TIME OF DAY MANAGEMENT FOR SATELLITE COMMUNICATIONS

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Abstract

The U.S. Naval Research Laboratory has installed GPS-based timing systems in several DSCS satellite communication facilities to support the Single Channel Transponder program. These systems were originally installed between 1998 and 2000 in 11 sites located around the world. The goals were to manage the satellite crystal oscillators to 25 microseconds and the ground cesium clocks to 5 microseconds. This paper will describe the project's progress, with results showing the time management of the satellite oscillators and the cesium-beam clocks. A Windows-compatible computer program written to facilitate the clock management will also be described.

INTRODUCTION

The Daymark Clock Management system was developed by the U.S. Naval Research Laboratory (NRL) for the Air Force Space and Missile Systems Center to manage timing of the Single Channel Transponder (SCT) satellite communications system residing on the DSCS-III satellites. Because the SCT is a frequency hopping system, timing is critical. The SCT Injection System (SCTIS) must provide signals with the frequency hopped exactly at the expected times. In addition, the satellite must receive the signals exactly at the expected times. Otherwise, communications with the satellite fail.

Accurate site timing allows for robust operation of the SCT independent of the satellite beacon signal. Accordingly, the controller sites must manage the Satellite Time Generator (STG) time accuracy and their terminal clock time accuracy. Maintaining STG time accuracy requires small frequency adjustments made to the satellite oscillator to account for the drifting oscillator frequency. These small frequency adjustments do not cause a communications loss. However, time adjustments or large frequency adjustments potentially could. The terminal clock accuracy is maintained through microsecond time adjustments and small frequency adjustments. For accurate time accuracy, the oscillators are compared to a common reference.

The goal of the Daymark system is to provide the means of keeping an accurate, stable, reliable, and survivable local time and frequency reference for user systems. To meet the accuracy requirement, a nominal system error budget of 25 microseconds from Universal Coordinated Time (UTC), as determined by the U.S. Naval Observatory (USNO) **[1]**, to be shared by the satellite's Satellite Time Generator (STG) and the cesium-beam atomic clock at the ground SCTIS terminal sites. The cesium clocks are required to maintain time accurate to 5 microseconds. However, due to the inherent stability of the cesium clocks, the 5 microseconds is small relative to the total 25 microsecond error budget and is not included in the overall error budget calculation. The STG depends on the satellite's high quality crystal oscillator. Because crystal oscillators are not as stable as the cesium clocks, the satellite is consumes most of the 25-microsecond error budget.

CLOCK MANAGEMENT

Before the Daymark system was developed, the terminal clocks were supported by USNO directly, and the STGs were referenced to the terminal clocks. However, the site clocks are no longer supported by USNO. To keep site timing accurate, the NRL developed the Daymark system and software. For a time reference, the system uses the UTC (USNO) Master Clock via GPS. The local clock time offset compared to UTC (USNO) is measured daily and sustains an accuracy of better than 0.1 microseconds.

The Daymark system aims to keep the system oscillator time within the specified error budget for as long as possible, reducing the reliance on GPS. To accomplish this, the NRL installed measuring equipment at most SCTIS field sites. Using this equipment, time-offset measurements from UTC (USNO) are taken regularly. The Daymark Clock Management software proposes time and frequency adjustments for the cesium clocks and frequency adjustments for the STG oscillator necessary to keep the time-offsets within their respective error limits for as long as possible (generally, at least a few months). The official message from the Defense Satellite Communications System (DSCS) Network Manager requiring the Daymark system to be used was distributed DTG 292143Z MAR 99.

ORIGINAL SITE EQUIPMENT

High-resolution site timing is maintained via 1PPS signals from the primary local cesium clock. The accurate standard frequencies provided by the local cesium clock are used for user systems and measuring equipment needing occasional time and frequency adjustments. At each site, there are two local cesium clocks, an active and a backup. A switch chooses which clock to use as the active clock. The active clock drives a Disciplined Time and Frequency (DTF) oscillator and a crystal oscillator, whose frequencies are distributed to the site. If the active clock fails, the backup cesium clock takes over.

