EndRun TECHNOLOGIES
"Smarter Timing Solutions"

UTC Time and Frequency Dissemination via the IS-95 CDMA Mobile Telecommunications Infrastructure

Overview

An exciting new way of obtaining precision, UTC traceable time and frequency has come of age during this year. Made possible by the rapidly expanding, global deployment of CDMA mobile telecommunications systems operating under the TIA/EIA IS-95 standard, *"indirect GPS"* is arguably the best description for it. In essence, these IS-95 base stations act as *repeaters* of the GPS timing information they must receive from the satellites to synchronize themselves to IS-95 system time. The spread-spectrum modulation scheme employed by the IS-95 system allows this GPS time reference to be extracted from the base station transmissions with a high degree of precision using a small, low cost receiver with integrated cell phone antenna. This new approach *eliminates the cost and hassle of installing a rooftop antenna* for users within range of one of these IS-95 base stations.

A strong combination of features should make this the technology of choice for many time and frequency applications that currently use traditional *"direct GPS"*. EndRun Technologies is pioneering the commercial implementations of this technology with its ***Præcis C*** series of products: *Præcis Ct Network Time Source, Præcis Cntp Network Time Server, Præcis Cf Time and Frequency Standard, Præcis Cfr Instrumentation Time/Frequency Reference* and the *Præcis Ce OEM Time and Frequency Engine.*

Why IS-95 Systems are Synchronized to GPS

Like the GPS, IS-95 is a *spread-spectrum* system. In the GPS, all of the satellites transmit on the same frequency. Each satellite uses a different PseudoNoise (PN) spreading code to distinguish itself from the other satellites which are all transmitting simultaneously. In the IS-95 system, all base stations transmit on the same frequency. They also transmit the same PN spreading code. How does this work?

Although each base station transmits the same spreading code, they each transmit it with a different delay, or time offset. This offset is large enough that a mobile unit could never be close enough to one base station and far enough from another one that the codes received from the two base stations would line up and interfere with each other. It turns out that base stations are assigned PN offsets which are multiples of 64 chips of the PN code. These offsets equate to multiples of 52.08333… microseconds.

It should be evident that the base stations need a way of knowing when to begin transmitting their copies of the PN code relative to all of the other base stations in the system. Since the granularity of the spacing between base station PN offsets is about 50 microseconds, it would seem that a local time base with about 5 to 10 microseconds of absolute accuracy relative to IS-95 system time would be needed.

There really are not any globally available options other than the GPS for maintaining this level of synchronization. For this reason, *the specification defines IS-95 system time to be the same as GPS time* and requires that base stations be synchronized to GPS time at the 10 microsecond level, even during periods of GPS satellite unavailability lasting up to twenty-four hours.

This high level of synchronization enables another feature of IS-95 systems called "soft-handoff". This relates to the mechanism for transferring an in-process call from one base station to the next as the mobile user is traveling though the coverage cells. A soft-handoff is accomplished when the mobile receiving unit and the two base stations *hitlessly* transfer the call. It is made possible in part by the mobile receiving unit being able to calculate the offset to the new base station's PN code accurately enough to jump to it and re-lock almost instantly as the quality of the connection to the current base station begins to fade.

How IS-95 Systems are Synchronized to GPS

Each base station in an IS-95 system has at least one (many sites have redundant systems) state-of-the-art GPS timing receiver with either a rubidium vapor local oscillator or an ultra-stable, ovenized quartz local oscillator with software temperature compensation.

How GPS Time and Frequency is Recovered

The IS-95 signal structure supports precision recovery of GPS time and frequency due to a couple of GPS-like characteristics it has. First, the spread spectrum modulation is performed at a GPS-like chipping rate of 1,228,800 chips/second, slightly higher than the GPS chipping rate of 1,023,000 chips/second. This chipping rate is important because it determines the precision with which the receiver may align its local timebase to the received modulation. Alignment to the *ten nanosecond level* is achievable with the IS-95 chipping rate.

As a side note, unlike GPS, the IS-95 pilot PN code can be acquired using almost an arbitrarily long integration time because there is no data modulation impressed on it. Only the accuracy of the frequency of the local oscillator limits this integration time. In practice this is generally not much of an issue since the received IS-95 signals are so much stronger than those from the GPS satellites.

The second important GPS-like characteristic is the frequencies of the carriers at which the IS-95 base station transmitters operate. The GPS uses an L1 carrier frequency of 1575 MHz for the C/A code channel used by civilians. IS-95 uses 881 MHz for the cellular band and 1960 MHz for the PCS band. These support GPS-like low-noise frequency recovery as well as aiding and smoothing of the code tracking loop. This is due to the high heterodyne phase time gain available after down-converting the carrier to an IF that is suitable for digital signal processing. The carrier phase time error measurement resolution can be just a few picoseconds, allowing very tight short-term control of the local oscillator frequency.

