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Frequency Stabilization for Mobile Satellite Terminals via LORAN

Gregory J. Ernst, Steven M. Kee, and Robert C. Marquart
Hughes Network Systems, Inc.
Germantown, Maryland 20876

ABSTRACT

Digital satellite communication systems require careful management of frequency stability. Historically, frequency stability has been accomplished by continuously powered, high cost, high performance reference oscillators. Today's low cost mobile satellite communication equipment must operate under wide ranging environmental conditions, stabilize quickly after application of power, and provide adequate performance margin to overcome RF link impairments unique to the land mobile environment. Methods for frequency stabilization in land mobile applications must meet these objectives without incurring excessive performance degradation. A frequency stabilization scheme utilizing the Loran (Long range navigation) system is presented.

INTRODUCTION

Position determination and reporting are requirements in many mobile satellite terminal applications. Presently, the Loran-C system is a widely available and a low cost means of providing position determination. Many mobile satellite terminals include an integrated Loran-C Receiver for this purpose. A high stability frequency reference can be derived from the received Loran-C signal. Application of this technique to transmit-only mobile satellite terminals is particularly useful.

As shown in Figure 1, the Loran-C Receiver determines the frequency offset between a voltage controlled oscillator reference and the received Loran-C signal. Periodically, the mobile satellite terminal baseband processor system interrogates the Loran-C Receiver to retrieve this frequency offset. After data processing, the baseband processor corrects the frequency offset by tuning the voltage controlled oscillator via a digital to analog converter. This negative feedback control loop removes the frequency offset effects due to both temperature and time.

The implementation of this control loop incorporates algorithms to ensure reliable frequency stabilization. The Loran-C Receiver computes the frequency offset and derives a received signal quality indicator. The baseband processor ignores frequency offsets accompanied with a poor signal quality indication. Otherwise, the frequency offset is processed to establish an updated frequency correction. The most recent frequency correction is always stored in nonvolatile memory so that upon power application, a stabilized frequency can be obtained promptly. During periods of extended Loran-C outages, the stability is maintained because the voltage controlled oscillator is temperature compensated.

REQUIREMENTS

The mobile satellite terminal must provide long-term and short-term frequency stability under the following conditions:

- Extreme operating temperatures
- Rapid recovery after power cycling
- Impaired Loran-C reception
- Aging effects over time and temperature

- Automatic operation without user intervention

In addition, the stabilized oscillator reference provides the critical clock timing and phase noise performance for the mobile satellite terminal.

CONCEPTUAL MODEL

Figure 2 shows a conceptual diagram of the mobile satellite terminal frequency stabilization scheme using the Loran system as the reference source. A quartz crystal voltage controlled oscillator (VCXO) is used as the frequency reference source within the mobile satellite terminal. This VCXO has stability characteristics as described in Figure 3. As shown in the Time Domain Characteristics of the VCXO, the quartz crystal oscillator by itself is sufficient to provide the short-term stability. However, the long-term frequency drift can become large when uncompensated. Utilizing the Loran system for frequency stabilization eliminates the effects of long-term frequency drift.

The Loran-C Receiver utilizes the 100 kHz Loran signal as the reference input, $r(t)$, to the frequency stabilization control loop. Embedded within the position determination process is a frequency comparison algorithm which calculates the frequency offset between the VCXO controlled output, $c(t)$, and the reference input. The frequency offset is represented by $e(t)$.

The digital controller provides the overall operational control for the frequency stabilization process. The input to the digital controller is the output of a sampled analog to digital conversion process, $e(kT)$. The sampling period T is defined by the baseband processor interrogation interval of the Loran-C Receiver. The sampled frequency offset data is processed by the digital controller to produce a frequency correction, $m(kT)$. The digital to analog converter develops an analog tuning voltage to the VCXO based upon the frequency correction.

The VCXO is temperature compensated and not ovenized; therefore, it can quickly stabilize in frequency when power is applied. The frequency characterization of the VCXO shown in Figure 3 forms the basis to determine the control loop parameters. In addition, the VCXO frequency tuning range must be sufficient to tune to the desired center frequency for temperature variations and design life of the mobile satellite terminal. When the Loran system is not available, the oscillator must be frequency compensated for temperature variations so that mobile satellite terminal operation is not disrupted. The long-term aging effects can be easily maintained to less than 0.1×10^{-6} with only monthly Loran availability. Temperature stability without Loran availability is determined by the design of the VCXO but can be less than 0.1×10^{-6} with a state-of-the-art implementation.