The DSCS-III STG is driven by a high-quality, space-qualified quartz crystal oscillator with a good temperature coefficient and a low frequency drift rate on the order of less than $1 \cdot 10^{-11}$ per day. The oscillator is capable of remote frequency adjustments through a D/A converter. Four-digit frequency "words" are sent to the satellite, which the D/A converter converts into voltages used to adjust the oscillator frequency. However, due to loading in the oscillator power supply, the relationship between the frequency words and the voltage adjustment is not linear. The Daymark software package predicts and compensates for this error. Time-of-day is adjusted in the STG, independent of the oscillator. Normally, the time is only adjusted when a leap second is implemented, because a time offset jump can easily cause communication problems. Instead, STG time offsets are improved by adjusting the frequency.

EQUIPMENT MODIFICATIONS

To implement the Daymark system, the NRL installed a set of measuring equipment at each site. A GPS receiver and antenna were installed to supply the system with a highly accurate 1PPS UTC (USNO) reference. A time-interval counter gives a measurement of the time-offset error of a particular oscillator with respect to UTC (USNO) via GPS. When a leap second occurs, GPS implements it immediately, but the Defense Information Systems Agency (DISA) sometimes does not. Therefore, a time code generator initially set on time with the GPS receiver maintains time with distributed 5 MHz and 1PPS and holds time when a leap second occurs. A remote time display supplies a time-of-day display at other local equipment. Finally, a distribution amplifier was provided to give an interface between original and added site equipment, so that if a piece of NRL's equipment went down, site operations would not be affected.

DAYMARK CLOCK MANAGEMENT SOFTWARE

The Daymark Clock Management software provides a straightforward method of adjusting the site oscillators over time. A separate log file with date, time, and time-offset entries may be created for each oscillator present in the system. Each oscillator also has a separate log of all time and frequency changes made to the oscillator during the range of data logging. For the STG, this log also includes parameters characterizing the D/A converter nonlinearities: a voltage regulation factor and a Hz per count factor, where a count is a ±1 change in the frequency word. Daymark provides modeling of the oscillator time offset. The STG has a parabolic curve fit to its time-offset data due to the satellite oscillator frequency drift rate. The local cesium clock has a linear line fit to its time offset data, because its frequency drift rate may be considered negligible. Based on these models, Daymark provides a prediction of necessary frequency adjustments to the STG in the form of the number of counts that the frequency word commanded to the satellite must change, and a prediction of the necessary time and frequency adjustments to the cesium clock.

The operation of the measurement-taking system is fairly uncomplicated. Measurements of an oscillator's time-offset from UTC (USNO) are taken at regular intervals and logged (three times daily for the STG, daily for the local clocks). If a time or frequency adjustment has been made, that too is recorded in the appropriate log. Manual data entry into the program is performed daily for the STG and monthly for local clocks. After the program is started, the operator may call up the desired oscillator's data file. The program then makes and displays the data plus a model of the clock's performance over a specified period of time. The operator may enter new data from the log and save the new data to the open file. Time and frequency adjustments are entered and saved in the current satellite's change file. Finally, the operator may enter a proposed data and time for an oscillator adjustment. Daymark advises on the frequency adjustments (and time adjustments for local clocks) to make at the specified time. For the STG, the program can also predict the best date, time, and frequency change for the oscillator. This process may be repeated for any other cesium clocks or STGs present in the system.

DIFFICULTIES ENCOUNTERED

Overall, NRL's Daymark Clock Management system has been very successful. Most sites have cesium clocks that stay well within the 5-microsecond error budget for over 6 months. The STGs cannot be controlled quite as well due to oscillator frequency drift, but the program predictions keep the oscillator on track fairly well when used properly. The length of time between corrections may be as short as a few days or as much as a month, depending on the stability of the particular STG and available corrections.

Most problems that have occurred have been shown to be user-based, due to frequent personnel turnover every 6 months. It has been difficult to keep trained personnel operating the system. Therefore, most personnel do not understand the necessity of the system. Also, because site personnel do not fully understand the system, they may log time-offset data, but they may not enter it into the program. Daymark has worked the best at sites where contractors handle the data entry and software portion of the system, because they stay at the site longer. Generally, we only hear from most sites when a problem occurs. Otherwise, it is difficult to monitor the operation of the system. Unfortunately, these problems mean that Daymark is not always used to its fullest capabilities, and site oscillators do not stay within their error budget for nearly as long as they potentially could.

