May, 2003

iPrecision Timing Solutions™

Understanding How the Smart Rubidium Technology Works

Contents

Basic Principle of Operation

The Rubidium (Rb) clock basically consists of a Voltage Controlled Crystal Oscillator (VCXO) which is locked to a highly stable atomic transition in the ground state of the Rb87 isotope. While the frequency of the VCXO is at the convenient standard frequency of 20 MHz, the Rb clock frequency is at 6.834... GHz in the microwave range. The 2 frequencies are matched by a phase-stabilized frequency multiplication scheme, in which a synthesized frequency is admixed to enable an exact matching. The Rb atoms are confined in a vapor cell at an elevated temperature. The cell is placed in a microwave resonator, which is coupled with the microwave power derived from the VCXO.

Optical Pumping Process

The Rb87 atoms in the cell occur with equal probability in the 2 hyperfine energy levels of the ground state (F=1 and F=2). In order to detect the clock transition between these 2 levels, the atoms need to be manipulated in such a way that most of them occur in only 1 level. This is done through optical pumping via a higher lying state (P). Figure 1 visualizes the atomic energy levels and transitions involved in the optical pumping process.

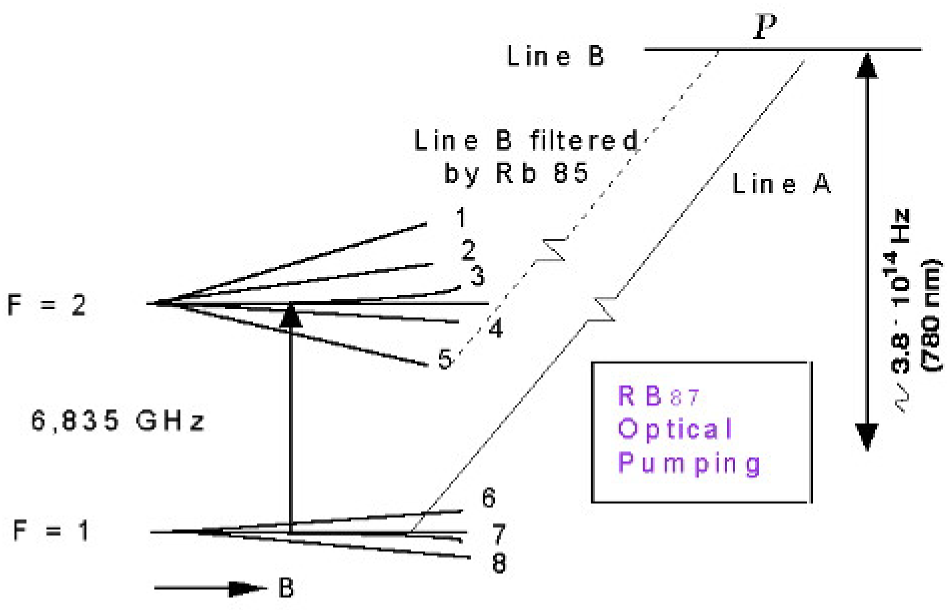

Figure 1 – Rubidium Optical Pumping Process

The pump light comes from an Rb resonance lamp which emits the light of Rb87 atoms. This light, which intersects the absorption cell, is filtered in such a way that mainly 1 optical frequency, which corresponds to a transition out of one of the 2 ground state levels (line A), enters the principal absorption region.

The pump light excites Rb87 atoms which are in the lower hyperfine level (F=1) to the short-lived excited state P from which they decay to the 2 ground state levels (F=1, 2) with equal probability. Since pumping occurs continuously out of the F=1 level, after some time almost all atoms are found in F=2 level and no further absorption occurs.

The transmitted light level is detected by a photodiode after the cell. If a microwave field resonant with clock transition F=2 to F=1 is coupled with the interaction region, the level F=1 is repopulated and light absorption is enhanced. A sweep of the microwave field over the resonance is detected as a small dip in the transmitted light level after the cell.

This signal is fed into a synchronized detector whose output generates an error signal which corrects the frequency of the VCXO when its multiplied frequency drifts off the maximum atomic resonance.

The absorption cell is filled with metallic vapor, containing Rb85 and Rb87 isotopes and a buffer gas. The pump light is filtered in the entrance region of the cell by absorption with Rb85 atoms which have an accidental overlap with one of the Rb87 resonance transitions (line B) - integrated filter cell.

The principal function of the buffer gas is to keep the Rb atoms away from the cell walls and restrict their movements. Consequently, they are practically "frozen in place" for the interaction time with the microwave field. In this way the Doppler-effect is virtually removed and a narrow line width results.

The cell region is also surrounded by a so-called C-field coil which generates a small axial static magnetic field to resolve the Zeeman sub-transitions of the hyperfine line and select the clock transition -, i.e. the one with the least magnetic sensitivity. To further reduce the magnetic sensitivity, the complete physics package is placed into nested magnetic shields (see Figure 2).