IMPLEMENTATION

The implementation of the frequency stabilization control loop has been developed using a 16 MHz VCXO. The output of the 16 MHz VCXO provides the reference frequency for critical timing including position determination and carrier generation. The VCXO tuning voltage is the output of an 8-bit digital to analog converter (DAC). The initial value for the DAC is stored in nonvolatile memory and is applied as the frequency correction upon application of power and initialization of the mobile satellite terminal. The DAC value is updated as required to compensate for the frequency drift of the VCXO.

The frequency offset from the Loran-C Receiver is derived from the Loran system timing as well as the average of all received Loran signals. This averaging minimizes the effects of Doppler induced errors due to the geographic separation of Loran system transmitting stations. The frequency offset provides a resolution of 62.4×10^{-3} Hz per bit.

After initialization of the mobile satellite terminal, the baseband processor waits for a received signal quality indication from the Loran-C Receiver. During periods of poor signal quality, the frequency correction is not updated. For extended periods of poor signal quality as a result of Loran-C impairments (e.g., interference, shadowing, areas of inadequate coverage), the frequency stability of the mobile satellite terminal is provided by the VCXO.

The frequency stabilization loop operates continuously once there is good received signal quality. The algorithms within the baseband processor correct the VCXO frequency at a rate that is sufficient to track out the effects of temperature and aging.

The baseband processor examines the frequency offset, and increments or decrements the frequency correction as required. The resolution of the frequency correction through the DAC is nominally 0.05×10^{-6} per bit. The frequency correction is updated whenever the frequency offset is equal to or greater than 0.1×10^{-6}. When the loop has been adjusted to a frequency offset of less than 0.1×10^{-6}, the baseband processor compares the current frequency correction to the value stored in nonvolatile memory. The nonvolatile memory is updated if the difference between these two values is greater than 0.5×10^{-6}.

TEST RESULTS

Figure 4 shows the measured response of the frequency stabilization loop to a $+1.00 \times 10^{-6}$ change of the VCXO frequency. Initially, the VCXO frequency was $+0.17 \times 10^{-6}$ from the nominal 16.00 MHz. A step change to $+1.17 \times 10^{-6}$ from the nominal 16.00 MHz was applied to the VCXO. The frequency offset response attained 63% of its final value in 50 seconds. In 180 seconds, the frequency offset had attained 95% of its final value. This test was performed for -1.00×10^{-6} change to the VCXO frequency and the results were comparable to the positive change in VCXO frequency. Both of these tests were repeated through successive trials, temperature cycling, and power cycling. Again, the results were consistent for a 1.00×10^{-6} change in VCXO frequency.

Incremental changes of the VCXO frequency were tested up to the $\pm 3.00 \times 10^{-6}$ acquisition limit of the Loran-C Receiver. The results showed that for a $+3.00 \times 10^{-6}$ step, 95% of the frequency offset was attained in 44 minutes on the average. A -3.00×10^{-6} step resulted in an average of 42 minutes to attain 95% of the frequency offset.

Testing of the frequency stabilization control loop also included parametrics, acquisition and tracking, firmware integration, and error handling. Parametrics and acqusition and tracking tests were also conducted over temperature and time.

Extensive field tests of the Hughes Network Systems SkyRider™ Mobile Satellite Terminal have demonstrated frequency stability performance of better than 0.03×10^{-6} over temperature and time with continuous Loran coverage.

CONCLUSION

An implementation scheme for obtaining a stabilized frequency reference for land mobile applications has been presented. A combination of long-term frequency drift compensation via Loran system and short-term frequency stability characteristics of a crystal oscillator meets the requirements for an accurate and stable mobile satellite terminal frequency source. This frequency stabilization technique is particularly applicable to transmit only or random access type mobile satellite terminals.