CHANGES SINCE LAST UPDATE

Due to an extension in the lifetime of the SCTIS mission, upgrades to the system components have become necessary. To solve our user problems, we have upgraded the system documentation and software to allow for a faster, more intuitive program run. The system documentation has been turned into step-by-step graphical walkthroughs for most aspects of program operation, plus searchable help file entries, so the documentation no longer strikes the users as intimidating. The program itself was upgraded from the original DOS version to a Windows version. Since most new users are more comfortable with Windows, the DOS-based approach was no longer adequate. In addition, the DOS version was not compatible with Windows XP or Windows 2000. Equipment upgrades have also made our job easier. Management of the local clocks is much easier in many sites due to the upgrade from Hewlett-Packard (HP) 5061s to HP5071s. With the increased ease-of-use from the system upgrades, we hope to solve our user problems.

OSCILLATOR EXAMPLES

The included figures show some of the latest oscillator data from our well-managed sites. Figure 1 shows a typical plot for an STG. The yellow vertical lines represent frequency changes the operator made; the dots represent time-offset entries. The green line is the model predicted by the program from the data and shows how the time-offset will change over time. This case is unusually good in that the STG could operate for about 1 month without additional corrections. Figure 2 shows an expanded view of the time-offset history of this satellite. Here one can see that sometimes the best available correction only gives a few days of in-specification operation. This is a consequence of the STG oscillator control nonlinearity previously discussed. The parabolic curve to the time-offset is clear in the months of August and September.

Figure 3 is a typical plot for a cesium clock. The clock is very accurate during this span; in fact, in the 3-month span of time-offset data shown here, it does not even reach a 1-microsecond offset from UTC (USNO), let alone a 5-microsecond offset.

CONCLUSION

Over the past 7 years that this system has been in operation, site timing has greatly improved. Most site oscillators are managed to well within the specified error budget. At a well-managed site, the cesium clocks will easily stay within their error budget for over 6 months. The STGs will remain within their error budget for about 1 to 2 months if they are managed well, with updates typically being required once a week. Our biggest challenge is making the system easy to operate for new users. The new version of the Daymark software and documentation will be released within the next few months, hopefully improving the user-friendliness of the system and resulting in better clock management.

REFERENCE

[1] R. Labonski, J. Murray, L. Urquhart, and J. White, 1993, *"Application of the Global Positioning System to Single Channel Transponder Timing,"* in Proceedings of MILCOM '93, October 1993, Boston, Massachusetts, USA (IEEE).

