GPS SYNCHRONIZED DISCIPLINED RUBIDIUM FREQUENCY STANDARD

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Abstract

A disciplined rubidium frequency standard steered by the corrected 1 PPS output from a GPS timing receiver or other stable 1 PPS source can provide a low phase noise, modest cost, frequency standard with long term frequency stability of a cesium standard and short term stability of better than 1×10^{-11}. Phase correlation to the 1 PPS input is maintained to within 50 nanoseconds during disciplining and within 100 nanoseconds during a five hour coasting period with no disciplining input.

INTRODUCTION

Disciplined crystal frequency oscillators have been around for many years. They are used mostly as "cleanup" oscillators following noisy frequency sources and as failsafe outputs driven by atomic frequency standards. Cesium and rubidium frequency standards incorporate disciplined crystal oscillators as part of their control loop. Even though rubidium frequency standards are used for many timing applications, disciplined rubidium frequency standards are not in wide use.

GPS timing receivers have been used for several years as a time correlation measuring instrument or time transfer instrument. One version of these receivers generates 1 PPS corrected to the GPS satellite epoch. There has been a lot of interest in using an output from this type of receiver as a disciplining source for 5 or 10 Mhz oscillators. The 1 PPS output from most of these receivers exhibits a very accurate long term stability, but, until we have full GPS satellite coverage, this output is present for only a portion of the day. Several timing instruments on the market provide a frequency output synchronized to GPS, but most of these units do not have the necessary long term frequency and temperature stability required for accurate time generation.

Over the past several years, TRAK Systems has gained considerable knowledge in using 1 PPS reference signals such as range time codes to discipline precision crystal oscillators used in synchronized time code generators. All of these oscillators have used CPU control and nonvolatile digital memory, and all of the units maintained both a frequency lock and precise phase lock to the disciplining 1 PPS. During our studies, we also investigated the various types of control loop approaches that provide satisfactory disciplining under a variety of laboratory and field conditions. Some algorithms provided fast attack for initialization, while others provided good long term smoothing through various noise conditions. All of these experiments were conducted with ovencontrolled oscillators, and over 200 units were successfully deployed worldwide.

In 1987, we were faced with a requirement to maintain precise time and frequency using a GPS receiver and a rubidium frequency standard. The required accuracy relative to GPS or UTC was on the order of 100 nanoseconds, with a required phase resolution of approximately 20 nanoseconds. Knowing that the GPS satellite coverage had gaps of up to six hours, we knew that, for several years at least, the design would have to provide for very low drift during coasting periods when there is no disciplining signal available. A market survey revealed that, although there were several good rubidium oscillators on the market, there were no suitable disciplined oscillators or oscillator disciplining modules available. It was decided that we would draw upon the knowledge gained from disciplining crystal oscillators and develop a rubidium standard operating at a constant temperature and using "C–field" voltage control. Of course, existing control algorithm would have to be translated three orders of magnitude from 1×10^{-9} to 1×10^{-11}. It was obvious from the beginning that three primary conditions had to be met:

1. A means had to be devised to overcome the rather large temperature drift problem that exists in commercially available rubidium modules, even over a limited temperature range.

2. Average frequency would have to be calculated with high precision, on a continuing basis, with the control voltage digitally stored. This would provide for minimum drift during coasting periods.

3. Vernier phase corrections, which were to be made by momentarily adjusting the frequency up or down, would have to be made almost continuously while tracking, but each increment would have to be small enough to preclude introducing measurable phase noise.

The task was undertaken, and we have designed a disciplined rubidium frequency standard that exhibits some very desirable characteristics previously not available on the market. This unit was designed especially to generate 10 Mhz, 5 Mhz, and 1 PPS outputs phase coherent to the long term average of a 1 PPS input. The 1 PPS input does not need to be continuous and may have jitter. This is important because the 1 PPS output from most GPS timing receivers exhibit these undesirable characteristics. The long term stability of the disciplined rubidium frequency standard takes on the long term stability of the 1 PPS input and keeps the short term stability of its rubidium oscillator.