Recovering UTC Time of Day

The last piece of the puzzle is to decode the IS-95 sync channel message to determine the parameters needed to calculate the position of an on-time 1PPS based on the position of the received pilot PN code epoch. The pilot PN code contains 32768 chips and repeats every 26.666… milliseconds. If it were not for the base station's pilot PN code offset, the beginning of every 75th PN code sequence would coincide with an even GPS second.

In order to transfer GPS time from the received IS-95 transmissions, it is necessary to decode the pilot PN code offset data which is modulated in the sync channel message. Once the sync channel message has been decoded, the particular PN code epoch that coincides with a particular even GPS second will be known as well. The sync channel message parameters that are needed are the base station PN offset, the current UTC leap second offset from GPS time and the GPS time 320 milliseconds after the end of the current sync channel message. In addition, the sync channel message contains the local time offset to UTC, including daylight savings time.

The sync channel message data rate is 1200 bits/second, but due to the difficulties of the mobile telecommunications environment elaborate means are included in the IS-95 signal structure to minimize and correct errors. First the data is convolutionally encoded with (k=2, m=9) to 2400 symbols/second. It is then block interleaved with 2:1 redundancy to 4800 symbols/second and a 30 bit CRC is transmitted with the complete message. The message is repeated every 240 milliseconds.

Strengths of the "Indirect GPS" Technology

The received IS-95 signal level in a coverage area is defined to be > -100 dBm at the fringes. Obviously, the signals may be –40 dBm or more at points closer to the base stations. The GPS specification is –130 dBm and varies very little, since the satellites are so far away. The "indirect GPS" approach provides a clear advantage in the ability to receive the signals indoors. In addition, the 881 MHz cellular band carrier penetrates buildings to a much greater degree than the GPS carrier.

With stationary users, the quality of the base station GPS receiver/oscillator system provides excellent transmitted frequency accuracy and stability which is virtually reproduced with a well-designed receiver. As the plots which follow will show, the quality of the recovered UTC frequency, and the stability of the recovered UTC time, are quite comparable to the "direct GPS" approach.

Caveats

Though the IS-95 coverage is expanding, there are significant regions of the globe without it. There is no simple way to determine the propagation delay from the base station to the receiver. In an urban environment, the distances between base stations is small and this delay is typically less than 10 microseconds. Fringe area users may receive signals from greater distances and have larger timing offsets. There is also no easy way to remove the doppler frequency shift experienced by a moving receiver. "Direct GPS" remains the best solution for many applications.

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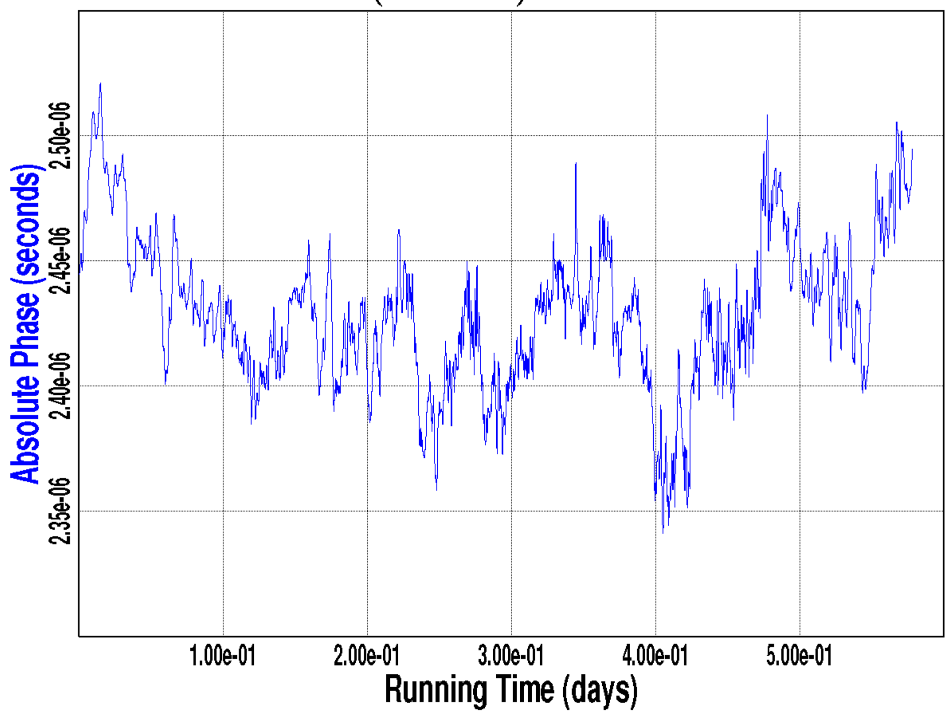
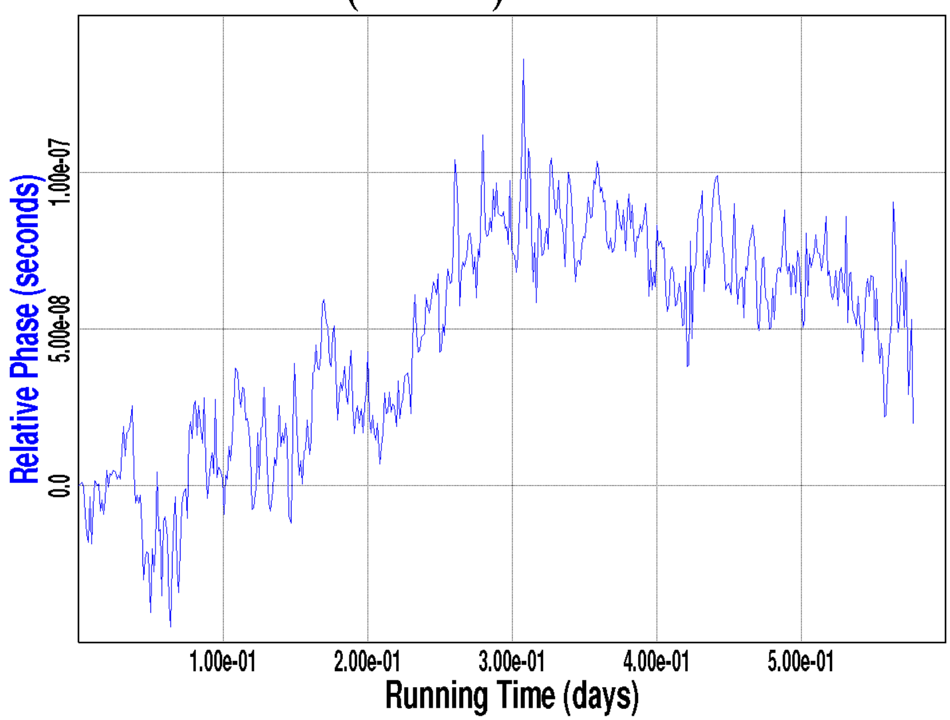
"Indirect GPS" (CDMA) vs "Direct GPS" 1PPS