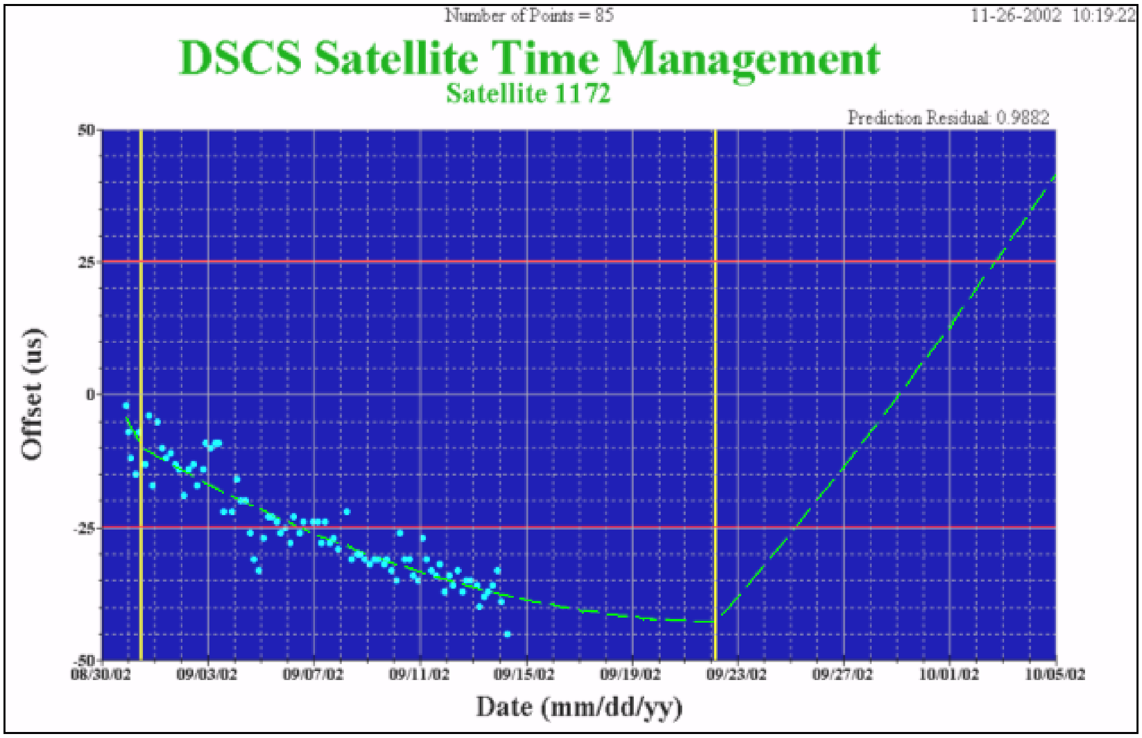

Figure 1. Typical STG plot.

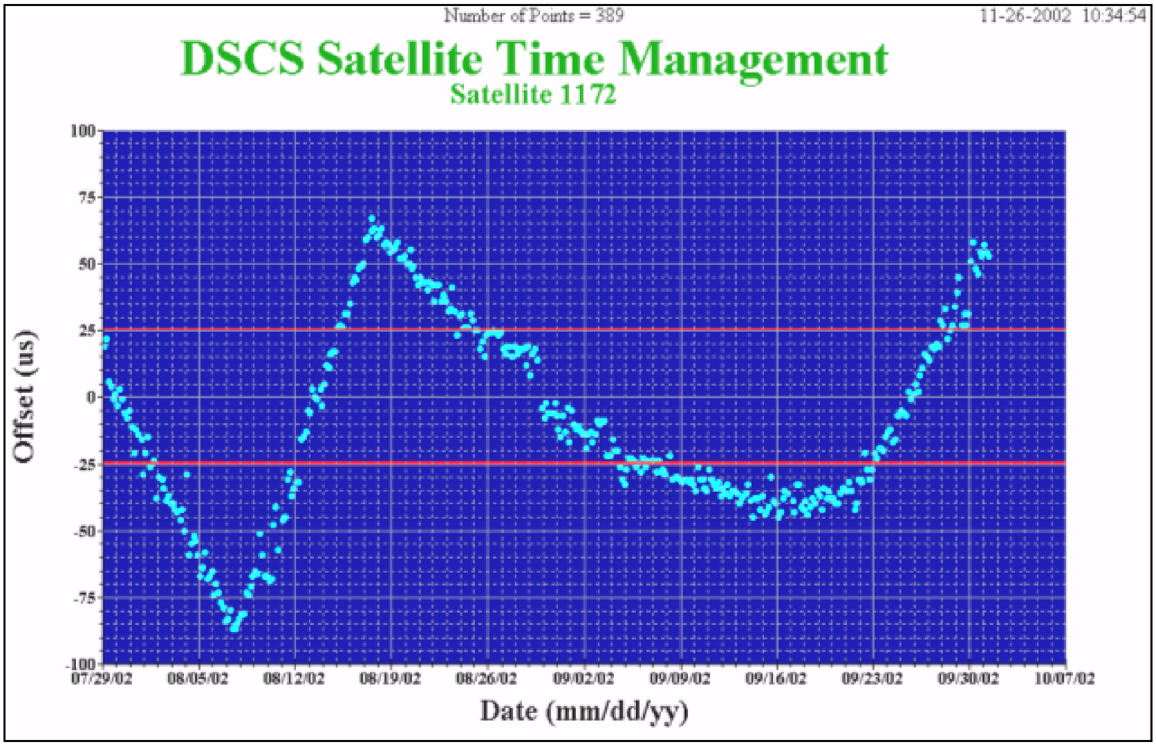

Figure 2. Expanded view of typical STG plot.