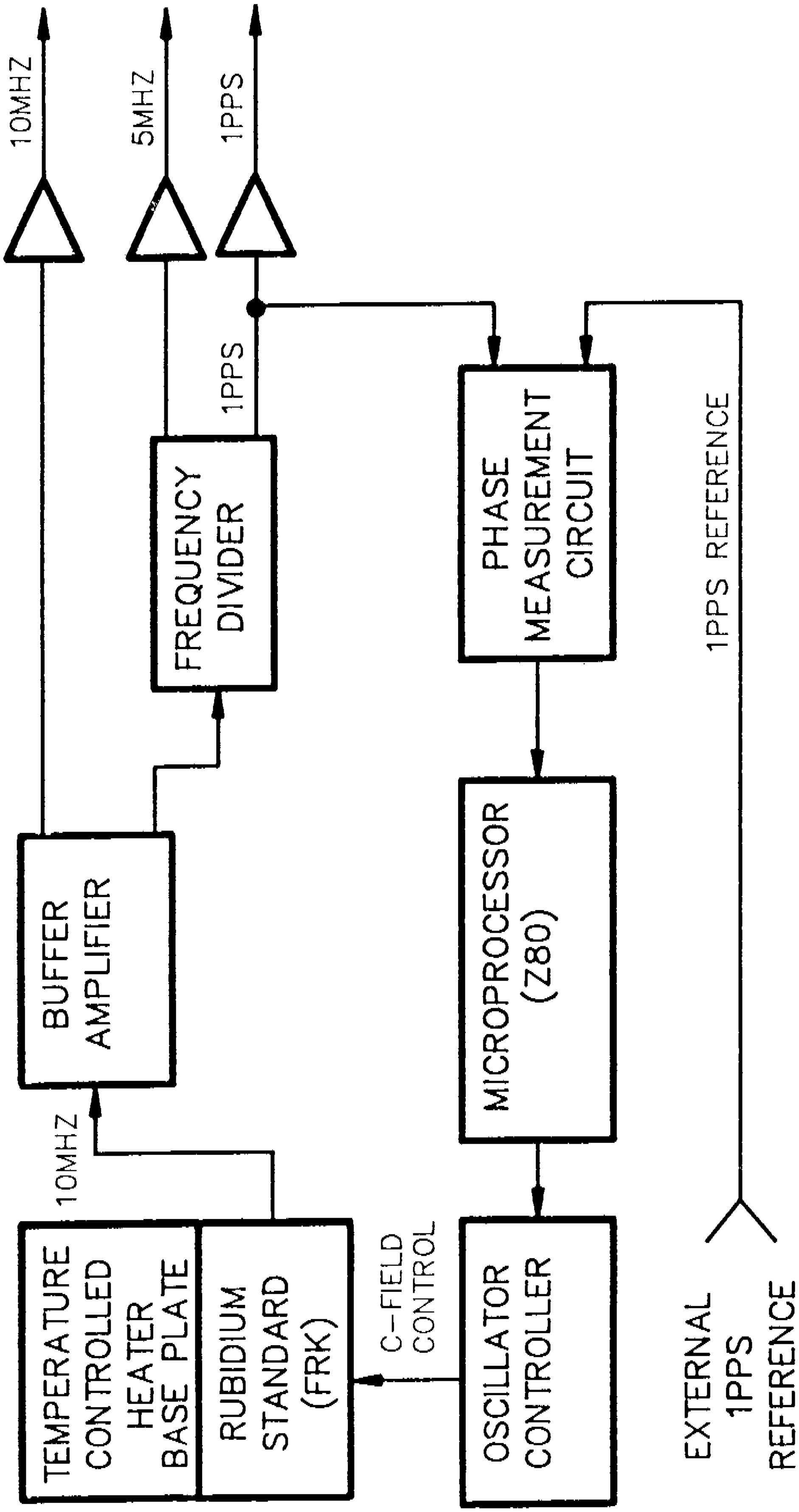
THE DESIGN

Precise frequency compensation for environmental temperature changes for rubidium oscillators is difficult to accomplish. The algorithm for temperature compensation is not the same for each unit; therefore, each unit must be characterized in order to assure accuracy over a wide temperature range. Furthermore, periodic recalibration is required to maintain this accuracy. We therefore chose to use a heated baseplate with dual proportional controlled heaters to maintain a constant rubidium module temperature. To further assure temperature stability, we purchased rubidium modules with internal compensation characteristic that is flat in the range close to the baseplate set point. Base plate temperature is held to within a plus or minus one degree Celsius. This design provides for the most stable frequency output over a normal temperature range.

The block diagram for the disciplined frequency standard shows the active elements used in our design. There are six major elements in this unit: the rubidium standard, an isolation amplifier, frequency dividers to provide the 5 Mhz and 1 PPS signals, a phase measurement circuit, the microprocessor, and the oscillator frequency control circuit. The rubidium standard produces a 10 Mhz output, which is buffered to supply the 10 Mhz sinewave output from the unit and is also used to supply the input to the frequency dividers. The frequency dividers generate the 5 Mhz and 1 PPS outputs from the unit and one of the 1 PPS inputs to the phase measurement circuit. The second input to the phase measurement circuit is the external reference 1 PPS. Since maintaining phase coherence of the output 1 PPS to the input 1 PPS reference is just as important as maintaining precise frequency from the 10 Mhz output, the phase measurement is done at 1 PPS. This phase detector measures the difference as a signed number between zero and one–half second with 20 nanosecond resolution.

The output of the phase measuring circuit is processed by the microprocessor and stored. Next, the stored digital number is converted to an analog output from the oscillator control circuit that directly controls the C–field input of the rubidium frequency standard. This closes the loop.

The characteristics of the control loop are provided by the microprocessor program. In order to assure the required disciplining characteristics, several modes of operation are used, with a different algorithm being employed for each mode. The first mode is entered upon power turn–on. After the 1 PPS reference signal is present and the rubidium module has obtained frequency lock, the microprocessor generates a jam–sync to synchronize the two 1 PPS signals to within 200 nanoseconds. During the first hour, a fast algorithm disciplines the rubidium to produce a 1 PPS phase coherence of better than 100 nanoseconds and a drift rate of less than 20 nanoseconds per hour. After two hours, the phase coherence is reduced to less than 50 nanoseconds, and After a day of disciplining, the unit can coast without a reference input with its 1 PPS output drifting less than eight nanoseconds per hour including the combined effects of frequency offset, aging, and temperature changes between $+5°C$ to $+40°C$. When the disciplined standard is driven by the 1 PPS output from our Model 8800 GPS Station Clock, the 1 PPS output of the disciplined frequency standard is maintained within 100 nanoseconds of UTC time using Block I satellites.



BLOCK DIAGRAM
DISCIPLINED RUBIDIUM
FREQUENCY STANDARD

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