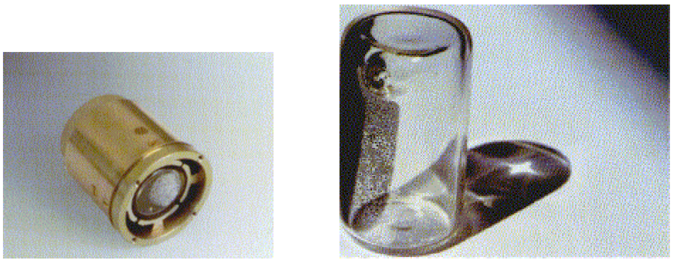

Figure 2 – Rubidium Cell & Microwave Cavity

Block Diagram: 3 Elements
Figure 3 gives a basic overview of the different functional blocks of the Rb atomic clock. An Rb consists of 3 basic elements. The 2 optical elements, including the Rb absorption cell and microwave cavity form the atomic resonator, while the electronics element is constituted of the generator and the detection circuitry.

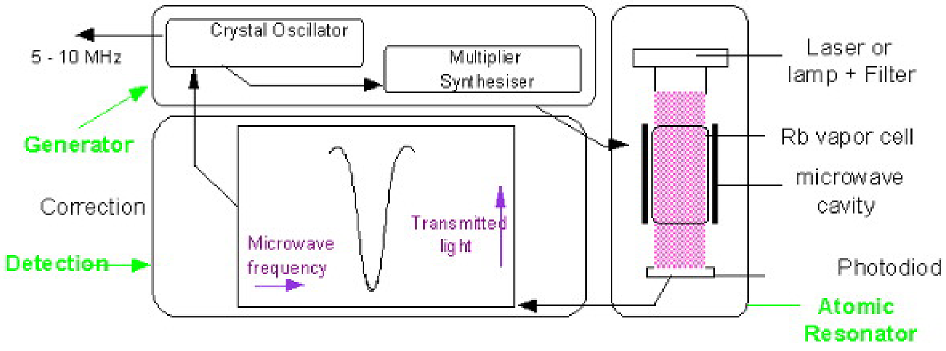

Figure 3 – Rubidium Block Diagram

Advanced Patented Physics Package

Temex Time uses an advanced patented Rb physics package, integrating the filtering technique into a magnetron type microwave cavity (see Figure 4). This patented configuration greatly reduces the physics package volume without giving up short-and long-term stability performance, allowing Temex Time to offer high performance, Swiss quality Rubidium clocks at the best price/performance ratio.

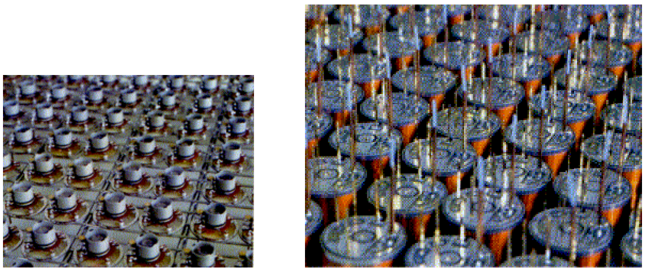

Figure 4 – Advanced Physics Package

The key design features of the physics package are the low power consumption, small size and weight, and minimal environmental sensitivity and mechanical ruggedness.

The complete physics package is incorporated in an aluminum tube surrounded by magnetic shields. Inside this tube, the lamp and cell sections form 2 separate blocks which operate at well-defined but different temperatures. The lamp and cell sections are separated by a glass window to greatly reduce the thermal flow between the blocks and the tube envelope. It allows a very compact design with low power consumption, short warm-up time and minimal environmental sensitivity.

Other design features that contribute to the compact design are the use of:
- Integrated filter technique (IFT)
- Magnetron-type microwave resonator

The integrated filter technique, which combines the optical filtering and pumping in one cell, also contributes to the high reliability as the configuration is simplified and the number of components is reduced. The thermal capacitance of the cell assembly is relatively low and the power required during warm-up is greatly reduced.

The magnetron resonator is a cylindrical cavity loaded with a concentric capacitive-inductive structure (annular metal electrodes). It allows smaller cavity dimensions and concentrates the microwave field at the right region of the cell.

The Rb lamp is an electrode-less RF-discharge lamp - a heated glass bulb which contains Rb and a starter gas surrounded by an RF-coil.

Although the atomic clock transition frequency is inherently quite stable, there are second order influences which affect the frequency, i.e. temperature (buffer gas), light intensity (light shift = optical Stark effect), magnetic field (2nd order Zeeman effect). Consequently, the temperatures of lamp and cell, the power of the lamp oscillator and the current in the C-field coil have to be carefully stabilized.