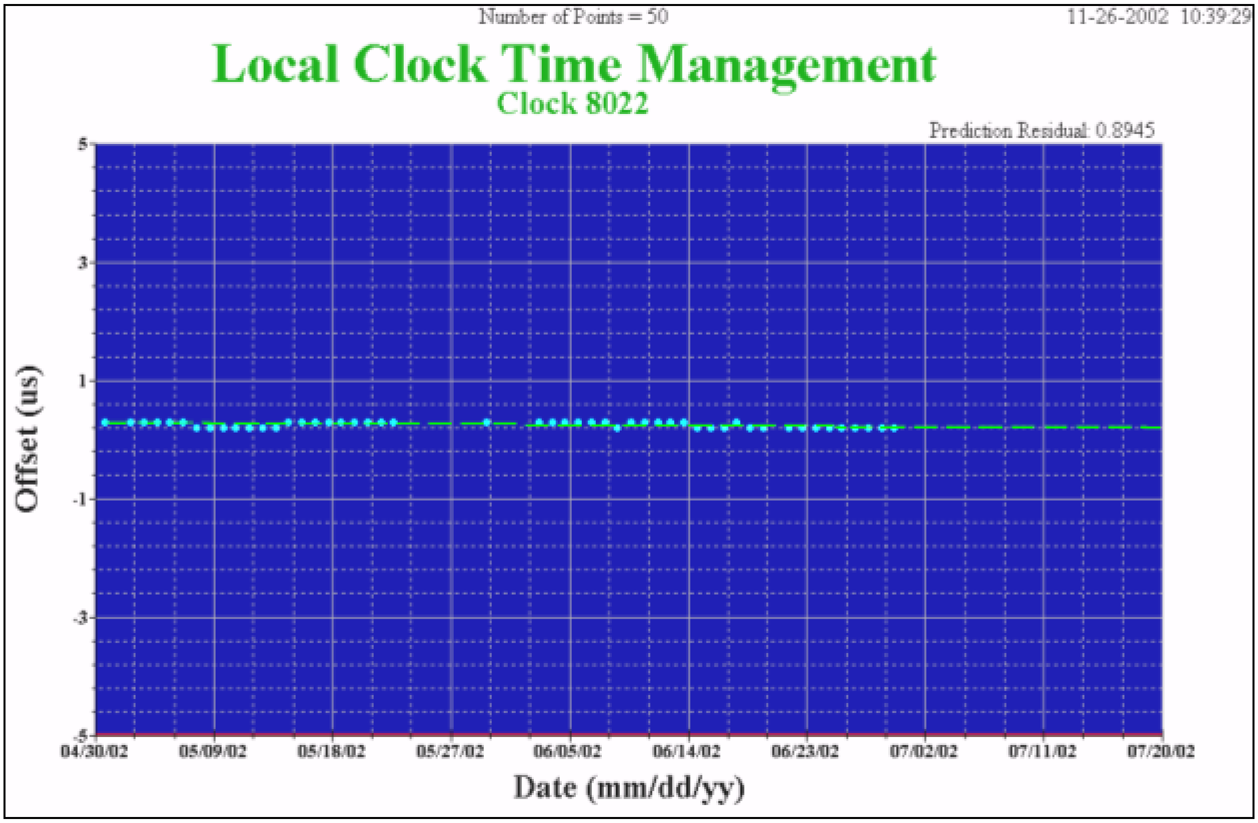

Figure 3. Typical cesium clock plot.

QUESTIONS AND ANSWERS

JIM CAMPARO (The Aerospace Corporation): I think I heard you say that you synchronized the clocks by doing frequency steering.

RACHEL EVANS: Yes.

CAMPARO: Could you just explain briefly what that algorithm is? Is it a triangle, or how do you do that?

EVANS: It is a parabolic curve. We look at the time offset and figure out exactly how much the frequency is off. And then it ends up corresponding to a counts change; the users know how much of a counts change it is. The program shows them how much how much of a counts change to make. And then it is a frequency word that they send up; it's a four-digit number, I guess that is 9 bytes, maybe 12, something like that. And they send that word to the satellite and the satellite adjusts frequency through its D to A converter.