*	10 MHz	5 MHz
Phase noise @ 1 Hz	-100 dBc/Hz	-101 dBc/Hz	-102 dBc/Hz	-120 dBc/Hz	-126 dBc/Hz
Phase noise @ 10 Hz s	-115 dBc/Hz	-115 dBc/Hz	-118 dBc/Hz	-134 dBc/Hz	-142 dBc/Hz
Phase noise @ 100 Hz	-122 dBc/Hz	-129 dBc/Hz	-131 dBc/Hz	-143 dBc/Hz	-152 dBc/Hz
Phase noise @ 1 kHz	-125 dBc/Hz	-153 dBc/Hz	-155 dBc/Hz	-150 dBc/Hz	-158 dBc/Hz
Phase noise @ 10 kHz	-145 dBc/Hz		-161 dBc/Hz	-152 dBc/Hz	-158 dBc/Hz
Phase noise @ 100 kHz	-145 dBc/Hz		-162 dBc/Hz	-153 dBc/Hz	-160 dBc/Hz

*) The 100 MHz output signals of 2 CLEANS are combined.

2. Frequency Stability

The performance that had been measured on a system employing two active H-masers is given below.

	Maser spec	**Maser versus maser 100 MHz**	**F&T System output versus a single maser 100 MHz**
ADEV @ 1 s	1.5 E-13	**1.36 E-13**	**1.42 E-13**
ADEV @ 10 s	2.0 E-14	**2.58 E-14**	**2.70 E-14**
ADEV @ 100 s	5.0 E-15	**4.24 E-15**	**4.32 E-15**
ADEV @ 1 ks	2.0 E-15	**1.16 E-15**	**1.18 E-15**
ADEV @ 10 ks	2.0 E-15	**0.72 E-15**	**0.74 E-15**

Note: The maser ADEV specification applies to a single maser being measured against an ideal reference source. In reality almost equally performing sources are measured against each other. The performance of a single source is derived from such measurements be dividing the measured values by SQRT(2).

Standard room air conditioning systems are controlling the room temperature to about 1 K_{pp}. The Heater/Cooler Unit increases the temperature stability of the maser environment by more than a factor of ten, i. e. the maser environmental temperature is stable to about 0.1 K_{pp}. The maser temperature coefficient is about 5 E-15 /K. Thus improving the maser environment temperature will result in an according improvement of the ADEV output. Due to the typical time constants of room air conditioning systems the temperature induced ADEV performance will appear at time intervals around 1000 s and above.

The F & T rack should be placed in an air-conditioned room for minimizing the impact of ambient temperature variations on the stability of the generated clocks.

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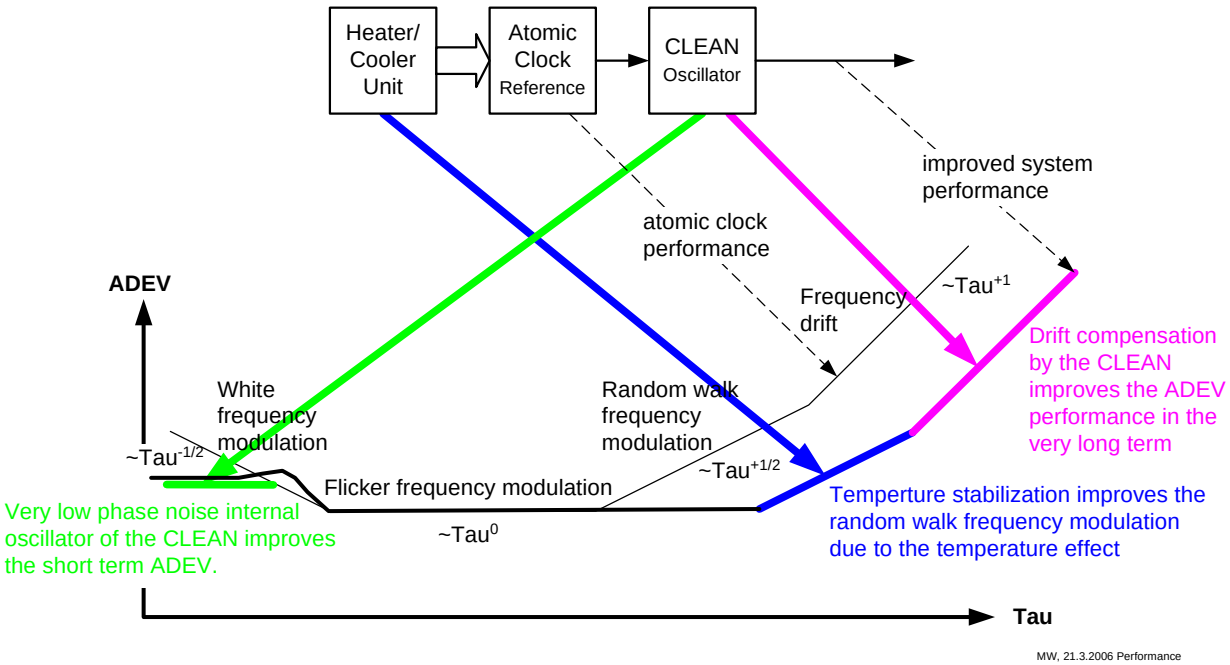
3. Clock Performance Improvement Capability

The F&T system is able to improve the stability performance of atomic clock sources. In the short term the excellent phase stability performance of the CLEAN improves the ADEV performance of less stable atomic clocks. At the corner where the oscillator ADEV exceeds that of the atomic clock the frequency output shows a bump, i. e. a interval of tau in which the output ADEV exceeds that of the atomic clock alone. The bump is caused by a systematic effect and cannot be removed by tuning.

In the long term the Heater/Cooler Unit improves the stability of the system frequency output by improving the environmental condition of the atomic clock.

In the very long term the micro stepper function of the CLEAN can be used for drift compensation. If the frequency drift of the atomic clock is known it can be compensated by suitable control of the micro stepper function.

The potential improvements on the ADEV performance are shown in the figure below.



ADEV improvement capability of the F&T system

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