Smart Electronics Package

The smart digitally controlled electronics of the Rb clocks is based on microcomputer technology, which integrates the required sensors, EEPROM memory, analog and communication interfaces (see Figure 5). This configuration provides effective and fully automated adjustments, greatly reducing the testing time. It is an efficient and cost-effective solution for easy, automated and fully traceable production

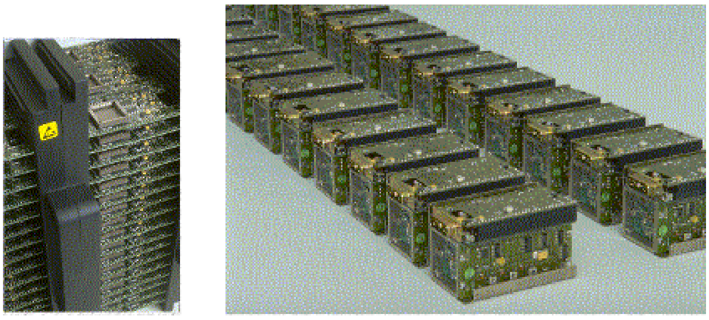

Figure 5 – Smart Electronics Package

The clock transition of an Rb resonator is a microwave transition at 6.834 ....GHz. The microwave resonance occurs as a dip in the optical signal; i.e. in the Rb lamp light which, after transiting the cell, is detected by a photodiode.

The basic purpose of the electronics package is to synchronize the in-going microwave frequency, derived from a quartz crystal oscillator, to this absorption dip. This is achieved by tuning the microwave frequency to maximum optical absorption.

The C-field coil within the physics package generates a magnetic field required for the separation of the Rb spectral lines. This magnetic field allows fine tuning of the 10MHz output frequency by shifting the Rb frequency hyperfine transition by the second-order Zeeman effect.

The user interface includes a RS-232 port for monitoring internal parameters and for center frequency adjustments. Coarse frequency adjustments can be made by changing the parameters of the loop synthesizer, whereas fine adjustment is performed by changing the C-field through a D/A converter.

An analog frequency control input is also available to the user for center frequency adjustment through an external potentiometer or an external DAC. The correct operation of the unit can be checked by a single open collector type output signal called “lock monitor” (OOL).

Figure 6 illustrates the block diagram of the digitally controlled electronics.

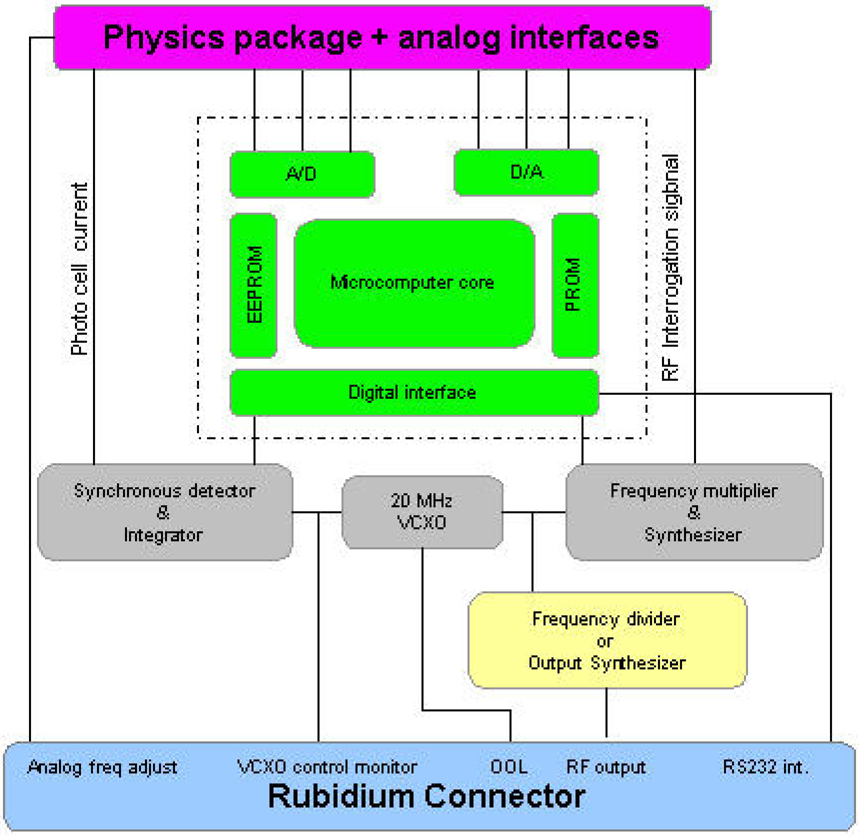

Figure 6 – Digital Electronics Block Diagram

Temex Time's technology leadership enabled the company to be the first in the industry to introduce a smart, cost-effective Rb physics package, in which complex parameters such as lamp and cell temperature, light level, C-field, and synthesizer are fully programmable into an EEPROM at the end of the automated production adjustment process.