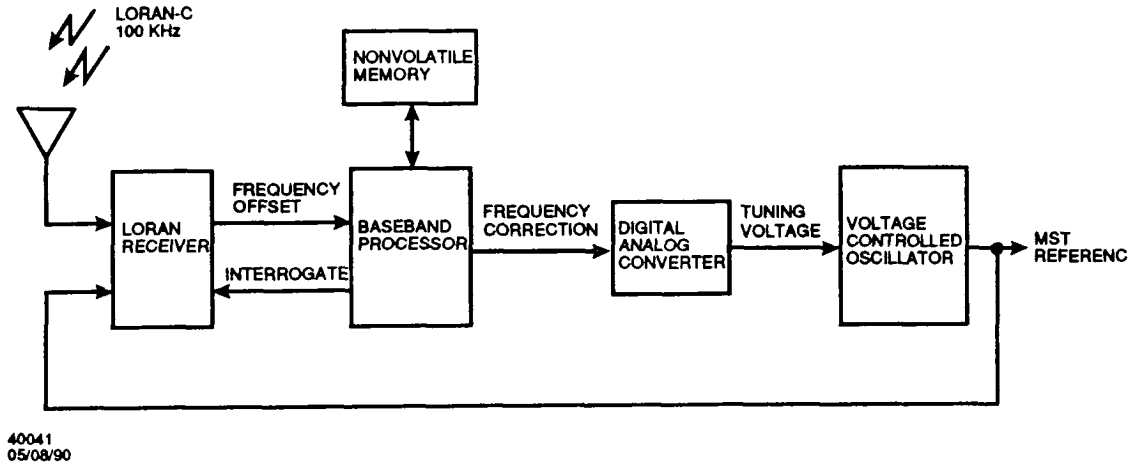
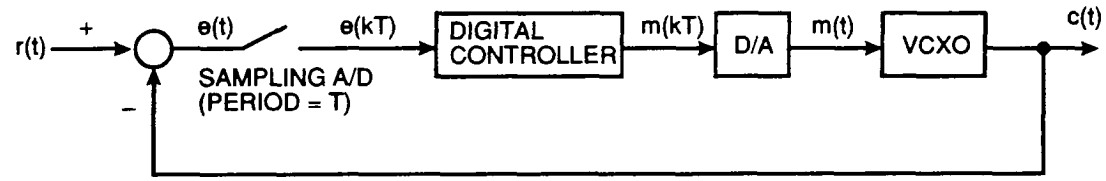