"Indirect GPS" (CDMA) vs "Direct GPS" 10 MHz



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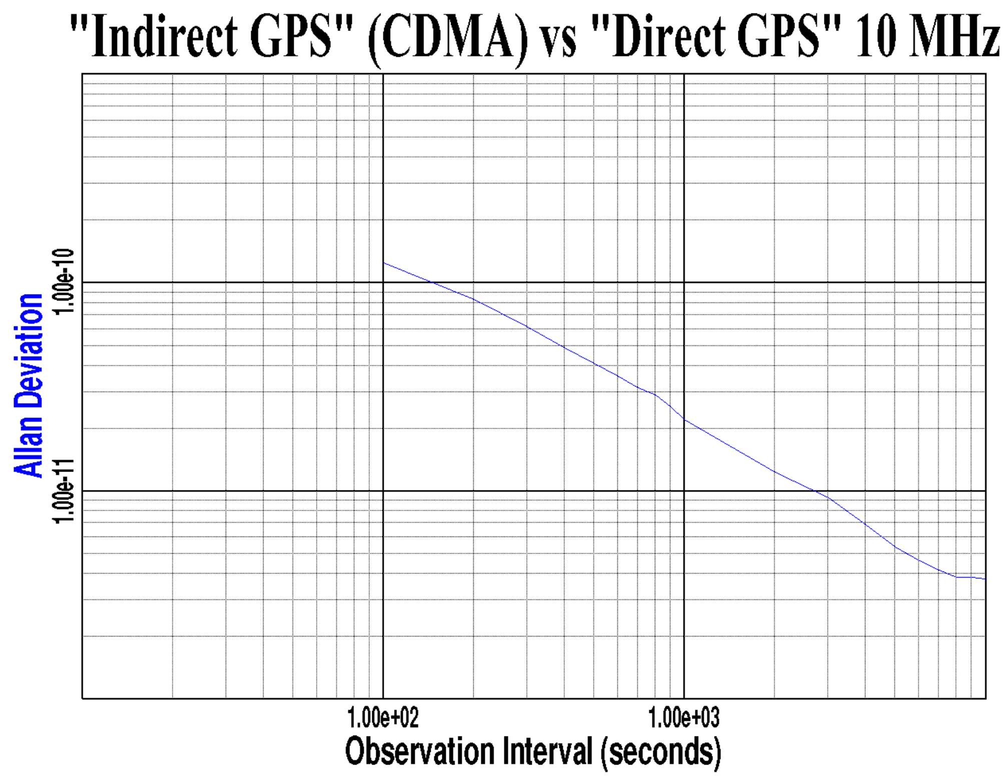

About the Plots

These plots show typical performance of a *Præcis Cf* with standard TCXO local oscillator against a high-quality, "direct GPS" timing receiver measured at EndRun Technologies during November 2000. The 1PPS plot indicates an offset between the *Præcis Cf* and "direct GPS" of about 2.45 microseconds. The *Præcis Cf* is late. The 1PPS and 10 MHz data were taken at different times. Measurements were made with an HP5334B counter with single-shot resolution of about 2 nanoseconds.

The Allan deviation data indicates performance very close to that achieved by a quality "direct GPS" receiver with a TCXO as its local oscillator.