Fig. 1. Functional Diagram



T = SAMPLING PERIOD

r(t) = REFERENCE INPUT

c(t) = CONTROLLED OUTPUT

e(t) = r(t) – c(t), ACTUATING SIGNAL

m(t) = MANIPULATED SIGNAL

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Fig. 2. Conceptual Model

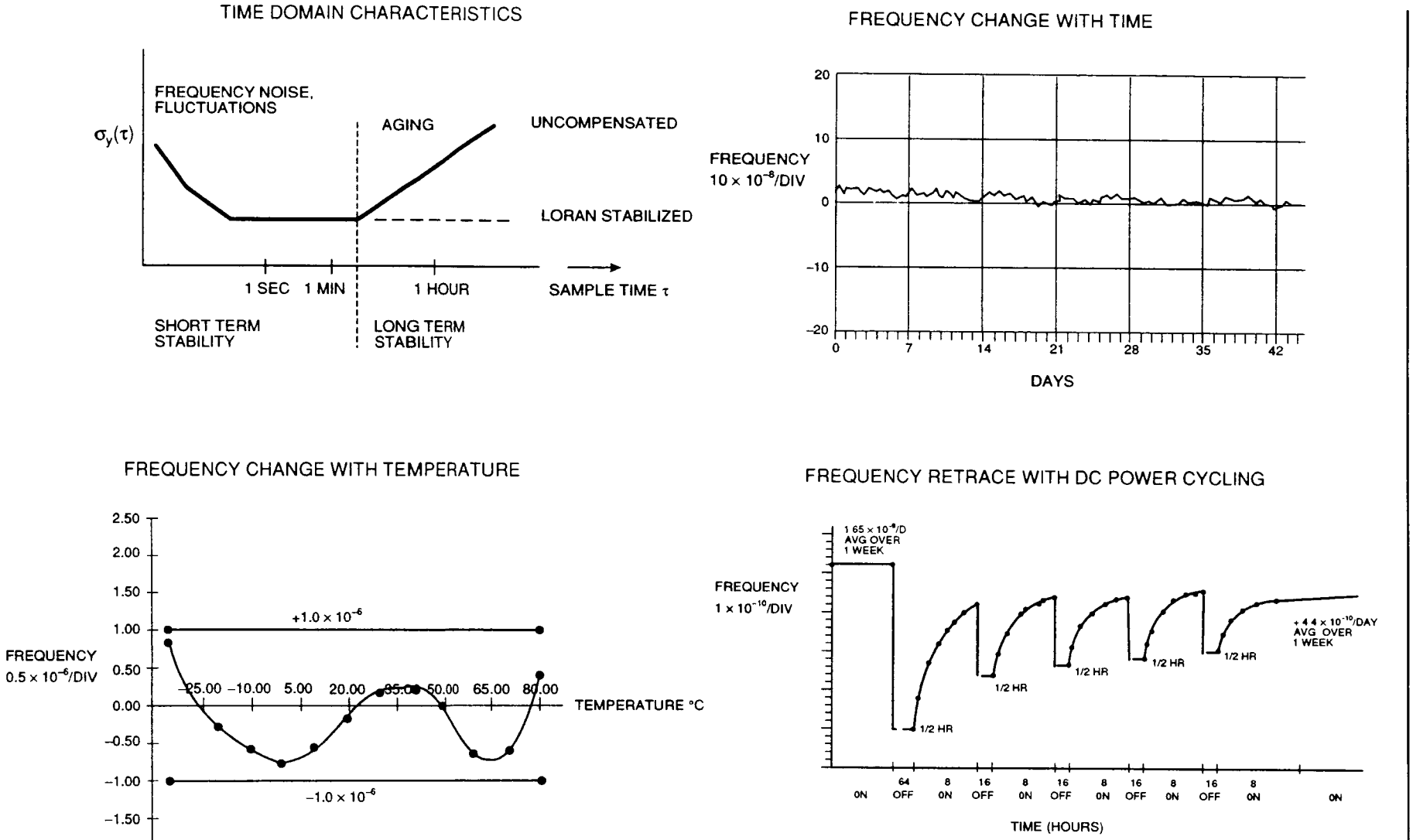

Fig. 3. VCXO Characteristics

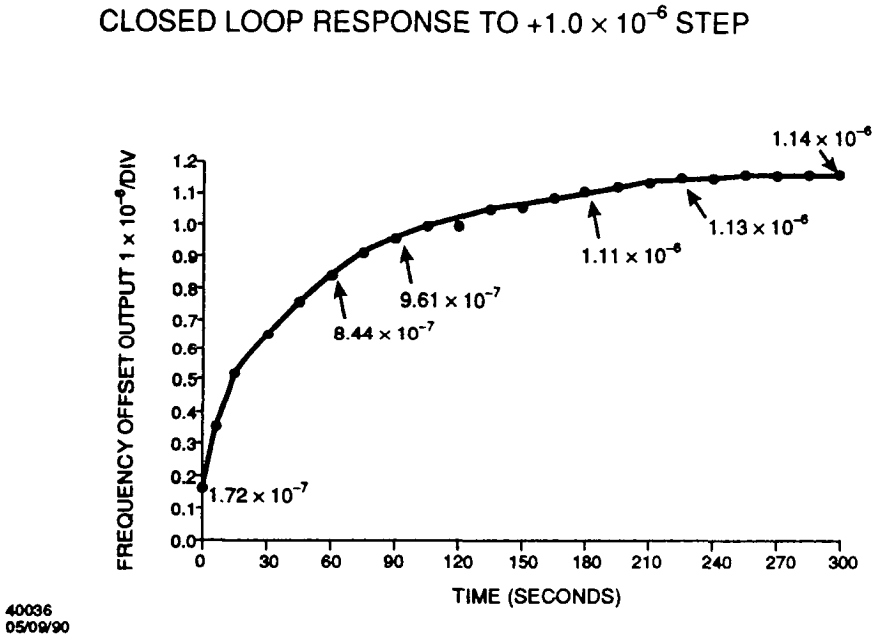

Fig. 4. Closed Loop Response